OPPD
Omaha Public Power District

OPPD BOARD OF DIRECTORS

BOARD MEETING MINUTES

May 21, 2026

The regular meeting of the Board of Directors of the Omaha Public Power District ("OPPD" or "District") was held on May 21, at 5:00 p.m. at the Omaha Douglas Civic Center, 1819 Farnam Street, 2nd Floor Legislative Chamber, Omaha, Nebraska and via WebEx audio and video conference.

Joining in person were Directors M. J. Cavanaugh, M. R. Core, S. E. Howard, C. C. Moody, M. G. Spurgeon and E. H. Williams. A. E. Bogner and J. L. Hudson were absent. Also present were L. J. Fernandez, President and Chief Executive Officer, P. M. Fischer, Vice President, General Counsel and T. Thalken of the Fraser Stryker law firm. E. H. Lane, Sr. Board Operations Specialist, and other members of the OPPD Board meeting logistics support staff. Chair M. R. Core presided, and E. H. Lane recorded the minutes. Members of the executive leadership team joining in person included K. W. Brown, C. V. Fleener, G. M. Langel, T. D. McAreavey, B. R. Underwood, T. R. Via and J.W. Wheeler.

Board Agenda Item 1: Chair Opening Statement

Chair Core gave a brief opening statement, including reminders for using the WebEx audio and video conferencing platform.

Board Agenda Item 2: Safety Briefing

J. Clark, Manager, Protective Services, provided safety reminders.

Board Agenda Item 3: Guidelines for Participation

Chair Core then presented the guidelines for the conduct of the meeting and instructions on the public comment process using WebEx audio and video conferencing features.

Board Agenda Item 4: Roll Call

Ms. Lane took roll call of the Board. All members were present, except for Director Bogner and Director Hudson, who were absent.

Board Agenda Item 5: Announcement regarding public notice of meeting

Ms. Lane read the following:

> *"Notice of the time and place of this meeting was publicized by notifying the area news media; by publicizing same in the Omaha World Herald and Nebraska Press Association, OPPD Outlets newsletter, oppd.com and social media; by displaying such notice on the first level of the OPPD administrative offices; and by e-mailing such notice to each of the District's Directors on May 15, 2026.*

> *A copy of the proposed agenda for this meeting has been maintained, on a current basis, and is readily available for public inspection in the office of the District's Corporate Secretary.*
>
> *Additionally, a copy of the Open Meetings Act is available for inspection on oppd.com."*

Board Consent Action Items:

6. Approval of the March 2026 Financial Reports, April 2026 Meeting Minutes, and May 21, 2026 Agenda
7. 2025 Annual Health Plan Report – Resolution No. 6763
8. RFP 6239 – Resources for Metro Cable Replacements – Labor Contract Award to Nielsen Construction – Resolution No. 6764
9. RFP 6240 – Resources for North Rural Cable Replacements – Labor Contract Award to Nielsen Construction – Resolution No. 6765
10. SD-3: Access to Credit Markets Monitoring Report – Resolution No. 6766
11. Update to Service Regulations – Resolution No. 6767

It was moved and seconded that the Board approve the consent action items.

Chair Core noted the Board discussed the action items during the All Committees meeting held on Tuesday, May 19.

Chair Core then asked for public comments in person and on WebEx. There were no comments.

Thereafter, the vote was recorded as follows: Bogner – Absent; Cavanaugh – Yes; Core – Yes; Howard – Yes; Hudson – Absent; Moody – Yes; Spurgeon – Yes; Williams – Yes. The motion carried (6-0).

Board Agenda Item 12: President's Report

CEO Fernandez next presented the following information:

- April 2026 Baseload Generation
- April 2026 Balancing Generation
- April 2026 Renewables
- Excellence in Action – Chartwell Awards
- OPPD Safety Recognition – National Safety Council Award
- Honoring our Communities – SHARE Omaha Do Good Days
- Supporting Basic Needs – Community Resource Fair, May 5
- In Memoriam – John Broderick

Board Agenda Item 13: Opportunity for comment on other items of District Business

Chair Core asked for comments from the public in the room. There were three comments.

David Begley, 4611 S. 96th St, provided comments on solar and wind legal cases and presented materials which are attached to these minutes.

David Corbin, 1002 N. 49th St, representing the Nebraska Sierra Club, provided comments on energy use behaviors and presented materials which are attached to these minutes.

John Traudt, 3316 Augusta Ave, provided comments on revenue stabilization and presented materials which are attached to these minutes.

Chair Core asked for comments from the public online. There was one comment.

John Pollack, 1412 N. 35th Street, provided a weather report.

There were no additional comments from the public in person or online.

There being no further business, the meeting adjourned at 5:29 p.m.

DocuSigned by:
Cliff Fleener
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C. V. Fleener
Vice President – Sustainability and
Environmental Affairs

DocuSigned by:
Erin Lane
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E. H. Lane
Sr. Board Operations Specialist

David D. Begley vs. Big Solar and Big Wind

Project	Location	MW	W or S	Status
North Fork Wind	Knox County	600	Wind	Pending in federal court
Beeline Solar	Burt County	250	Solar	Pending in state court
Panama Energy	Lancaster County	304	Solar	Pending in the S. Ct.
Cass County Solar	Cass County	265	Solar	Pending in state court
K-Junction Solar	York County	310	Solar	Abandoned by OPPD
		1729		
		1.7 GW		
		4 GW	Needed by 2035 per Aurora Research and NE Chamber	
		1.3 GW	Short of goal due to Begley's efforts	
		42%	**Begley's reduction**	

4-May-26

As of 2024, approximately **41% of Spanish homes** are equipped with air conditioning. This adoption is heavily divided by geography:

dealista +1

- **Southern Spain (e.g., Seville, Córdoba):** AC is considered essential due to extreme summer heat (regularly exceeding

). In Seville, up to **75% of homes** have units installed.

  alista +4
- **Central Spain (e.g., Madrid):** High temperatures make AC very common, with roughly **65% of flats** equipped.

  alista +1
- **Northern Spain (e.g., Bilbao, Santander):** Due to a cooler Atlantic climate, residential AC is rare, appearing in only **1% to 4% of homes** in many northern cities

Omaha, Nebraska: The average residential rate is approximately **$0.118 per kWh**. This is among the lowest in the U.S., with the local utility, Omaha Public Power District (OPPD), implementing seasonal rates:

- **Summer**: ~$0.102 per kWh.
- **Winter**: ~$0.087 per kWh.

Seville, Spain: Residential users pay a moderate rate for Europe but high compared to the U.S., averaging roughly **$0.226 to $0.282 per kWh**.

- Rates in Spain often use **time-of-use pricing**, where costs can fluctuate hourly from as low as **€0.11 (~$0.12) to over €0.23 (~$0.25) per kWh** depending on demand.

Key Differences

- **Price Stability**: Omaha utilizes fixed seasonal rates set by OPPD. In Seville, consumers often choose between "free-market" contracts with fixed rates (e.g., Endesa's €0.127/kWh plan) or regulated rates that change hourly based on the wholesale market.

- **Energy Sources**: Omaha relies heavily on local resources like coal, natural gas, and wind. Seville benefits from Spain's high integration of **solar and wind**, which helps keep its prices lower than many other European capitals, though still higher than U.S. averages.

- **Billing Factors**: Spanish bills often include significant **fixed power charges** (based on contracted capacity) and specific network tolls updated annually.

Show all

What percentage of the electric grid in Seville Spain is wind and solar

The electric grid supplying **Seville**, part of Spain's Andalusia region, is primarily powered by wind and solar, which together provided roughly **50–60%** of the region's electricity in 2024–2025.

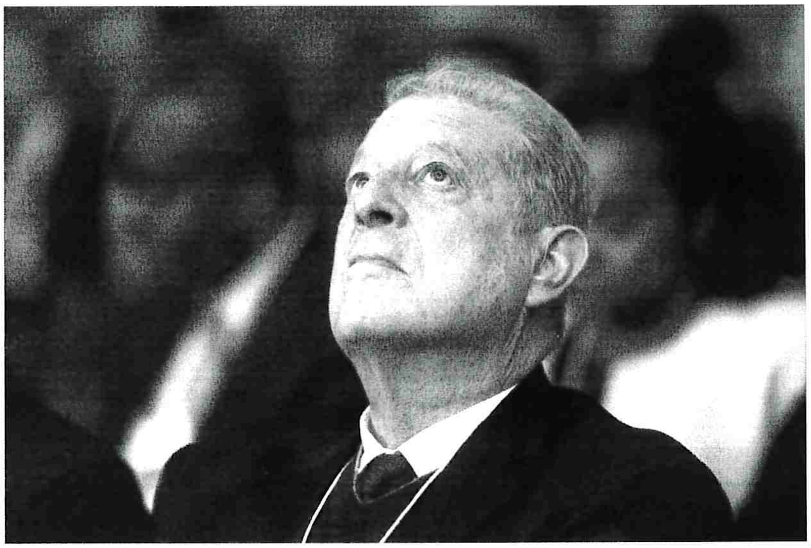
https://www.wsj.com/opinion/free-expression/al-gores-long-and-persistent-record-of-miserable-failure-8ebbeaca

FREE EXPRESSION

Al Gore's Long and Persistent Record of Miserable Failure

The former vice president has been predicting imminent climate doom for so long it's become a joke.

By Kyle Smith Follow
May 18, 2026 6:17 am ET



Al Gore in Davos, Switzerland, on Jan. 20. PHOTO: MARKUS SCHREIBER/ASSOCIATED PRESS

Free Expression is a daily newsletter on American life, politics and culture from the Opinion pages of The Wall Street Journal. Sign up and start reading Free Expression today.

In his 1992 book "Earth in the Balance," Al Gore wrote, with what would become his customary hyperbole, "the evidence of an ecological Kristallnacht is as clear as the sound of the glass shattering in Berlin." The then-senator claimed that "according to some predictions"—no specifics were offered—“in the next few decades,” “up to 60 percent of the present population of Florida may have to be relocated.”

It’s been a “few decades.” How is Mr. Gore’s prophecy working out? Did he even get the direction right?

Florida’s population in 1992 was around 13 million. Mr. Gore’s notional Flexodus would have reduced that figure below six million. Today, the state’s population has nearly doubled instead of more than halved. More than 23 million souls now call Florida home.

Yet there is a greater chance that all of them will be eaten by gators by next Friday than there is of Mr. Gore issuing an “Oops.” Hey, he was merely saying, “According to some predictions,” right? Maybe he was quoting a soothsayer he met in Reno. Maybe he did some research at the local facility for the criminally insane.

As Mr. Gore’s Oscar-winning sci-fi classic “An Inconvenient Truth” observes its 20th anniversary on May 24, it would be far too easy to dub him the Chicken Little of climate change. The fowl of legend, unlike Mr. Gore, didn’t devise the means to profit spectacularly from his doomsday squawking. Mr. Gore has successfully convinced the political world to design subsidies, regulations and mandates that fattened his bank account by immense amounts.

Mr. Gore was famously dubbed potentially the world’s first “carbon billionaire” in a New York Times article back in 2009, many years of wealth accumulation ago. We don’t know what he’s worth now; estimates suggest it’s in the hundreds of millions. He was worth less than $2 million when he left the vice presidency in 2001 and has breezily dismissed charges that there is an inherent conflict of interest in being both the Visionary Saint of Climate Change and a rent-seeking businessman who turns doomcasting into profit.

In 2026, even the New York Times has started publishing pieces advising its progressive readership to calm its climate change-related fears, gently pointing out that despite all the hype, the issue still doesn’t grab actual voters much. "Climate politics is in undeniable withdrawal," notes the paper's David Wallace-Wells. This détente must be hurtful to Mr. Gore, who foresaw, in "Earth in the Balance," "a kind of global civil war" between green "resistance fighters" and the "silent partners of destruction."

Thought leaders such as Breakthrough Institute co-founder Ted Nordhaus and President Obama's under secretary for science in the Energy Department, physicist Steven Koonin, have said they've changed their minds about the severity of the threat. Today's leading thinkers are now approaching climate change as a long-term challenge to manage rather than a dire, immediate emergency—an "ecological crisis" as Mr. Gore dubs the situation on the first page of his 1992 book. He set the template for institutions to shout the C-word at every opportunity, as though incantation will create reality.

Let's review some of Mr. Gore's predictions, errors and fabrications in "An Inconvenient Truth" and elsewhere.

In the movie, Mr. Gore said that within 15 years Glacier National Park would become "the park formerly known as Glacier." No, the glaciers are still there. He also claimed, "Within the decade, there will be no more snows of Kilimanjaro." The snow on Africa's highest mountain is still there. Mr. Gore was forced to remove a slide that he said proved global warming "is creating weather-related disasters that are completely unprecedented" after climate scientist Roger Pielke pointed out the conceptual error behind it.

Data show that hurricanes, which were the centerpiece of Mr. Gore's scare-marketing, don't exhibit a trend toward increased frequency or severity over the half-century; the Goracle suggested we have been ignoring "warnings that hurricanes were getting stronger" due to climate change, compared that threat to the rise of the Nazis in 1930s, and added in 2013 that hurricane trackers had been forced to dream up a new category—Cat 6. This was false.

In 2009 he claimed in a speech to the Copenhagen climate summit, "Some of the models suggest to [climatologist] Dr. [Wieslav] Maslowski that there is a

75 per cent chance that the entire north polar ice cap, during the summer months, could be completely ice-free within five to seven years." That is, by 2016.

Mr. Maslowski responded that he didn't say that: "It's unclear to me how this figure was arrived at," he noted at the time. In 2026 the polar ice caps remain, even in summer. As for polar bears, which Mr. Gore suggested were endangered because they had to swim up to 60 miles to find ice to stand on, their greatest enemy wasn't climate change but hunting, which was banned in 1973. Their numbers have roughly tripled since the late 1960s.

Mr. Gore's fundamental unseriousness is evident in a head-spinningly misleading scene in his 2017 followup, "An Inconvenient Sequel: Truth to Power." In that film, he had the astonishing temerity to claim vindication for his 2006 suggestion that downtown Manhattan would soon be inundated by displaying the supposed proof: images from Superstorm Sandy, in 2012. This is almost comically mendacious. The first film suggested lower Manhattan would be inundated *permanently* because of melting polar ice, not *temporarily* because of a storm.

Mr. Gore is perhaps long past the point of caring about his public reputation; when you've pocketed hundreds of millions of dollars by selling distortion and hysteria, you might as well chuckle at your successes instead of dwelling on your failures. But as the tone on climate change adjusts to reality, he risks joining Thomas Malthus and Paul Ehrlich to go down in intellectual history as one of the Three Stooges of man-caused global disaster.

Mr. Smith is a Free Expression columnist at WSJ Opinion.

WSJ Opinion | Free Expression

Spencer Pratt Is the Mayor of Social Media

Drilling Toward Decline

Probable Trajectories for U.S. Domestic Production of Crude Oil, Natural Gas, and Coal, 2026–2070

A multi-scenario assessment of how current production, planned exports, and depletion physics interact over the next four decades.

Prepared by Jon Traudt
May 18, 2026

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Executive Summary

This report estimates the probable decline trajectory of U.S. domestic production of crude oil, natural gas, and coal between 2026 and 2070. Rather than presenting a single forecast, it constructs three internally-consistent scenarios that span the credible range of expert opinion:

- **EIA AEO 2026 Reference** — the official U.S. government baseline. Production is broadly maintained through 2050 through a combination of Tier-2 acreage development, secondary recovery, and incremental technology gains.
- **IEA WEO 2025 Stated Policies** — the international mainstream view, where policy-driven demand changes and steady but unspectacular extraction technology produce a gradual decline.
- **Depletionist (Berman / Peak Oil Barrel / Hubbert-style)** — the geology-constrained view, in which Tier-1 acreage exhaustion in the Permian and other tight-oil basins triggers accelerated decline rates.

Each scenario is then stress-tested against the U.S. export commitments that are already under contract or under construction — most importantly the doubling of LNG export capacity by 2030, the maintenance of crude oil net-export status, and the structural decline of coal exports.

Headline findings

- **Crude oil.** Across the three scenarios, U.S. oil production falls from 13.6 MMb/d in 2025 to between 5.0 and 12.6 MMb/d in 2050, an implied average annual change of -3.9% to -0.3% per year. By 2070, the range widens to 2.7–9.3 MMb/d.
- **Natural gas.** Production diverges sharply by scenario. The EIA reference case has gas reaching 140 Bcf/d in 2050 (driven by LNG demand); the depletionist scenario sees production peak by 2032 and decline to 55 Bcf/d by 2050 as associated gas falls with oil.
- **Coal.** Production trajectory is dominated by policy, not geology. All three scenarios converge on a decline of 4–6% per year through 2050, taking production from 483 Mst in 2025 to 103–153 Mst.
- **Combined fossil energy.** Total U.S. fossil-energy output (in quadrillion BTU) reaches a plateau in the late 2020s in all three scenarios. Beyond that, the EIA case sees flat output through 2050; the IEA case sees a ~35% decline by 2070; the depletionist case sees a ~75% decline by 2070.
- **Export exposure.** Committed LNG export capacity reaches ~30 Bcf/d by 2030 (roughly 25–30% of current production), and total petroleum exports are near 7 MMb/d. In the depletionist case, honoring those export commitments would require domestic-availability reductions of more than 25% by 2040.

Where the scenarios agree

Three conclusions hold across all three scenarios and should be considered "robust" for planning purposes:

- Coal continues to decline structurally. By 2050, U.S. coal production is in the 100–150 Mst range under every scenario — a fraction of its 2008 peak of 1,172 Mst.
- U.S. crude oil production is at or very near peak in 2025–2027. Even the most expansive scenario does not see a new sustained production record before 2040, and most see no new record at all.
- Domestic prices for natural gas will increasingly track global LNG markets rather than regional supply. The historical "stranded gas" discount is closing.

Where the scenarios diverge

The bigger uncertainty is the rate of decline after the peak. The EIA reference case assumes that drillers can find new Tier-2 acreage at acceptable cost and that the legacy decline from older shale wells is offset by new wells. The depletionist case assumes the opposite — that Tier-1 acreage is largely exhausted and that drilling Tier-2 wells delivers half the output for the same capital. This single assumption explains most of the gap between scenarios.

Implications for decision-makers

- If the EIA reference case is right, the U.S. has roughly a 25-year window of stable fossil production before meaningful decline. Most of the energy-transition planning currently in motion fits this window.
- If the IEA case is right, the U.S. has roughly a 15-year window before decline becomes structurally visible in the economy, and the transition has to be roughly complete by 2050 to avoid energy-supply gaps.
- If the depletionist case is right, the window closes earlier. By 2040, the U.S. is producing materially less oil and gas than today, and either domestic consumption or exports must fall. The exports are typically harder to cut than domestic consumption because they are contractually committed.

Part I — Methodology

1.1 Framework

Forecasting fossil-fuel production over a multi-generational horizon is intrinsically uncertain. Production depends not only on the underlying physical resource but on price, technology, capital availability, regulatory regime, and the demand-side competition from renewables and efficiency. Single-point forecasts past about 10 years are essentially fictional. The standard practice in the literature is to construct several scenarios that span the credible range of outcomes.

This report uses three scenarios. The first two correspond to widely-published reference cases from the U.S. Energy Information Administration[1] and the International Energy Agency[2]. The third synthesizes the geology-constrained or "depletionist" position articulated by petroleum geologist Arthur Berman[3], the Peak Oil Barrel analytical group[4], and the Hubbert-style logistic literature, most recently updated for shale by Reynolds (2024)[5].

1.2 The Hubbert framework and its limitations

M. King Hubbert's 1956 logistic model is the conceptual ancestor of all resource-decline forecasting. The intuition is that cumulative production from a finite resource follows an S-shaped curve: slow at first while infrastructure is built, accelerating as the best sites are developed, peaking, and then declining symmetrically as remaining resources become harder to extract. Hubbert correctly predicted the 1970 U.S. conventional oil peak using a 200 Gb ultimately-recoverable-resources (URR) estimate.

Hubbert's framework has two well-documented weaknesses. First, the URR is not a constant: it changes as price rises and as technology improves. The shale revolution — effectively unknown when Hubbert wrote — added several hundred billion barrels of recoverable resource that no Hubbert curve from the 1990s captured[6]. Second, real production curves are not symmetric: declines are often steeper than buildups because the cheapest oil is taken first.

This report uses Hubbert intuition rather than a strict Hubbert curve. The depletionist scenario assumes accelerating decline once Tier-1 acreage is exhausted; the EIA and IEA cases assume slower or no decline because of continued resource expansion. Reynolds (2024) applied a modified Hubbert to U.S. shale and

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[1] EIA, Annual Energy Outlook 2026, with projections to 2050 www.eia.gov/outlooks/aeo.
[2] IEA, World Energy Outlook 2025 – Stated Policies Scenario www.iea.org/reports/world-energy-outlook-2025/stated-policies-scenario.
[3] Arthur Berman, "Beginning of the End for the Permian" www.artberman.com/blog/beginning-of-the-end-for-the-permian.
[4] Peak Oil Barrel (Dennis Coyne et al.), Short-Term Energy Outlook commentary peakoilbarrel.com.
[5] Reynolds, D. B., "U.S. shale oil production and trend estimation: Forecasting a Hubbert model," Economic Inquiry, 2024 onlinelibrary.wiley.com/doi/10.1111/ecin.13169.
[6] USGS, "An estimate of undiscovered, technically recoverable oil and gas resources underlying Federal lands of the onshore United States, 2025" pubs.usgs.gov/publication/fs20253032.

concluded that U.S. crude-plus-condensate output would probably peak around 2027 with natural-gas peaking three to five years later[7]; this is a useful anchor for the depletionist scenario.

1.3 Shale-specific physics

Tight-oil wells differ from conventional wells in one critical respect: they decline very fast. A typical Permian or Bakken well loses 60–70% of its initial output in the first year and is producing roughly half its lifetime cumulative output within three years[8]. Figure 4 illustrates a generic Permian-style hyperbolic decline curve normalized to an initial production rate of 1,000 barrels per day.

Two consequences follow. First, the total production from a basin depends on the rate at which new wells are drilled, not just the inventory of wells already drilled. A modest reduction in drilling activity translates quickly into total-production decline. Second, the population of wells drilled each year produces a "legacy decline" — the sum of declines from all previously-drilled wells — that grows over time. Once the rate of new drilling falls below the rate of legacy decline, total production falls regardless of well-quality improvements.

The EIA reports that monthly legacy decline in U.S. tight-oil basins has been roughly equal to new-well additions in 2024–2025 — the production plateau is, in effect, a treadmill[9].

1.4 Export commitments as a hard constraint

A novel contribution of this report is to treat planned exports as a near-fixed obligation. LNG export terminals are 20-year-plus capital projects, typically backed by binding long-term offtake agreements with foreign buyers. Seven LNG projects currently under construction will add 17.4 Bcf/d of capacity[10] by 2030, with another 17.7 Bcf/d approved but not yet under construction[11]. The crude side is similar: Corpus Christi alone has ~5 MMb/d of nameplate export capacity[12] and the Texas GulfLink and SPOT terminals expand that further. These commitments effectively turn 25–30% of U.S. fossil production into a non-discretionary outflow.

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[8] Journal of Petroleum Technology, "Shale Wells Producing More Early On, Then Declining Faster Than Ever" jpt.spe.org/shale-wells-producing-more-early-on-then-declining-faster-than-ever.

[9] EIA, Short-Term Energy Outlook (May 2026) www.eia.gov/outlooks/steo.

[10] FERC, "U.S. LNG Export Terminals – Existing, Approved Not Yet Built, and Proposed" www.ferc.gov/media/us-lng-export-terminals-existing-approved-not-yet-built-and-proposed.

[11] EIA Today in Energy, "North America's LNG export capacity could more than double by 2029" www.eia.gov/todayinenergy/detail.php?id=66384.

[12] RBN Energy, "How High? – Surge in U.S. Crude Exports Ups Estimates of What Gulf Coast Terminals Can Handle" rbnenergy.com/daily-posts/blog/surge-us-crude-exports-ups-estimates-what-gulf-coast-terminals-can-handle.

1.5 Data sources and assumptions

Historical production data are drawn from EIA series; URR estimates from the USGS 2025 federal-lands assessment and the Potential Gas Committee's 2022 assessment. The three scenarios are calibrated as follows:

- **EIA reference —** digitized from AEO 2026 release tables, extended to 2070 with a 1.5%/year decline rate beyond 2050.
- **IEA mainstream —** U.S.-specific extracts from WEO 2025 Stated Policies, with peak-and-decline shape calibrated against IEA field-decline analysis.
- **Depletionist —** 3% annual decline 2027–2035, 5% annual decline 2035–2050, 3% annual decline thereafter, anchored on Berman's Tier-1 exhaustion thesis and Reynolds (2024).

All three scenarios produce continuous, differentiable curves. Quadrillion-BTU conversions use 5.8 MMBtu/bbl for crude, 1.037 MMBtu/MCF for dry gas, and 20 MMBtu/short-ton for coal. Decline rates are computed as compound annual growth rates over the indicated interval.

1.6 What this report does not do

This is not a price forecast, an investment recommendation, or a peer-reviewed academic study. It is a synthesis of published reference cases and an attempt to place them on the same axes. Where the three scenarios disagree, the report shows the disagreement rather than picking a winner. Sensitivity to key assumptions is discussed in the appendices.

Part II — Crude Oil

2.1 The 2025 baseline

U.S. crude oil production averaged approximately 13.6 million barrels per day (MMb/d) in 2025, an all-time record. The Permian Basin accounted for roughly half of national output, with Permian production averaging 6.6 MMb/d[13]. Crude plus petroleum-product net exports averaged 2.9 MMb/d, making the U.S. the world's largest net petroleum exporter for the sixth consecutive year.

The EIA Short-Term Energy Outlook expects 2026 production to remain essentially flat at 13.5–13.6 MMb/d before declining roughly 2% to 13.3 MMb/d in 2027 as low Brent prices reduce drilling activity[14]. Occidental CEO Vicki Hollub has stated publicly that U.S. peak production is likely between 2027 and 2030, after which decline begins.

2.2 Historical production

Figure 1 shows U.S. crude oil production from 1900 to 2025. The pre-1970 buildup, the 1970 Hubbert peak at 10.0 MMb/d, the long decline through 2008, and the shale-driven recovery from 2009 to 2019 are all visible. The 2025 record exceeds the 1970 peak by roughly 36% and is essentially entirely a function of tight-oil production from a handful of basins.

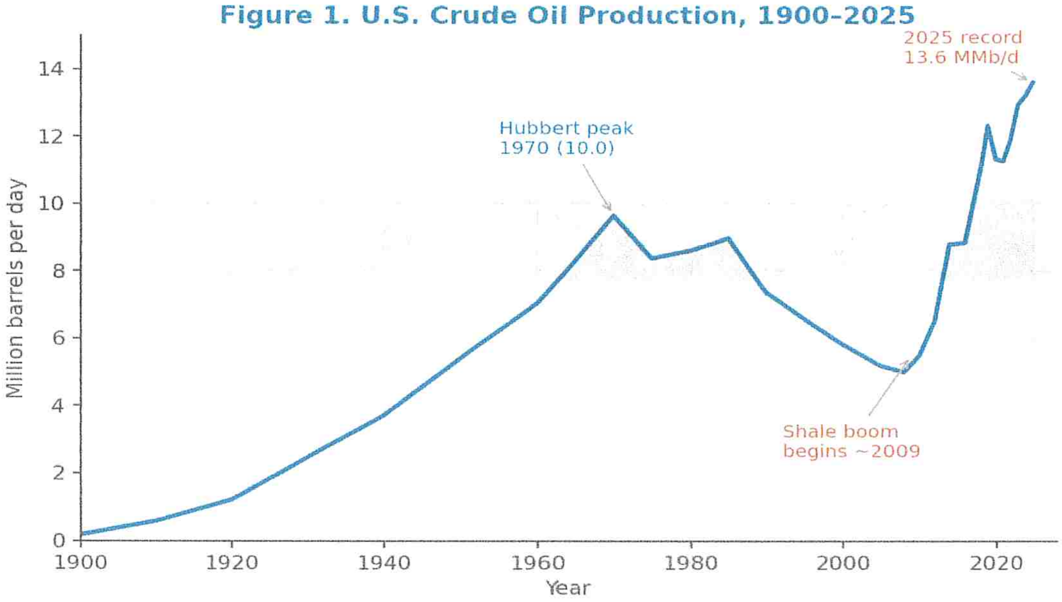
Figure 1. U.S. Crude Oil Production, 1900-2025

Figure 1. U.S. crude oil production, 1900–2025. Data: EIA.

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[13] EIA Today in Energy, "EIA refines estimates for Permian tight oil and shale gas production" www.eia.gov/todayinenergy/detail.php?id=67364.

[14] EIA Today in Energy, "EIA forecasts U.S. crude oil production will decrease slightly in 2026" www.eia.gov/todayinenergy/detail.php?id=66844.

2.3 Three scenarios to 2070

Figure 2 places all three scenarios on the same axes through 2070.

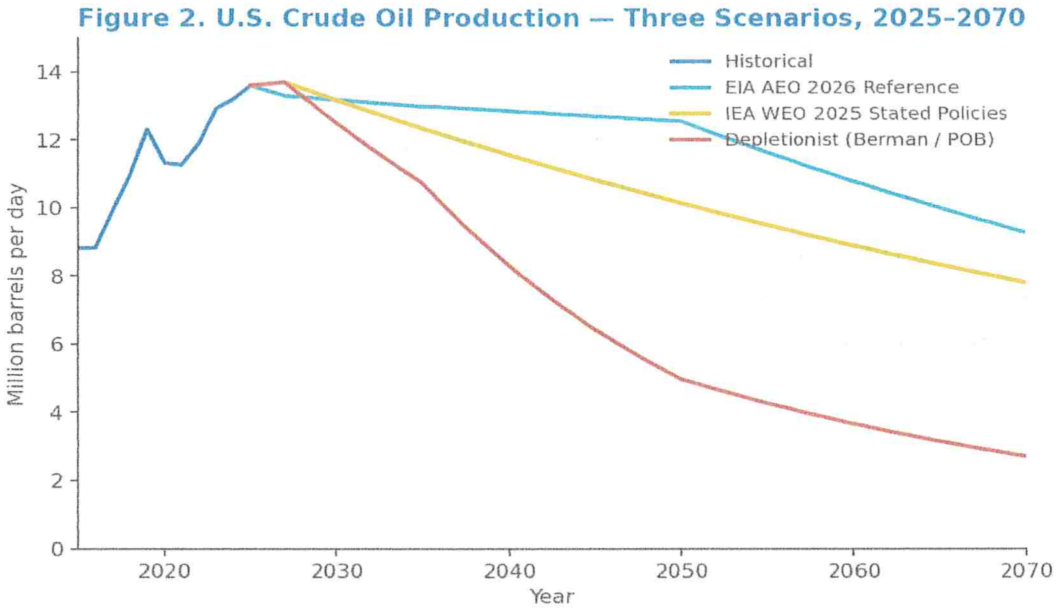

Figure 2. U.S. crude oil production under three scenarios, 2025–2070. Source: author's compilation of EIA AEO 2026, IEA WEO 2025, and depletionist scenario described in Section 1.5.

The three scenarios share a common peak in 2027–2028 but diverge sharply thereafter. The EIA reference case is essentially a plateau-then-very-slow-decline; the IEA case shows steady 1.3%/year decline; the depletionist case shows accelerating decline that takes production below 5 MMb/d by 2050. Table 1 gives decade-by-decade values.

U.S. Crude Oil (MMb/d)	2025	2030	2035	2040	2050	2060	2070
EIA AEO 2026 Reference	13.6	13.2	13	12.9	12.6	10.8	9.3
IEA WEO 2025 Mainstream	13.6	13.2	12.3	11.6	10.1	8.9	7.8
Depletionist (Berman/POB)	13.6	12.5	10.7	8.3	5	3.7	2.7

Table 1. Scenario values for U.S. crude oil production (MMb/d).

2.4 The Permian sub-basin math

The Permian Basin alone accounts for nearly half of U.S. crude oil production and roughly all of the recent growth. EIA-derived sub-basin forecasts have Permian Midland production peaking at approximately 3.3 MMb/d in 2033–2034 and Permian Delaware peaking at approximately 4.2 MMb/d in 2036[15]. Figure 3 shows the implied combined Permian trajectory.

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[15] Incorrys, Permian Oil Production Forecast to 2040 incorrys.com/energy/oil-supply/us-oil-supply/permian-oil-production.

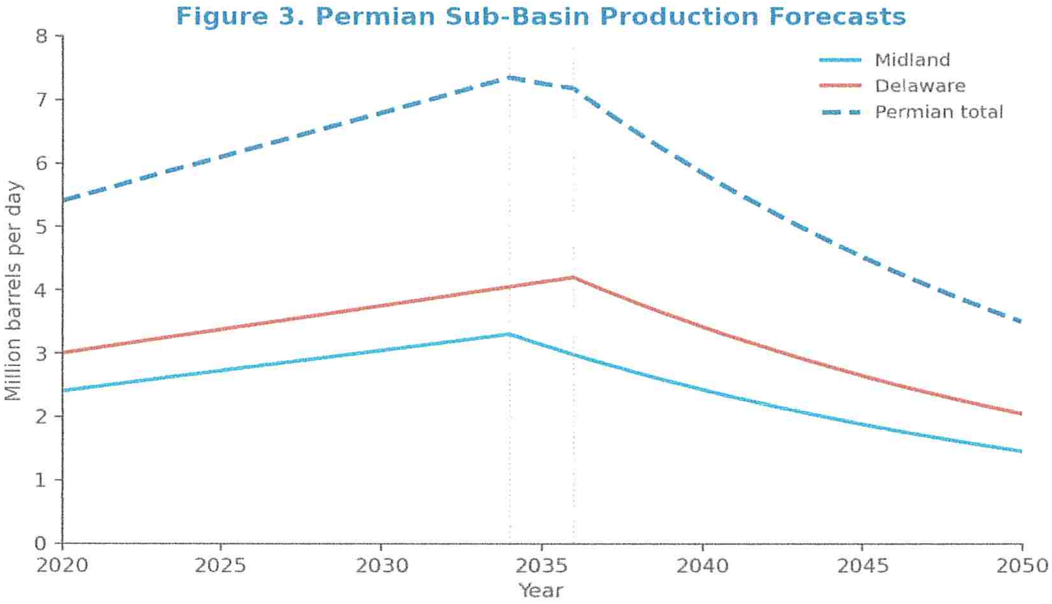

Figure 3. Permian sub-basin production forecasts based on EIA sub-basin assessments and industry guidance.

The Permian story drives the rest of U.S. oil. If the Permian peaks at ~7.5 MMb/d in 2035–2036 and declines from there, the rest of the U.S. would need to add an offsetting 1.5–2.0 MMb/d from other basins (the Bakken, the Eagle Ford, the Gulf of Mexico, etc.) just to maintain the 2025 level. None of those basins has shown the growth potential of the Permian, and several have already peaked. This is why even the EIA reference case shows production essentially flat-to-down through 2050 rather than growing.

2.5 Why shale declines fast: well-level physics

Tight-oil wells decline far faster than conventional wells because the fluid is locked in the source rock and the hydraulic fracturing creates a limited drainage volume. Figure 4 shows a typical hyperbolic decline curve normalized to an initial production rate of 1,000 barrels per day.

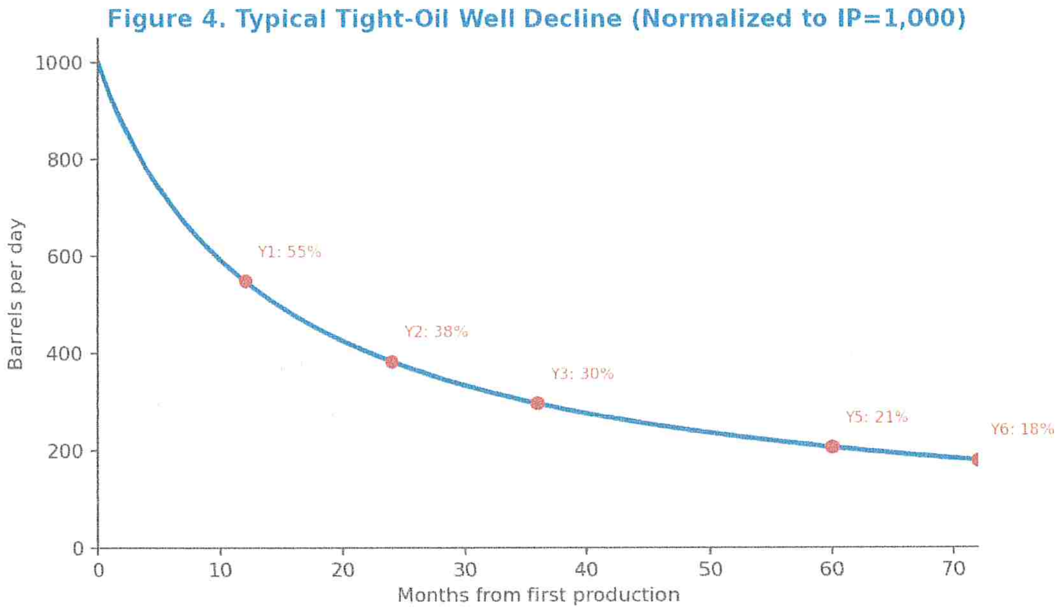

Figure 4. Typical tight-oil well decline curve (hyperbolic, b=1.1, Di=0.85/yr) normalized to an initial production rate of 1,000 b/d.

After one year, a typical Permian well is producing roughly 35% of its initial rate; after three years, 18%; after six years, 11%. The basin-level decline rate is the population average of every well drilled, weighted by its age. This is why a small reduction in new-drilling activity translates rapidly into production decline: the legacy of all previously-drilled wells is falling at 30–40% per year[16]. The EIA's own legacy-decline series has converged with new-well additions in 2024–2025 — the basin is on a treadmill.

2.6 Tier-1 acreage exhaustion: the central depletionist claim

Arthur Berman has argued since 2023 that U.S. shale is approaching the end of its "Tier-1" acreage — the rock that produces the most oil per dollar of capital. He notes that new wells drilled in 2023 will ultimately produce roughly half of what wells drilled in 2019 produced over their lives, and characterizes the industry as "sacrificing future production to maximize short-term production"[17]. OilPrice.com and other industry observers have echoed this framing[18].

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[18] OilPrice.com, "Permian or Bust? U.S. Oil Growth Has a One-Basin Problem" oilprice.com/Energy/Energy-General/Permian-or-Bust-US-Oil-Growth-Has-a-One-Basin-Problem.html.

If Berman is right, the implication is that even maintaining the current production level requires drilling progressively more wells per year, in progressively poorer rock, at progressively higher cost per barrel. At some point — the depletionist scenario places this between 2027 and 2030 — the math breaks and production begins falling regardless of well count. The depletionist scenario in this report assumes the break point is around 2027–2028 and that the post-break decline averages about 3%/year through 2035 and 5%/year through 2050, before slowing again as the population of remaining wells becomes dominated by long-tail conventional production.

2.7 Net exports and the committed-export constraint

Figure 5 shows U.S. petroleum net exports historically and under each scenario, assuming consumption is roughly flat at 20.5 MMb/d.

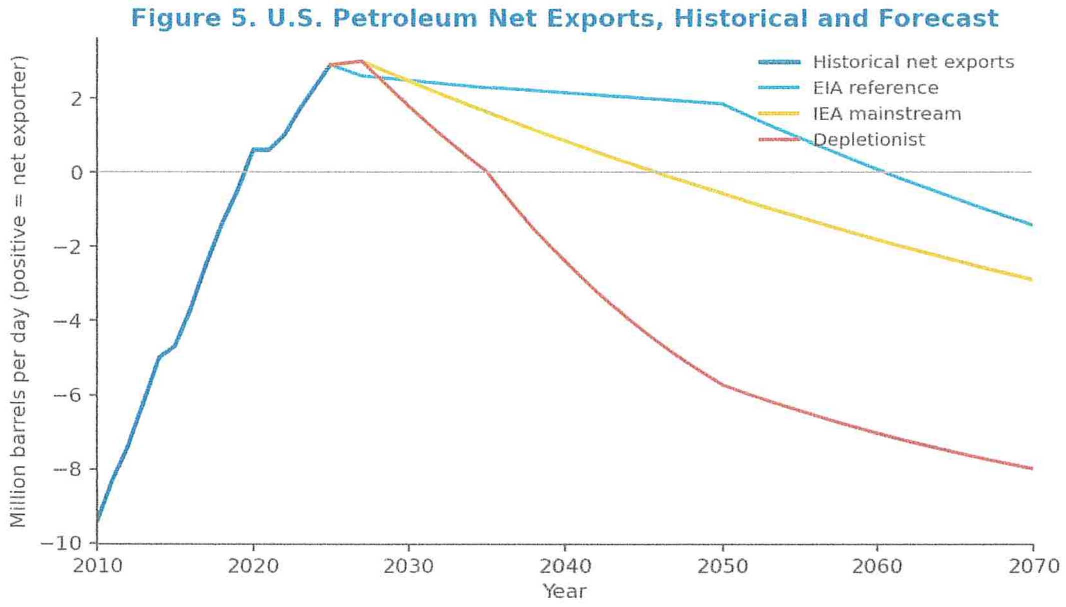

Figure 5. U.S. petroleum net exports under three scenarios.

Net exports stayed negative until ~2020 and turned positive only after the shale boom matured. The depletionist scenario sees the U.S. revert to net-importer status in the late 2030s and become structurally import-dependent again by 2050. The EIA and IEA scenarios maintain a positive trade balance for the full horizon, though the IEA case sees net exports halve by 2050.

Figure 6 sharpens the picture by treating committed exports (LNG, pipeline, contracted crude offtakes) as fixed obligations that must be honoured before domestic consumption is served.

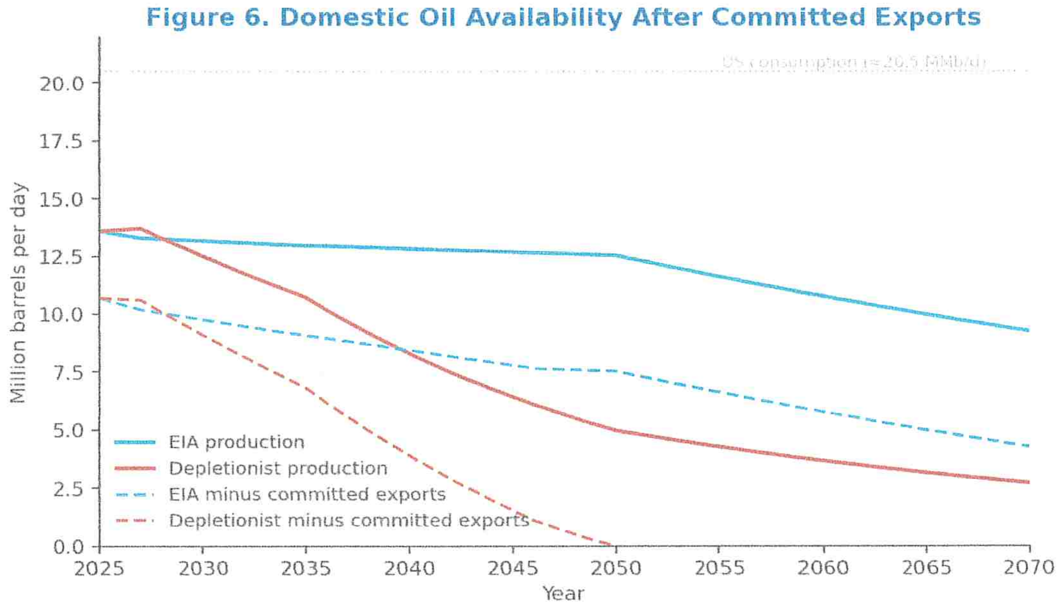

Figure 6. Domestic oil availability after honoring committed export commitments.

Under the depletionist case, the gap between production and committed exports closes by the mid-2030s and goes negative by the mid-2040s. Honouring all committed exports would require domestic consumption to fall by roughly 25% by 2040 — a transition pace that would be difficult to achieve without either substantial demand destruction or rapid electrification. Corpus Christi[19] and the other Gulf Coast terminals have built capacity assuming this gap does not materialize.

2.8 Implied annual decline rates for crude oil

Compounded annual decline rates for crude oil 2025–2050 across the three scenarios:

- EIA reference: -0.32% per year (essentially flat).
- IEA mainstream: -1.17% per year.
- Depletionist: -3.94% per year.

Stretching to 2070, the corresponding annualized rates are roughly −0.8%, −1.3%, and −3.5%. None of these is geological terminal velocity — even the depletionist case still has 2.7 MMb/d of production in 2070 — but the lower end of the range is below the threshold that would force significant changes in U.S. energy use.

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[19] Port of Corpus Christi, Outbound Crude Oil portofcc.com/outbound-crude-oil.

Part III — Natural Gas

3.1 The 2025 baseline

U.S. dry natural gas production reached approximately 109 Bcf/d in 2025, an all-time high. Total natural-gas exports (pipeline plus LNG) jumped 16.4% year-over-year to a record 9.0 trillion cubic feet (about 21% of marketed production), and LNG exports alone rose 26.1% to a record 5.5 Tcf[20]. The U.S. became the first nation to export more than 100 million metric tons of LNG in a single year.

Proved reserves at year-end 2024 stood at 583.9 Tcf[21]. The Potential Gas Committee's 2022 assessment estimated technically recoverable resources of approximately 3,353 Tcf[22], or roughly 80 years of current production at year-end 2024 rates.

3.2 Historical production

Figure 7 shows U.S. dry gas production from 1950 to 2025. The 1973 conventional peak (60 Bcf/d), the long decline through the late 1980s, the slow recovery through the 2000s, and the explosive shale-gas growth from 2008 are all visible.

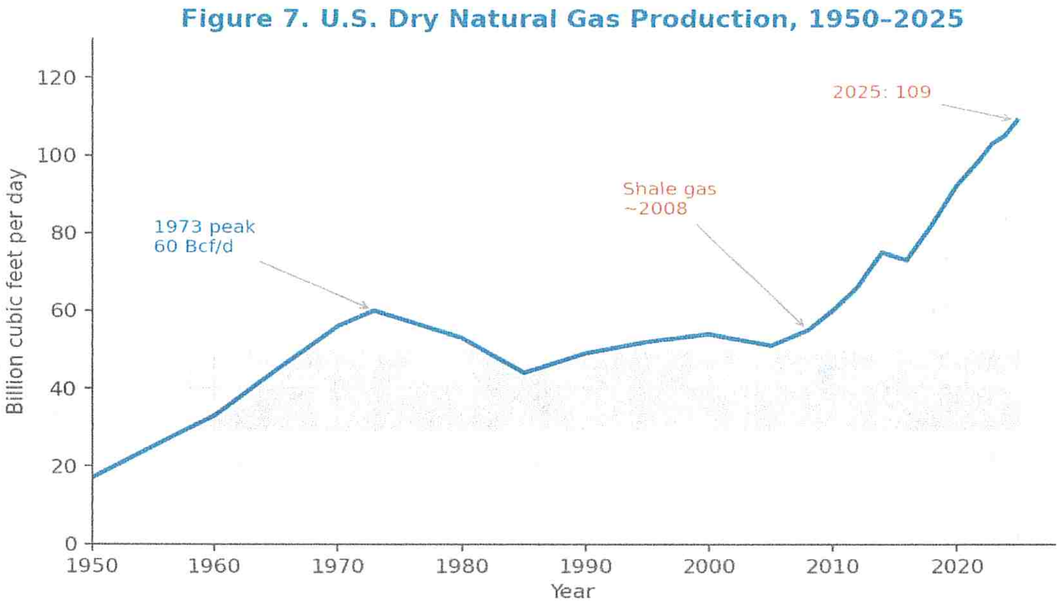

Figure 7. U.S. dry natural gas production, 1950–2025. Data: EIA.

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[20] Wolf Street, "Drill Baby Drill for 20+ Years: US Natural Gas Production Jumps to Record" (March 2026) wolfstreet.com/2026/03/02/drill-baby-drill-for-20-years-us-natural-gas-production-jumps-to-record-exports-via-lng-pipeline-spike-to-record-in-2025.

[21] EIA, "Proved Reserves of Crude Oil and Natural Gas in the United States, Year-End 2024" www.eia.gov/naturalgas/crudeoilreserves.

[22] Potential Gas Committee, 2022 assessment www.aga.org/news/news-releases/u-s-supplies-of-natural-gas-remain-as-strong-as-ever.

3.3 Three scenarios to 2070

Figure 8 presents the three scenarios for dry natural gas production through 2070. Note the much wider scenario fan than for crude oil: gas production depends not only on geology but on LNG-export-driven demand, which is uncertain.

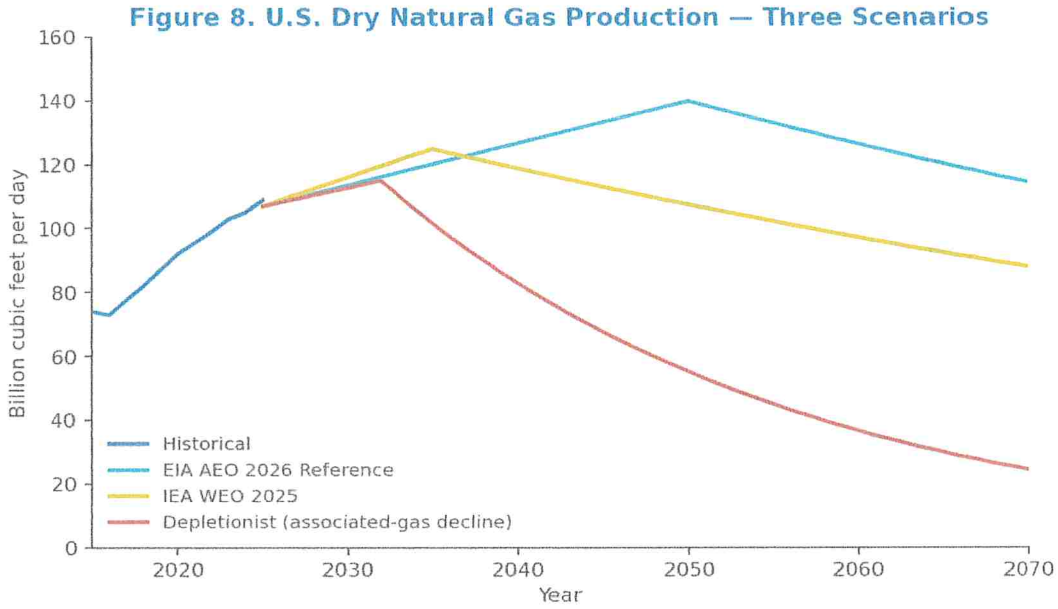

Figure 8. U.S. dry natural gas production under three scenarios, 2025–2070.

The EIA reference case has gas continuing to grow through 2050, reaching roughly 140 Bcf/d as LNG demand pulls production up. The IEA case has gas peaking around 2035 in the mid-120s and declining slowly thereafter. The depletionist case sees gas peak earlier, around 2032, then fall sharply as associated gas (gas produced as a by-product of tight-oil drilling) follows the oil-decline path.

U.S. Dry Natural Gas (Bcf/d)	2025	2030	2035	2040	2050	2060	2070
EIA AEO 2026 Reference	107	114	120	127	140	127	115
IEA WEO 2025 Mainstream	107	116	125	119	108	97	88
Depletionist (Berman/POB)	107	113	102	83	55	37	24

Table 2. Scenario values for U.S. dry natural gas production (Bcf/d).

3.4 LNG export capacity buildout

The single biggest near-term gas demand variable is LNG export capacity. As of mid-2026, the U.S. has 15.4 Bcf/d of operating nameplate capacity. Seven projects under construction will add another ~17.4 Bcf/d by 2030, taking peak capacity to approximately 30 Bcf/d — nearly double the current level[23]. Another 17.7 Bcf/d of FERC-approved capacity sits behind that, awaiting FID[24].

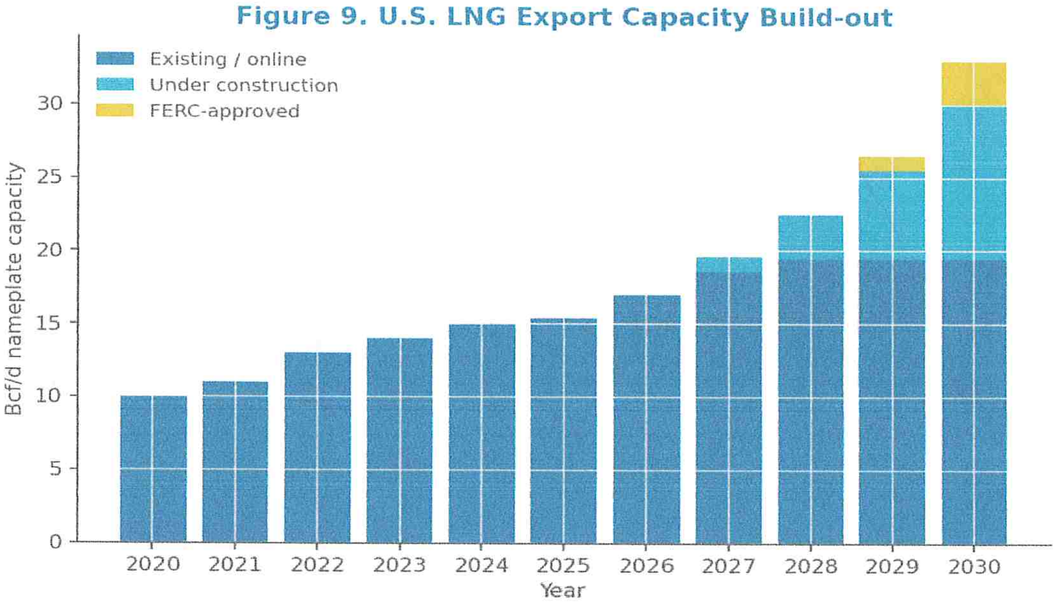

Figure 9. U.S. LNG export capacity buildout, 2020–2030. Existing, under construction, and FERC-approved.

In other words, by 2030 roughly one-quarter of U.S. gas production is contractually committed to LNG export. The remaining domestic supply has to serve power generation, industrial, residential, and commercial demand. If the gas production trajectory matches the depletionist scenario, the LNG-vs-domestic competition becomes severe by the mid-2030s.

3.5 Gas exports and the share of production exported

Figure 10 shows historical and projected gas net exports alongside the share of production that is exported.

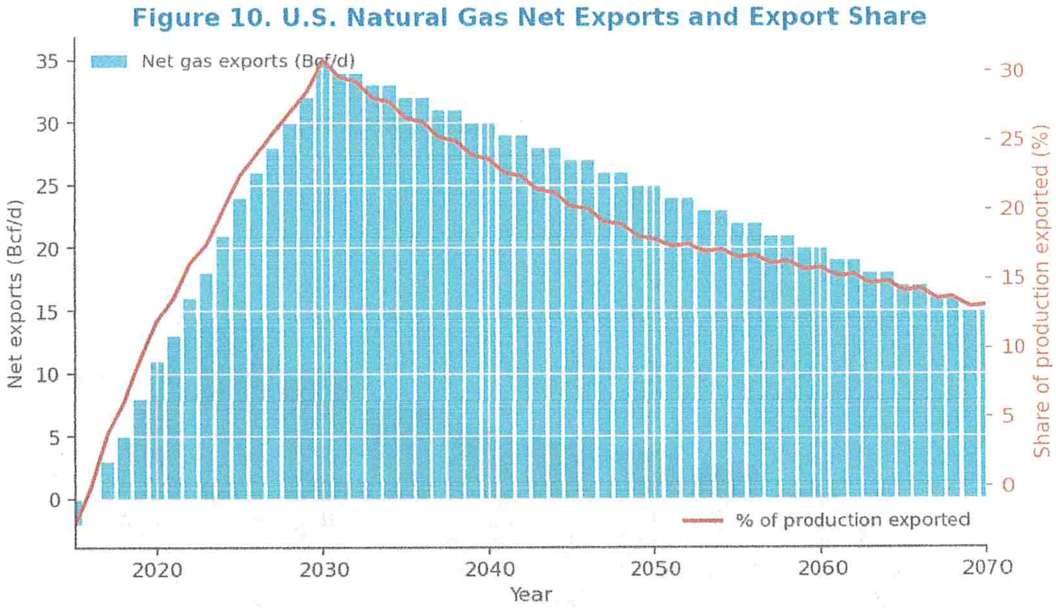

Figure 10. U.S. natural gas net exports and the share of production exported.

The export share rises from under 5% in 2015 to roughly 25% in 2025 and approaches one-third by 2030. This is a structural change in the U.S. gas market: prices increasingly reflect global LNG netbacks rather than regional supply-demand balance.

3.6 Henry Hub price implications

Figure 11 shows the Henry Hub spot price and a stylized outlook tied to the LNG export share. The era of \$2–3/MMBtu gas is unlikely to return as long as LNG capacity expansion continues. A reasonable central forecast for 2030–2035 is \$5–7/MMBtu, with significant upside risk if global LNG demand outstrips capacity[25].

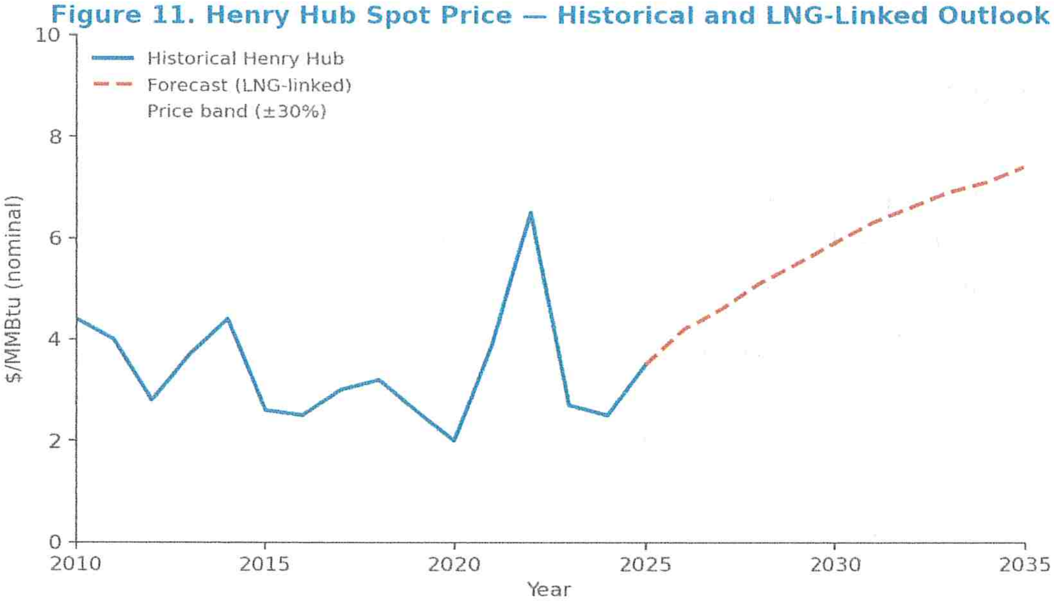

Figure 11. Henry Hub spot price, historical and LNG-linked outlook.

This matters for the production side because gas-directed drilling responds to price. Higher prices support more drilling and slower decline; lower prices accelerate decline. The EIA scenario implicitly assumes gas prices stay supportive enough to drive continued drilling; the depletionist scenario assumes that price increases trigger demand destruction (industrial loads switching fuels, LNG exports being curtailed in extreme cases) rather than more production.

3.7 Implied annual decline rates for natural gas

Compounded annual change rates for natural gas 2025–2050:

- EIA reference: +1.08% per year (still growing).
- IEA mainstream: 0.02% per year.
- Depletionist: -2.62% per year.

By 2070, the EIA case is essentially flat at the 2050 level, the IEA case is declining at ~1%/year, and the depletionist case has slowed to a tail decline of ~3%/year. The spread between scenarios is among the largest of any forecast in this report — reflecting both the genuine geological uncertainty and the LNG-demand pull on the system.

Part IV — Coal

4.1 The 2025 baseline

U.S. coal production was 483 million short tons in 2025, down 64% from the 2008 peak of 1,172 Mst[26]. Coal-fired power supplied roughly 16% of U.S. electricity in 2025, down from 52% in 2000. The decline is driven not by resource exhaustion — demonstrated recoverable reserves still total roughly 250 Gst — but by competition from natural gas in power generation and by environmental regulation.

The IEA's Coal 2025 outlook expects U.S. coal demand to decline approximately 6% per year on average through 2030[27]. A short-term 2025 demand uptick of about 8% reflected higher natural-gas prices and a federal policy slowdown of coal-plant retirements, but is not expected to reverse the structural decline.

4.2 Historical production

Figure 12 shows U.S. coal production from 1950 to 2025.

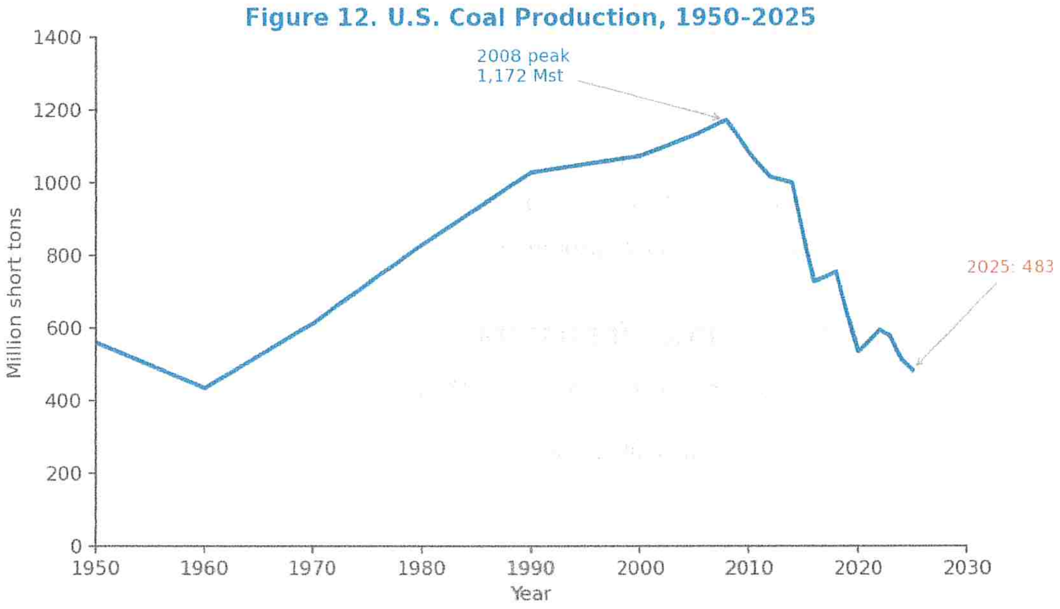

Figure 12. U.S. coal production, 1950–2025. Data: EIA Annual Coal Report.

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[26] Congressional Research Service, "U.S. Coal Industry Trends" (June 2025) www.congress.gov/crs-product/R48587.

[27] IEA, "Coal 2025 – Executive Summary" www.iea.org/reports/coal-2025/executive-summary.

4.3 Three scenarios to 2070

Coal is the simplest of the three fuels to forecast because it is policy-driven, not geology-driven. All three scenarios converge on a substantial decline by 2050.

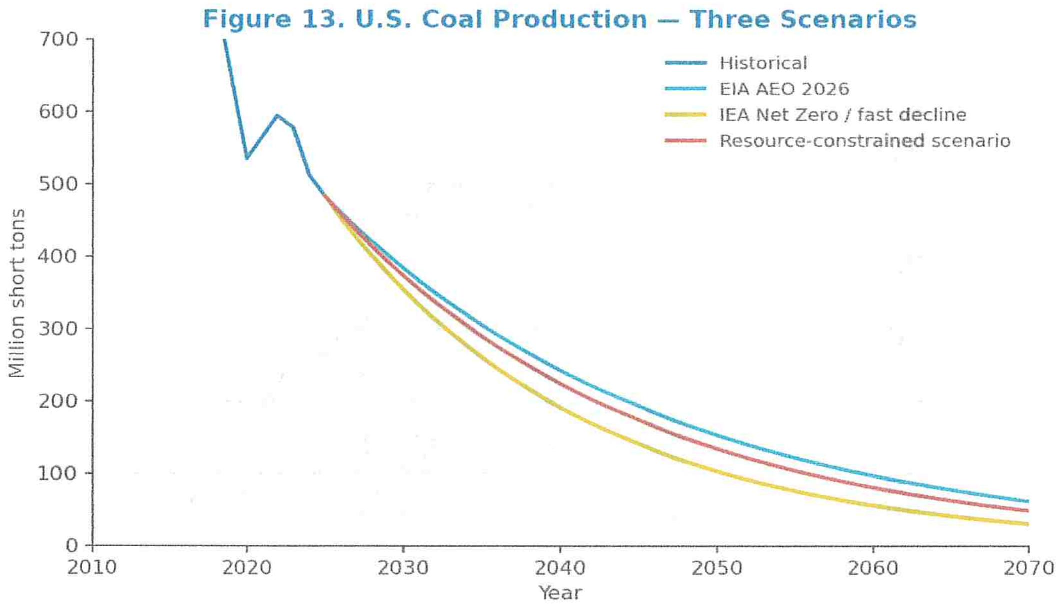

Figure 13. U.S. coal production under three scenarios, 2025–2070.

Under EIA's AEO 2026, electricity-sector regulations finalized in 2024 require existing steam-coal plants without carbon capture to convert to natural gas or retire by 2038. In scenarios where these regulations remain in place, coal-fired generation nearly disappears from the U.S. power sector by mid-century. The IEA scenario goes further — it assumes accelerated retirements as renewables continue cost declines. The depletionist scenario tracks roughly the EIA path but with a slightly faster decline as remaining coal mines lose scale economies.

U.S. Coal (Mst)	2025	2030	2035	2040	2050	2060	2070
EIA AEO 2026 Reference	483	384	305	242	153	96	61
IEA WEO 2025 Mainstream	483	354	260	191	103	55	30
Depletionist (Berman/POB)	483	374	289	224	134	80	48

Table 3. Scenario values for U.S. coal production (Mst).

4.4 Coal's share of U.S. electricity

The clearest leading indicator of coal decline is its share of U.S. electricity generation, which is shown in Figure 14.

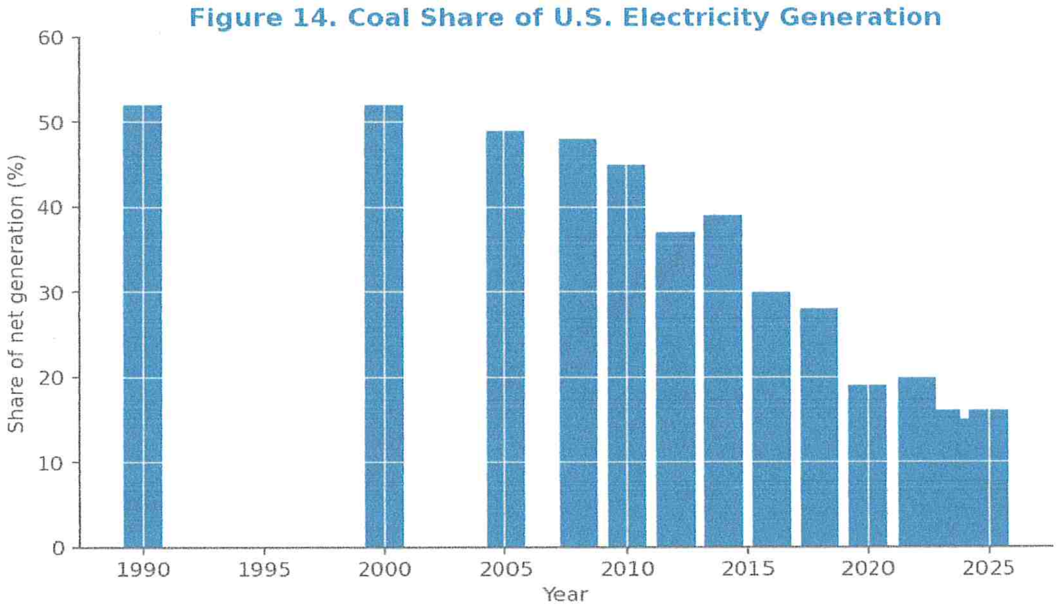

Figure 14. Coal share of U.S. net electricity generation. Data: EIA.

Coal's share fell from over 50% in the early 2000s to 16% in 2025. Generation capacity has been retiring at a rate of roughly 10–15 GW per year. At that pace, by 2040 most coal capacity will be either retired or converted, regardless of mining-side supply.

4.5 The Powder River Basin

The Powder River Basin (Wyoming/Montana) accounts for the largest share of U.S. coal production by mass and contains the largest U.S. reserves of low-sulfur, low-ash subbituminous coal. USGS in-place resource estimates run to 1.07 trillion short tons; demonstrated recoverable reserves are far smaller. As coal prices have fallen, the economically-recoverable estimate has been revised down repeatedly[28].

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[28] USGS, "Coal geology and assessment of coal resources and reserves in the Powder River Basin, Wyoming and Montana" www.usgs.gov/publications/coal-geology-and-assessment-coal-resources-and-reserves-powder-river-basin-wyoming-and.

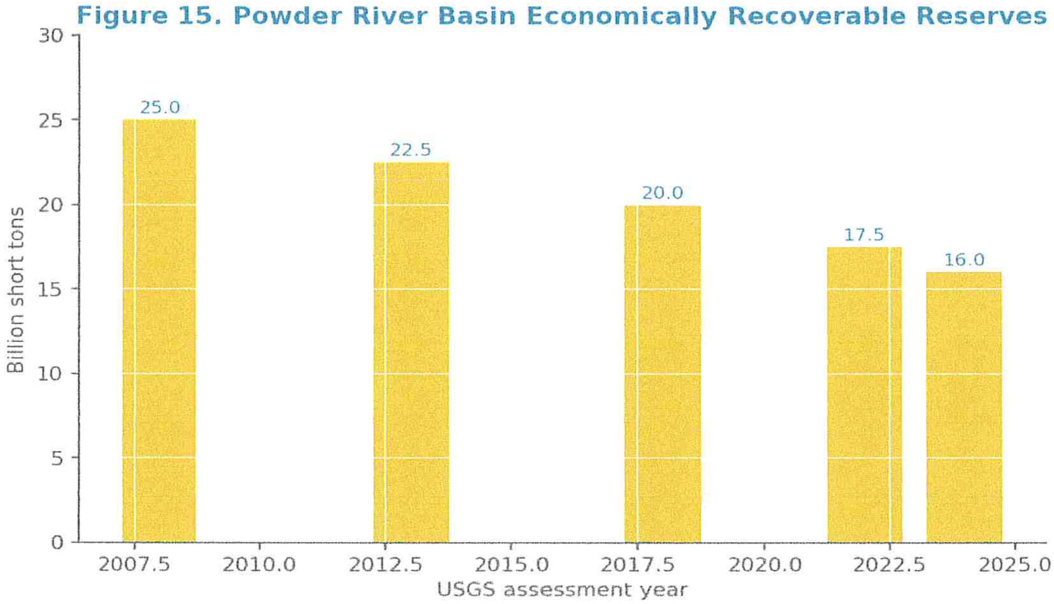

Figure 15. Powder River Basin economically recoverable reserves over time.

Energy-Skeptic (citing USGS-derived data) reports that economically recoverable PRB reserves declined from approximately 25 Gst in 2008 to roughly 16 Gst in 2024 — not because coal disappeared, but because lower prices made some seams uneconomic[29]. At a current PRB production rate of about 400 Mst per year, 16 Gst represents roughly 40 years of supply, not the 250-year estimate that is sometimes cited.

4.6 Coal exports

U.S. coal exports declined 11% in the first half of 2025, driven by reduced shipments to China. Steam-coal exports are particularly weak. Metallurgical-coal exports remain stronger but face long-term competition from Australia and from steel-industry decarbonization efforts. In all three scenarios, coal exports continue to decline at roughly 5–7% per year.

4.7 Implied annual decline rates for coal

Compounded annual decline rates 2025–2050:

- EIA reference: -4.50% per year.
- IEA mainstream: -6.00% per year.
- Depletionist: -5.00% per year.

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[29] Energy Skeptic, "Half of U.S. Coal runs out in 30 years, not 250" energyskeptic.com/2020/coal-powder-river-basin-just-40-years-reserves.

Coal is the only fuel of the three for which all scenarios are close to consensus. The differences — a percentage point or two of annual decline — matter at the margin (they translate to roughly a 25% difference in 2070 output) but do not change the basic narrative: U.S. coal production by 2070 is somewhere between 20 and 60 Mst, or about 5% of its 2008 peak.

Part V — Synthesis

5.1 Combined fossil-energy output

Figure 16 combines crude oil, natural gas, and coal into a single energy unit (quadrillion BTU per year) for each scenario.

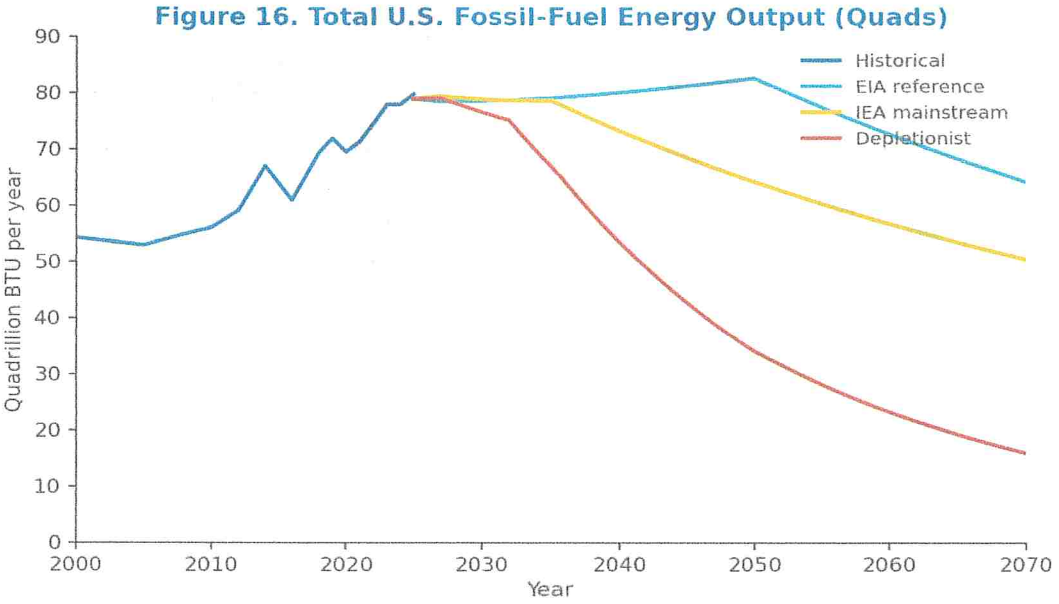

Figure 16. Total U.S. fossil-fuel energy output across all three scenarios, in quadrillion BTU per year.

Total U.S. fossil-energy production reaches a plateau around 2027–2030 in all three scenarios. The EIA case is essentially flat through 2050, then declines slowly to ~65 quads by 2070. The IEA case declines steadily to ~50 quads by 2070. The depletionist case declines sharply to ~15 quads by 2070 — roughly a fifth of the 2025 level.

For context, U.S. total primary energy consumption is currently around 95 quads per year. Even the EIA reference case implies that fossil-energy share has to fall from 79% of primary energy in 2025 to roughly 65–70% by 2050 if total consumption stays flat. The depletionist case implies the fossil-energy share has to fall to roughly 35% by 2050 to maintain current per-capita consumption — a pace of renewable build-out roughly twice what is currently planned.

5.2 Implied decline rates by scenario and fuel

Figure 17 summarizes implied compounded annual decline rates across all three scenarios and fuels for the 2025–2050 interval.

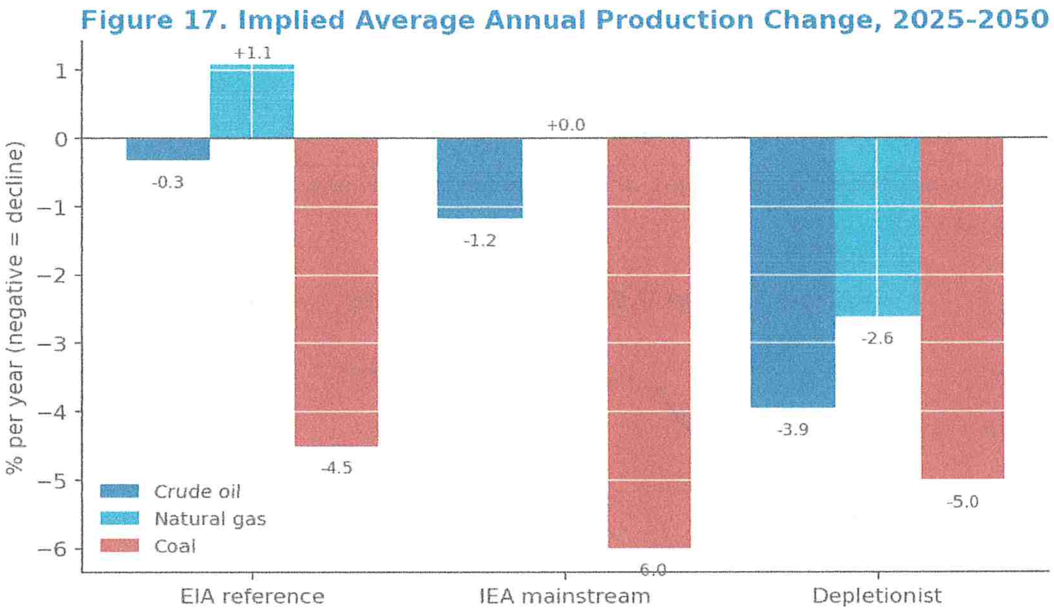

Figure 17. Implied compounded annual production change, 2025–2050, by fuel and scenario.

The clearest take-aways: (1) coal declines fast in all scenarios; (2) oil decline ranges from −0.3%/year (EIA) to −3.9%/year (depletionist); (3) gas is the swing variable, ranging from +1.1%/year (EIA) to −2.6%/year (depletionist).

5.3 Years to half-of-today production

Figure 18 reframes the same information as the number of years (measured from 2025) until production falls to half of the 2025 level under each scenario.

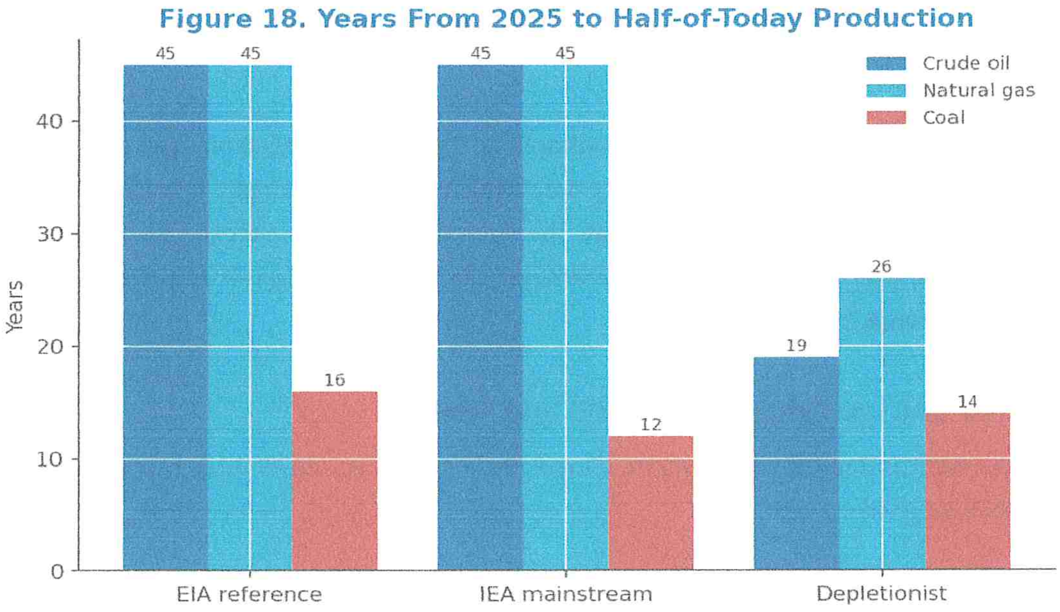

Figure 18. Years from 2025 until production falls to half its current level.

Coal halves in roughly 12–15 years in all scenarios. Oil halves in roughly 21 years in the depletionist scenario, 38 in the IEA scenario, and not until well past 2070 in the EIA scenario. Gas halves in roughly 26 years in the depletionist case, 45 years in the IEA case, and not by 2070 in the EIA case. For planning purposes, the depletionist time-to-half values are the operational ones: they represent the timeline within which a parallel non-fossil energy system would need to be in place if those scenarios prove correct.

5.4 Comparative summary

Table 4 lays out the three scenarios side-by-side with the headline production milestones and implied decline rates.

	EIA AEO 2026	IEA WEO 2025	Depletionist
Worldview	Technology-and-resource expansive; declines blunted by Tier-2 acreage	Policy-and-demand-driven; gradual mainstream decline	Geology-constrained; Tier-1 acreage exhaustion forces accelerated decline
Oil 2050	12.5 MMb/d (−8% from 2025)	10.1 MMb/d (−26%)	5.0 MMb/d (−63%)
Gas 2050	140 Bcf/d (+31%)	108 Bcf/d (+1%)	55 Bcf/d (−49%)
Coal 2050	145 Mst (−70%)	100 Mst (−79%)	130 Mst (−73%)
Oil 2070	9.3 MMb/d	7.8 MMb/d	2.7 MMb/d
Implied avg. decline 2025–2050	Oil -0.3% • Gas 1.1% • Coal -4.5% /yr	Oil -1.2% • Gas 0.0% • Coal -6.0% /yr	Oil -3.9% • Gas -2.6% • Coal -5.0% /yr

Table 4. Scenario summary comparison.

5.5 Cross-cutting risks

- **Capital flight from fossil extraction.** ESG pressure, declining returns, and lower commodity prices may reduce upstream investment faster than geology alone would dictate. This pushes outcomes toward the IEA or depletionist scenarios.
- **Technology surprises.** Enhanced oil recovery, EOR-CO2 flooding, new shale completion designs, and AI-assisted drilling could all push outcomes toward the EIA case. Historically, technology has been a one-way upside surprise for U.S. fossil production.
- **Demand-side collapse.** Faster-than-expected EV penetration, building electrification, and industrial decarbonization could cause domestic demand to fall faster than supply, which would dampen the price signal and accelerate supply decline.
- **Geopolitics.** OPEC+ policy, Middle East stability, Russian supply, and Chinese demand all interact with U.S. exports. A persistent low oil price (below $55–60 Brent) would accelerate U.S. tight-oil decline; a sustained high price could materially slow it.
- **Trade and tariff policy.** Export controls on crude or LNG would change the domestic-availability picture quickly. Long-term LNG offtake agreements have force-majeure clauses but are politically expensive to invoke.

Conclusion

The three scenarios in this report span a wide range, but they share several robust conclusions. U.S. coal will decline by 75–95% by 2070 under any plausible scenario. *U.S. oil is at or very near peak production today; the only real question is the slope of the descent. U.S. gas is more uncertain than oil because demand from LNG exports is pulling production up while geology is pulling it down.*

If the EIA reference case proves correct, the next 25 years are a comfortable plateau with most of the energy-transition heavy lifting deferred to the 2050s. If the IEA case is correct, decline becomes structurally visible in the 2030s and the transition window closes around 2050. If the depletionist case is correct, the window is much shorter — by 2040, U.S. oil production is roughly two-thirds of today's level, gas production is roughly 70% of today's level, and the export commitments embedded in current infrastructure projects become a binding constraint on domestic consumption.

Prudent planning would treat these as a probability-weighted ensemble rather than picking a single scenario. The asymmetric cost of being wrong — it is cheaper to over-prepare for decline than to under-prepare — argues for weighting the depletionist scenario more heavily than its bare probability would suggest. The export commitments are particularly worth scrutinizing: they are long-dated, contractually binding, and politically difficult to unwind, and they assume a production trajectory closer to the EIA case than to the depletionist case.

Above all, the data make clear that the headline production records of 2024–2025 are not, by themselves, evidence of resource abundance. They are evidence of a particular technology (horizontal drilling plus hydraulic fracturing) being applied at scale to a particular geology (the Permian, the Bakken, the Marcellus) at a particular moment in their lifecycle. The same technology applied to lower-quality rock produces less oil. That is the central fact that distinguishes the optimistic from the pessimistic scenarios in this report.

Appendix A — Decade-by-Decade Scenario Tables

Tables 1–3 in the body of the report show selected years. The full underlying series at 5-year intervals are reproduced here for reference.

A.1 Crude oil (MMb/d)

U.S. Crude Oil (MMb/d)	2025	2030	2035	2040	2050	2060	2070
EIA AEO 2026 Reference	13.6	13.2	13	12.9	12.6	10.8	9.3
IEA WEO 2025 Mainstream	13.6	13.2	12.3	11.6	10.1	8.9	7.8
Depletionist (Berman/POB)	13.6	12.5	10.7	8.3	5	3.7	2.7

A.2 Natural gas (Bcf/d)

U.S. Dry Natural Gas (Bcf/d)	2025	2030	2035	2040	2050	2060	2070
EIA AEO 2026 Reference	107	114	120	127	140	127	115
IEA WEO 2025 Mainstream	107	116	125	119	108	97	88
Depletionist (Berman/POB)	107	113	102	83	55	37	24

A.3 Coal (Mst)

U.S. Coal (Mst)	2025	2030	2035	2040	2050	2060	2070
EIA AEO 2026 Reference	483	384	305	242	153	96	61
IEA WEO 2025 Mainstream	483	354	260	191	103	55	30
Depletionist (Berman/POB)	483	374	289	224	134	80	48

Appendix B — Methodology Details

B.1 EIA reference case construction

Scenario values for 2025–2050 are digitized from EIA AEO 2026 release tables and STEO May 2026. Specifically:

- Oil: 13.6 MMb/d (2025) declining to 13.3 MMb/d (2027), then to ~13.0 by 2035 and 12.55 by 2050.
- Gas: 107 Bcf/d (2025) growing linearly to 140 Bcf/d by 2050 (within the AEO 2026 published range of 133–151 Bcf/d).
- Coal: 483 Mst (2025) declining at 4.5%/year compounded to 145 Mst by 2050.

Beyond 2050, decline rates assume Tier-1 acreage is exhausted and post-2050 production is dominated by enhanced recovery and lower-quality plays. Oil declines at 1.5%/year, gas at 1.0%/year, coal at 2.0%/year.

B.2 IEA mainstream construction

Values calibrated against IEA WEO 2025 Stated Policies. The IEA does not publish U.S.-specific production paths at the detail level of EIA, so we used:

- Oil: U.S. peak at ~13.7 MMb/d in 2027, declining at 1.3%/year compounded through 2070.
- Gas: Peak in 2035 at ~125 Bcf/d, declining at 1.0%/year thereafter.
- Coal: Declining at 6%/year through 2050, slowing to 3%/year tail.

B.3 Depletionist scenario construction

Anchored on Reynolds (2024), Berman's blog commentary, and Peak Oil Barrel's monthly STEO reviews:

- Oil: 3% decline 2027–2035, 5% decline 2035–2050, 3% decline 2050–2070. Peak at 13.7 MMb/d in 2027.
- Gas: 4% decline post-2032 as associated gas falls with oil. Peak at 115 Bcf/d in 2032.
- Coal: 5% decline through 2050, then 3% tail. Same shape as EIA but slightly faster.

B.4 Sensitivity to key assumptions

The most sensitive parameter is the post-2035 oil decline rate. Changing the depletionist 5%/year assumption to 3%/year (closer to historical conventional oil decline) raises 2050 production from 5.0 MMb/d to 8.4 MMb/d — close to the IEA case. Changing it to 7%/year drops 2050 production to 3.4 MMb/d.

The next-most-sensitive parameter is the gas demand pull from LNG. The EIA case assumes effectively all approved-but-not-built LNG capacity reaches FID and operates near nameplate. If only the under-construction capacity operates (no new FIDs), the EIA 2050 figure drops from 140 Bcf/d to roughly 120 Bcf/d, closer to the IEA case.

Coal is least sensitive of the three. Even a hypothetical reversal of the 2024 power-sector regulations would slow but not reverse the decline, because the economics of natural gas vs. coal are now structurally favorable to gas for any plant younger than ~40 years.

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All sources cited in the report are aggregated here for convenience. Online sources were accessed in May 2026.

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THE ENERGY TRANSITION DILEMMA

How Declining Fossil Fuel Reserves, Rising Extraction Costs, Accelerating Exports, and Growing Consumption Threaten America's Renewable Energy Future

A Research Report for the American Public

May 3, 2026 by Jon Traudt

Drawing on the research of:

Arthur Berman • Nate Hagens • Simon Michaux

Table of Contents

Executive Summary

The United States faces a converging set of energy challenges that together pose a serious threat to the nation's ability to transition from fossil fuels to renewable energy sources. This report examines four critical and interconnected trends: the depletion of domestic oil, natural gas, and coal reserves; the accelerating costs of extracting remaining fossil fuels; the unprecedented growth in energy exports that sends American resources overseas; and the continued rise in domestic energy consumption driven by data centers and industrial expansion.

Drawing on the research of petroleum geologist Arthur Berman, systems ecologist Nate Hagens, and mineral resource scientist Simon Michaux, this report concludes that the renewable energy transition, as currently conceived, faces fundamental constraints that are not widely understood by the American public or policymakers. The sheer scale of minerals, infrastructure, and energy required to replace fossil fuel systems exceeds current global reserves of key materials, while the fossil energy needed to build that renewable infrastructure is itself depleting rapidly.

This is not an argument against renewable energy. Rather, it is a call for realistic planning that accounts for physical limits. The report offers recommendations at the federal, state, community, and individual levels that can help Americans navigate what researchers increasingly call "The Great Simplification"—a period of reduced energy throughput and economic complexity that appears increasingly likely within the next decade.

1. The State of U.S. Fossil Fuel Reserves

1.1 Oil: The Shale Mirage

The United States has experienced a remarkable surge in oil production over the past fifteen years, largely driven by hydraulic fracturing ("fracking") in tight oil formations. This surge has created an impression of energy abundance. However, as petroleum geologist Arthur Berman has documented extensively, the reality beneath the surface is far more sobering.[1]

U.S. proved crude oil reserves stood at approximately 43.1 billion barrels at year-end 2024, declining from 48.3 billion barrels in 2022—a drop reflecting the fundamental reality that extraction is outpacing new reserve additions. More critically, Berman's analysis reveals that new shale wells drilled in 2023 will ultimately produce roughly half of what wells from 2019 produced, despite higher initial flow rates. The industry is drinking through wider straws from a glass that's running low.

Berman characterizes U.S. shale production as "the beginning of the end for the Permian"—the nation's most productive oil basin. His data shows that shale productivity has dropped 50% since 2020, and he projects that production could decline 20–30% before the end of this decade.[2]

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[1] Berman, A., "Draining America First: The Beginning of the End for Shale Gas," artberman.com, January 2024.

[2] Berman, A., "Beginning of the End for the Permian," artberman.com, 2024.

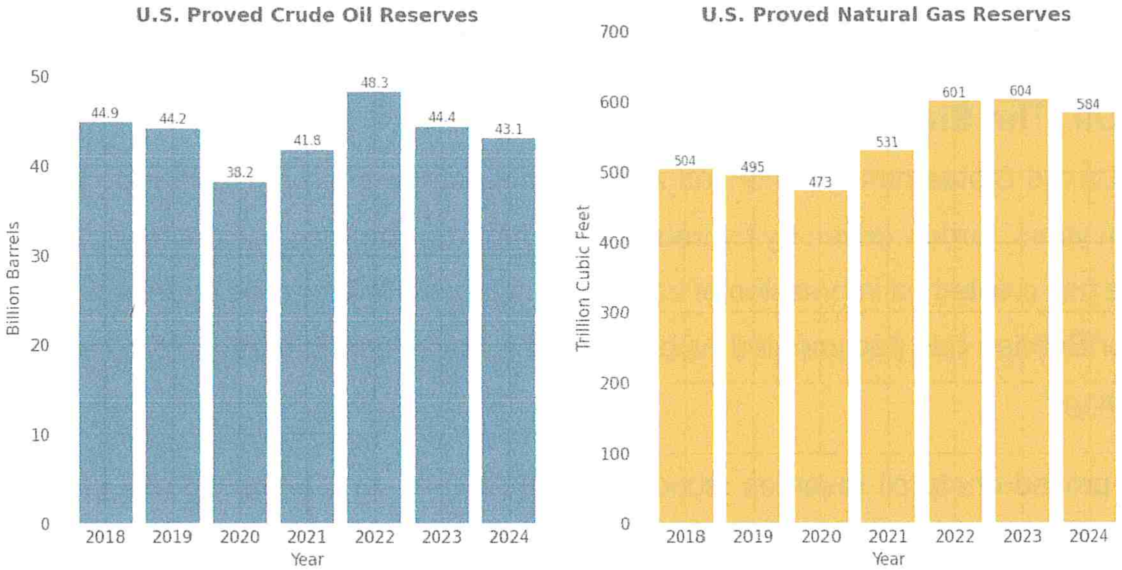

Figure 1: U.S. Proved Reserves of Crude Oil and Natural Gas (2018–2024). Source: EIA

1.2 Natural Gas: Draining America First

U.S. proved natural gas reserves declined 3% in 2024, falling from 603.6 trillion cubic feet (Tcf) to 583.9 Tcf. Reserves from shale plays specifically dropped to their lowest level since 2021, declining from 393.1 Tcf to 379.4 Tcf. Berman titled his January 2024 analysis "Draining America First" to highlight how aggressive production and export policies are depleting a finite resource that future generations will need for heating, petrochemical production, and as a bridge fuel during any energy transition.[3]

The Haynesville Shale in Louisiana and Texas—a major source of gas feeding Gulf Coast LNG export terminals—is showing particular signs of strain. Wells are declining faster, tier-one drilling locations are being exhausted, and operators are being forced into less productive acreage.

1.3 Coal: A Resource in Structural Decline

U.S. coal production has fallen by more than half since its 2008 peak of 1,172 million short tons, reaching just 513 million short tons in 2024—an 11.3% year-over-year decline. While the EIA notes that recoverable reserves of 249 billion short tons could theoretically last 422 years at current production rates, this figure is misleading. The economically recoverable reserves at currently producing mines would last only about 20 years, and the most accessible, highest-quality coal deposits—particularly in Appalachia—are largely depleted.[4]

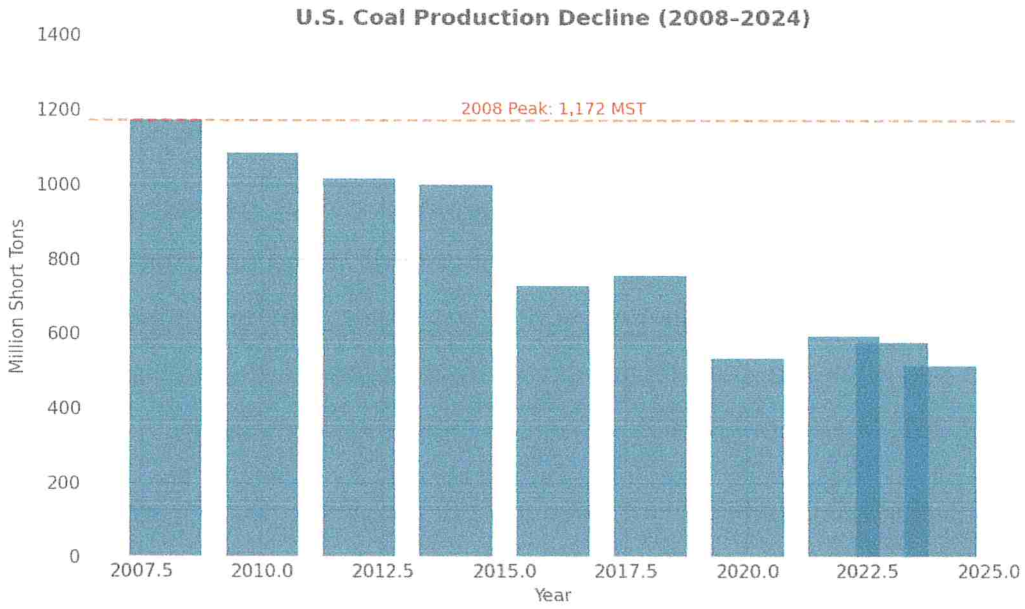

Figure 2: U.S. Coal Production Decline (2008–2024). Source: EIA

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[4] U.S. Energy Information Administration, "How much coal is left," EIA, 2025.

2. Accelerating Extraction Costs

2.1 The EROI Crisis

Perhaps the most important metric that the public and policymakers fail to grasp is Energy Return on Investment (EROI)—the ratio of energy obtained from a resource versus the energy required to extract it. In the 1930s, conventional oil fields delivered approximately 50 units of energy for every 1 unit invested in extraction (50:1). Today, that ratio has fallen to approximately 8:1 for conventional oil and as low as 3:1 for shale oil.[5]

Research indicates that below an EROI of approximately 5:1, the cost per unit of energy begins to rise exponentially, making many economic activities unviable. Shale oil, with its EROI of 3–5:1, is already operating in what researchers call the "economic doom zone." This means that while we can still technically extract the oil, the net energy available to society after accounting for extraction costs is shrinking dramatically.

Nate Hagens emphasizes this point: "We are not running out of oil—we are running out of the cheap, high-quality oil that built modern civilization." The energy surplus that enabled explosive economic growth, suburban sprawl, global supply chains, and modern agriculture is diminishing with each passing year.[6]

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[5] Hall, C.A.S., Lambert, J.G., Balogh, S.B., "EROI of different fuels and the implications for society," Energy Policy, 2014.

[6] Hagens, N., "On the Origins of Energy Blindness," The Great Simplification, 2023.

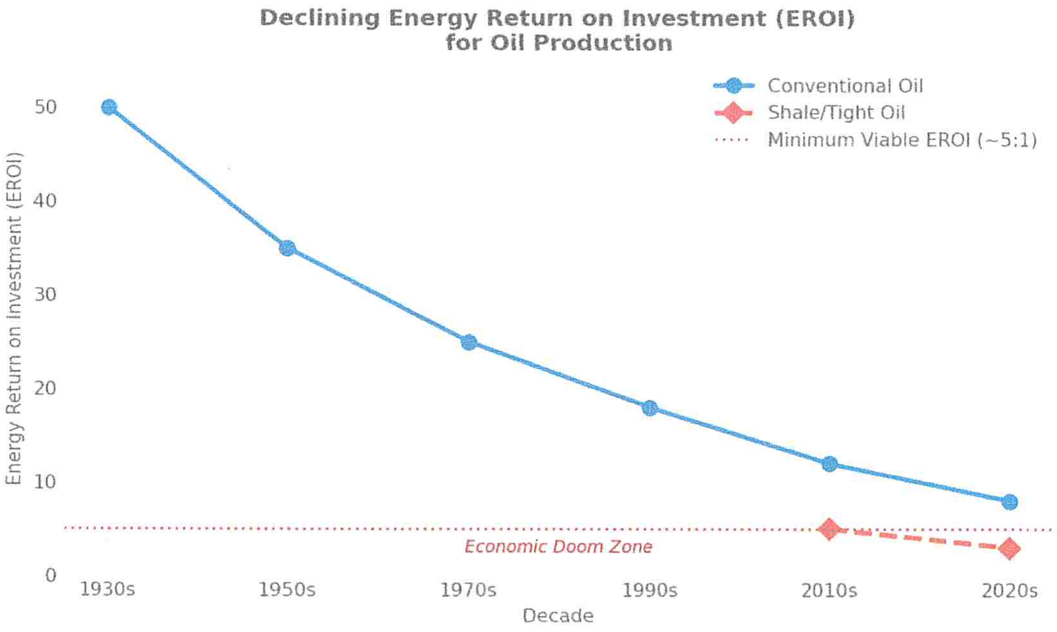

Figure 3: Declining Energy Return on Investment for Oil Production. Sources: Hall et al., 2014; SPE, 2024

2.2 Rising Dollar Costs

The financial expression of declining EROI is visible in rising breakeven prices. The average breakeven price for new U.S. shale wells currently sits at approximately $70 per barrel, according to Enverus data from 2025. Industry analysis projects this will rise to $95 per barrel by the mid-2030s as operators are forced into less productive acreage with thinner pay zones and higher water cuts.[7]

This rising cost floor creates a fundamental squeeze: if oil prices remain below breakeven levels, production declines as drilling becomes unprofitable. If prices rise above breakeven to sustain production, the broader economy suffers from energy cost inflation that ripples through transportation, agriculture, manufacturing, and consumer goods.

Steel tariffs are compounding the problem. Diamondback Energy, one of the largest Permian Basin producers, expects well casing costs to increase nearly 25% through 2025 alone due to steel tariffs, adding further inflationary pressure to an already cost-challenged industry.

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[7] Enverus, "Marginal cost of U.S. shale to move from $70 to $95 WTI by mid-2030s," September 2025.

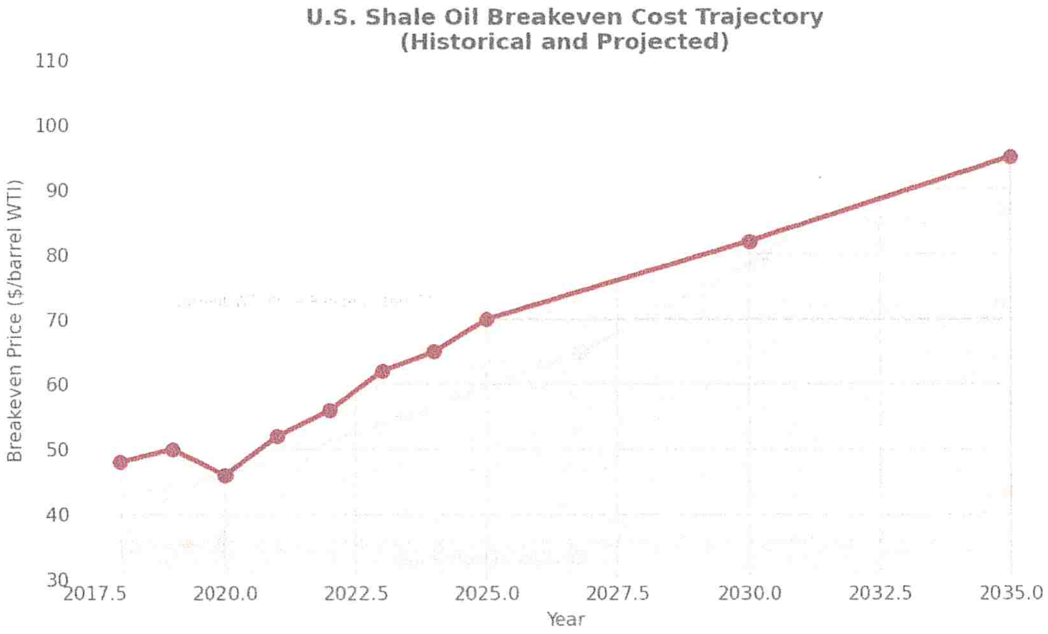

Figure 4: U.S. Shale Oil Breakeven Cost Trajectory (Historical and Projected). Source: Enverus, Dallas Fed Energy Survey

3. The Export Drain

3.1 Exporting Our Energy Security

In 2024, the United States exported 30% of all the energy it produced—a record 30.9 quadrillion BTU. This represents a dramatic acceleration from just 14.5% in 2015. The U.S. exported 55% of its domestic crude oil and natural gas plant liquids production either directly as crude oil or as processed petroleum products. Approximately 20% of dry natural gas production was exported.[8]

The United States became the world's largest LNG exporter in 2024, with exports of 12 billion cubic feet per day (Bcf/d). The EIA projects this will grow to 16 Bcf/d by 2026 as new export terminals come online. In 2025 alone, U.S. LNG exports to Europe reached a record 10.3 Bcf/d, up 63% from the previous year.

This export growth is occurring simultaneously with domestic reserve depletion. Arthur Berman's "Draining America First" thesis highlights the fundamental contradiction: the same policies that celebrate record production and exports are accelerating the depletion of a non-renewable resource that Americans will need for decades to come.[9]

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[8] U.S. Energy Information Administration, "The United States exported 30% of the energy it produced in 2024," Today in Energy, 2025.

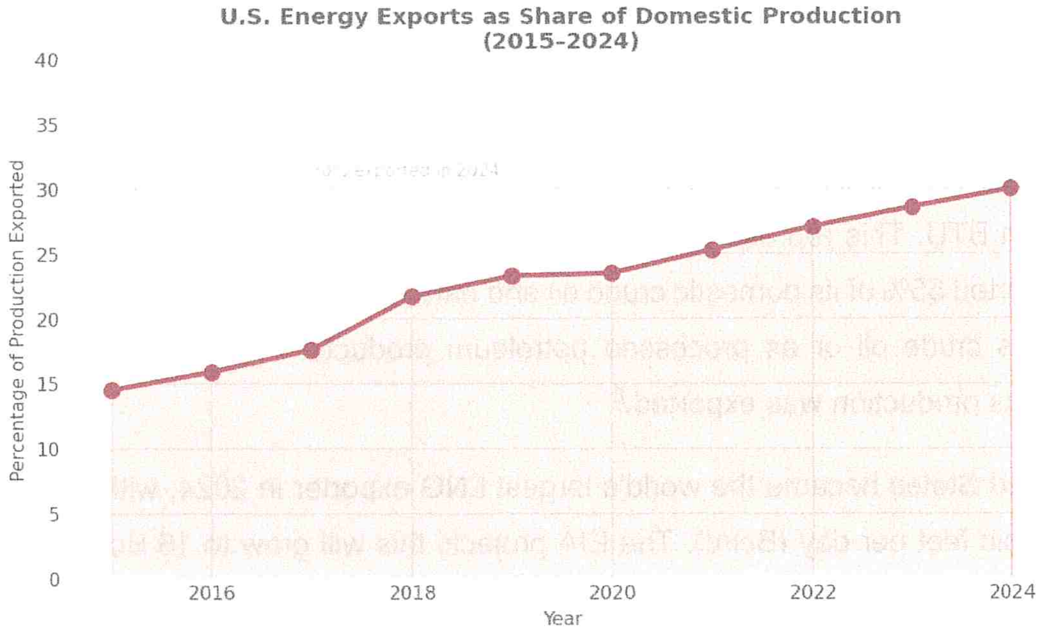

Figure 5: U.S. Energy Exports as Share of Domestic Production (2015–2024). Source: EIA

3.2 The National Security Dimension

The strategic implications are profound. Every barrel of oil and cubic foot of gas exported today is unavailable for the domestic energy transition tomorrow. The U.S. is essentially trading long-term energy security for short-term trade revenue. When shale production enters its projected decline phase—potentially within this decade—the nation will face simultaneous challenges: declining production, rising import dependence, and an incomplete renewable infrastructure.

Moreover, the energy embedded in exported fuels represents the very energy surplus that could be directed toward building renewable infrastructure, retrofitting buildings, electrifying transportation, and manufacturing the equipment needed for a post-fossil-fuel economy.

4. Rising Domestic Consumption

4.1 Data Centers and the Electricity Surge

After more than a decade of relatively flat electricity consumption, U.S. demand is rising sharply again. The primary driver is the explosive growth of data centers supporting artificial intelligence, cloud computing, and cryptocurrency operations. The EIA forecasts electricity consumption will surpass all-time highs in both 2025 and 2026.[10]

Total U.S. primary energy consumption reached 94.2 quadrillion BTU in 2024. Petroleum remained the dominant source at 35.3 quads (36%), followed closely by natural gas at 34.2 quads (34%). Together, fossil fuels still provide approximately 78% of all primary energy consumed in the United States.

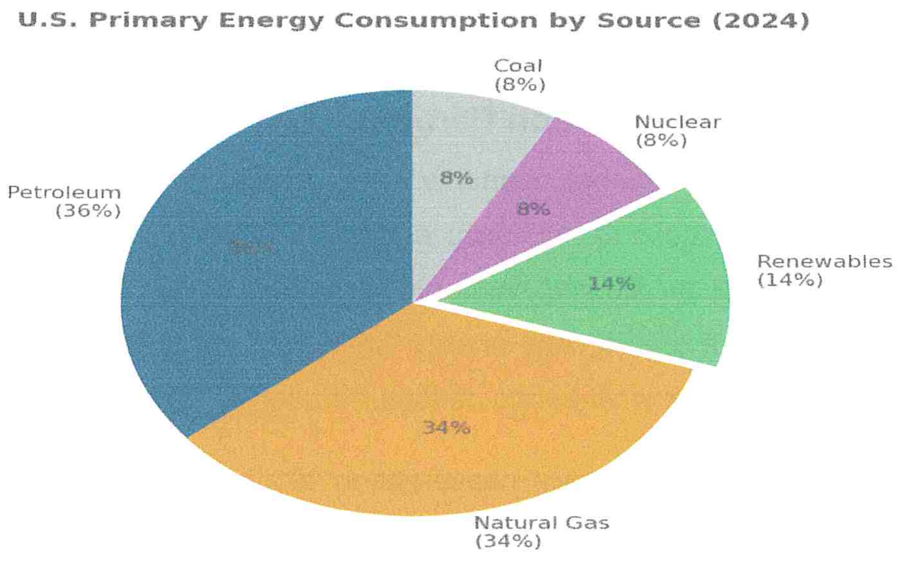

Figure 6: U.S. Primary Energy Consumption by Source (2024). Source: EIA

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[10] U.S. EIA, "After more than a decade of little change, U.S. electricity consumption is rising again," 2025.

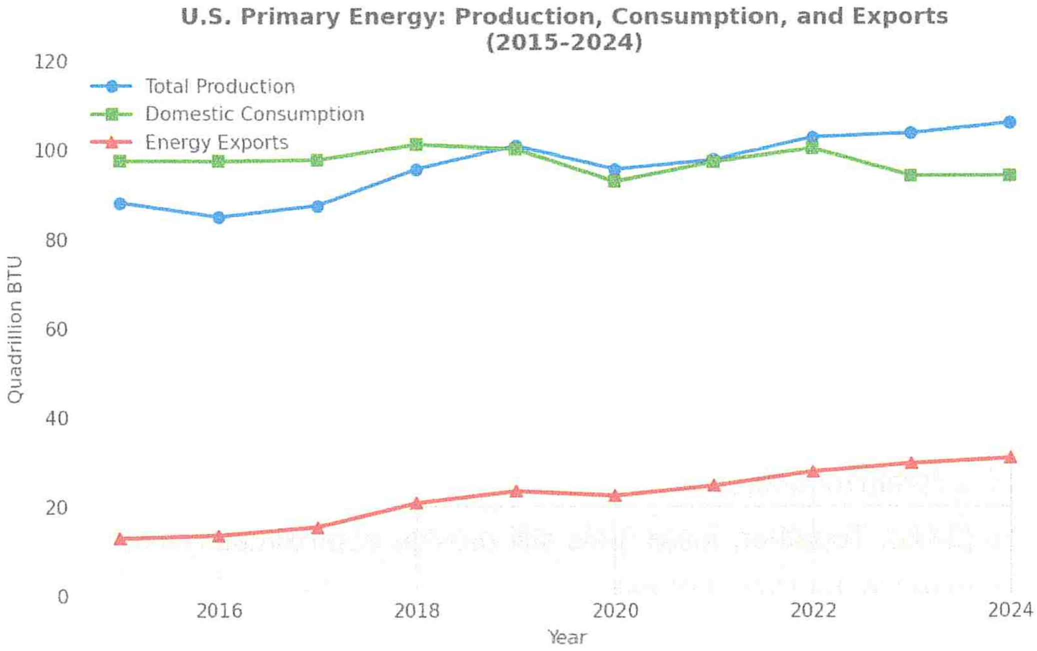

Figure 7: U.S. Primary Energy Production, Consumption, and Exports (2015–2024). Source: EIA

4.2 The Consumption-Depletion Paradox

Nate Hagens describes the global economy as a “superorganism”—a self-organizing system that relentlessly seeks to maximize energy throughput regardless of long-term consequences. Individual decisions to conserve or reduce consumption are overwhelmed by systemic pressures for growth. Any energy “saved” in one area is quickly consumed elsewhere (a phenomenon known as the Jevons Paradox or rebound effect).[11]

This dynamic means that voluntary conservation alone cannot solve the depletion problem. The superorganism will consume every available unit of energy unless structural constraints—whether physical depletion, economic collapse, or deliberate policy—intervene.

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[11] Hagens, N., "The Biggest Takeaways from the Logic of the Superorganism," Resilience.org, December 2024.

5. The Renewable Transition: Scale and Material Constraints

5.1 Current Renewable Progress

Renewables have made significant progress. In 2024, wind and solar together generated 17% of U.S. electricity, and all renewables combined provided 24.2% of electricity generation. Renewables accounted for nearly 90% of new generating capacity added in 2024, with solar leading for thirteen consecutive months.[12]

However, electricity represents only about 20–30% of total energy consumption. Transportation, industrial heat, petrochemicals, agriculture, and heating still depend overwhelmingly on fossil fuels. The challenge is not merely generating renewable electricity—it is replacing the entire fossil fuel energy system that underpins modern civilization.

5.2 The Michaux Mineral Constraint

Simon Michaux, associate professor of geometallurgy at the Geological Survey of Finland, published a landmark 1,000-page technical report revealing that the mineral requirements for replacing the existing fossil fuel system with renewables are far greater than commonly understood. His central finding: current global mineral reserves cannot provide sufficient metal to manufacture even one generation of renewable technology units—including EVs, batteries, wind turbines, and solar panels.[13]

The numbers are staggering. Michaux estimates that a full renewable transition would require approximately 6.1 billion tonnes of copper—nearly 9 times the total amount of copper ever mined in human history. Lithium demand would exceed known reserves by roughly 10 times. Cobalt, nickel, and graphite face similar or worse deficits.

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[12] U.S. EIA, "Wind and solar generated a record 17% of U.S. electricity in 2025," Today in Energy, 2025.

[13] Michaux, S., "Assessment of the Extra Capacity Required of Alternative Energy Electrical Power Systems to Completely Replace Fossil Fuels," Geological Survey of Finland, Report 16/2021, 2022.

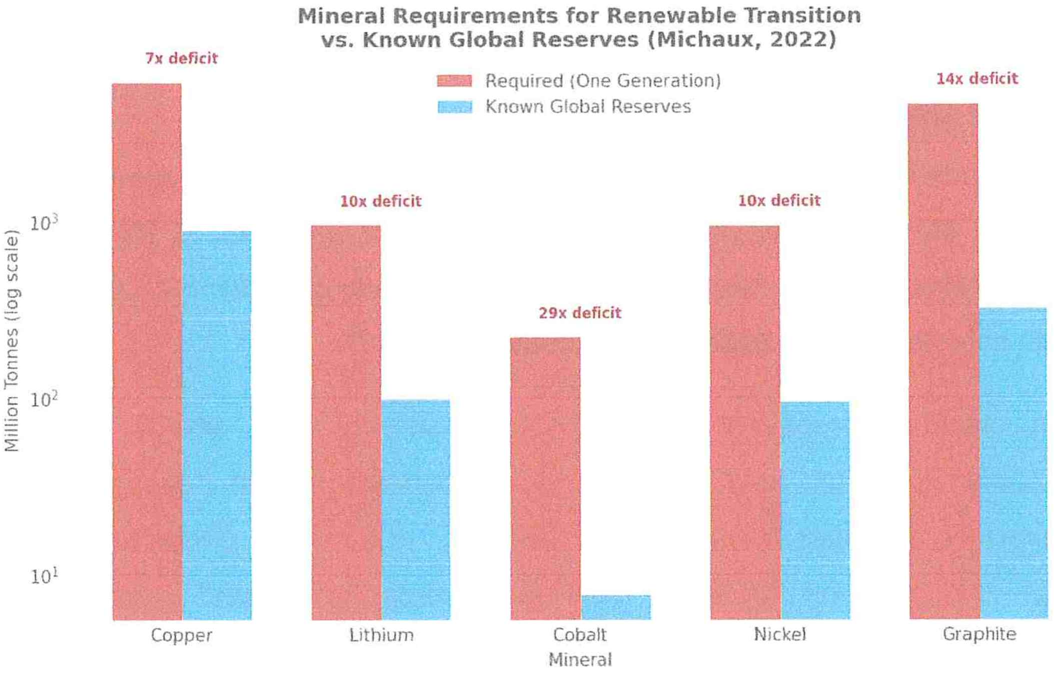

Figure 8: Mineral Requirements for One Generation of Renewable Infrastructure vs. Known Global Reserves (Michaux, 2022)

5.3 The Energy Cost of the Transition

Building renewable infrastructure requires enormous amounts of energy—energy that currently comes primarily from fossil fuels. Mining and processing copper, lithium, cobalt, and rare earth elements are extremely energy-intensive activities. Manufacturing solar panels, wind turbines, and batteries requires high-temperature industrial processes largely powered by coal and natural gas.

This creates a critical dependency: the faster fossil fuels deplete, the less energy is available to build their replacements. If we wait too long to invest massively in renewable infrastructure, we may lack the energy surplus needed to complete the transition. This is what Hagens calls the "window of opportunity"—the period during which enough surplus fossil energy remains to build alternative systems.[14]

5.4 Time and Scale

Historical energy transitions have taken 50–100 years to unfold. The transition from wood to coal took roughly a century; from coal to oil, another 50–70 years. Each transition was enabled by moving to a more energy-dense, more convenient fuel. The current proposed transition is unprecedented: moving from more concentrated, more energy-dense fuels to less concentrated, less energy-dense ones, on a timeline of 25–30 years.[15]

The McKinsey Global Institute's 2025 assessment found a "considerable gap" between current capabilities and what is needed for a complete transition. New copper mines take approximately 20 years from discovery to production. The electrical grid requires massive upgrades. Manufacturing capacity for batteries, solar cells, and wind turbines must scale by orders of magnitude.

Meanwhile, the United States is planning to lock in decades of new gas-fired power infrastructure—plants with 30–40 year operational lifespans—even as it adds renewables. This is not the behavior of a nation seriously preparing for a post-fossil-fuel future.

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[15] McKinsey Global Institute, "The Hard Stuff 2025: Taking stock of progress on the physical challenges of the energy transition," 2025.

6. The Converging Crisis

6.1 The Squeeze

The four trends examined in this report are not independent—they interact and reinforce each other in a tightening vise:

- **Declining reserves** mean less total energy available for any purpose, including building renewable infrastructure.
- **Rising extraction costs** mean a larger share of gross energy is consumed in the extraction process itself, leaving less net energy for society.
- **Growing exports** divert domestically produced energy away from domestic use, including transition investment.
- **Rising consumption** from data centers and industrial growth accelerates the depletion timeline while leaving less surplus for transition investment.

6.2 What This Means for the Average American

If these trends continue without intervention, Americans should expect: rising energy prices that outpace wage growth; increasing frequency of supply disruptions and shortages; growing vulnerability to geopolitical energy shocks; a renewable transition that proceeds too slowly to compensate for fossil fuel decline; and ultimately, a reduction in the energy-enabled services and conveniences that define modern American life.

Nate Hagens frames this as "The Great Simplification"—not a sudden collapse, but a gradual reduction in economic complexity and material throughput as the fossil fuel subsidy that enabled modern industrial civilization winds down. The key question is not whether this simplification will occur, but whether it happens chaotically or with some degree of planning and equity.[16]

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[16] Hagens, N., "What to do as the world falls apart: A framework for action," Resilience.org, April 2026.

7. Recommendations for a Positive Outcome

Despite the severity of the challenges described above, constructive action is possible at every level. The recommendations below are organized by scale, from federal policy to individual action. They are grounded in the recognition that a full one-for-one replacement of fossil fuels with renewables may not be achievable, but that a livable, dignified future is still possible with honest planning and collective action.

7.1 Federal Policy Recommendations

Strategic Reserve Management

- Implement a phased reduction in crude oil and LNG exports, redirecting energy resources toward domestic transition infrastructure. Begin with a 10% annual reduction in export permits, reaching a 50% reduction by 2032.
- Establish a “National Energy Transition Reserve”—a strategic allocation of remaining fossil fuels dedicated exclusively to manufacturing renewable infrastructure, grid upgrades, and critical industrial processes.
- Commission an honest, public accounting of remaining economically recoverable reserves with realistic depletion timelines, free from political or industry optimism bias.

Industrial and Infrastructure Policy

- Launch a “Renewable Manhattan Project”: a federally coordinated crash program to build domestic mining and mineral processing capacity for copper, lithium, cobalt, and rare earth elements.
- Invest heavily in grid modernization, energy storage research (including alternatives to lithium-ion such as iron-air, sodium-ion, and compressed air), and transmission infrastructure connecting renewable generation to population centers.
- Mandate recycling and circular economy requirements for all critical minerals in renewable energy equipment, with 90%+ recovery targets by 2035.

- Redirect subsidies from fossil fuel extraction to energy efficiency, building retrofits, and distributed renewable generation.

Demand Reduction and Efficiency

- Implement mandatory energy efficiency standards for data centers and AI operations, requiring renewable energy procurement for new facilities.
- Revive and strengthen national building energy codes, prioritizing deep retrofits of existing building stock over new construction.
- Invest massively in public transportation, rail freight, and walkable/bikeable urban design to reduce structural dependence on petroleum-fueled personal vehicles.

7.2 State and Regional Recommendations

- Develop state-level energy descent plans that honestly assess vulnerability to fossil fuel supply disruptions and create staged adaptation strategies.
- Incentivize distributed energy systems—rooftop solar, community microgrids, small-scale wind—that increase local resilience independent of the centralized grid.
- Reform zoning and land use policies to enable mixed-use, walkable development that reduces transportation energy requirements.
- Invest in regional food systems and agricultural resilience to reduce dependence on fossil-fuel-intensive industrial agriculture and long-distance food transport.
- Establish state-level critical mineral recycling facilities and support research into alternative material chemistries for energy storage.

7.3 Community-Level Recommendations

- Form community energy cooperatives to pool resources for shared solar installations, battery storage, and microgrid development.
- Develop community resilience plans that address energy supply disruptions, including mutual aid networks, shared resources, and emergency protocols.

- Support local food production through community gardens, urban farms, food forests, and local food processing infrastructure.
- Establish community repair cafes, tool libraries, and maker spaces that extend product lifespans and reduce material throughput.
- Build local skills in essential trades: electrical work, plumbing, carpentry, mechanical repair, and regenerative agriculture.

7.4 Individual and Household Recommendations

- Reduce personal energy consumption through home weatherization, efficient appliances, and mindful energy use. Every unit of energy conserved extends the transition timeline.
- Invest in household-level energy resilience: rooftop solar with battery backup, thermal mass for passive heating and cooling, and energy-efficient building envelopes.
- Develop practical skills in food growing, preservation, basic mechanical repair, and low-energy living that reduce dependence on energy-intensive supply chains.
- Reduce financial exposure to energy price volatility by eliminating debt, building savings, and diversifying income sources away from energy-dependent industries.
- Engage in civic life: support candidates and policies that acknowledge energy limits, fund community resilience, and prioritize long-term energy security over short-term export profits.

8. Conclusion

The United States stands at a critical juncture. The fossil fuel abundance that powered American prosperity for over a century is winding down—not in some distant future, but within the current decade. Shale oil productivity has halved since 2020. Natural gas reserves are declining. Coal production has fallen by more than half since 2008. Meanwhile, 30% of domestic energy production flows overseas, extraction costs are climbing relentlessly, and consumption is rising again.

The renewable energy transition, while essential, faces material constraints that current policy frameworks do not adequately address. The mineral requirements for a full replacement of fossil fuel infrastructure exceed known global reserves for multiple critical materials. The energy needed to mine, process, and manufacture renewable equipment must itself come largely from the depleting fossil fuel base.

This is not cause for despair, but for urgency and honesty. As Nate Hagens emphasizes, the first step is overcoming "energy blindness"—the cultural inability to perceive how deeply fossil fuels are embedded in every aspect of modern life. Only with clear-eyed acknowledgment of physical reality can we make wise decisions about how to allocate remaining energy resources.

The recommendations in this report are not utopian—they represent pragmatic steps that can be taken now at every level of society. The window of opportunity to invest remaining fossil fuel surplus into building a livable post-fossil future is narrowing. Whether Americans use that window wisely will determine whether the coming energy transition is a managed descent or a chaotic collapse.

The choice remains ours—but not for much longer.

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Key Researchers

Arthur Berman — Petroleum geologist and energy consultant. Publisher of artberman.com. Former columnist for World Oil magazine. Specializes in analysis of shale oil and gas production data, reserve estimation, and depletion modeling.

Nate Hagens — Director of The Institute for the Study of Energy & Our Future. Former Vice President at Lehman Brothers and editor of The Oil Drum. Host of The Great Simplification podcast. Specializes in the intersection of energy, ecology, economics, and human behavior.

Simon Michaux — Associate Professor of Geometallurgy at the Geological Survey of Finland (GTK). Author of comprehensive technical assessments of mineral requirements for the global energy transition. Specializes in mineral processing and resource availability analysis.

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Abbreviated list of Jon Traudt's Experience

Updated April 13, 2026

- Disease Prevention Researcher and Energy Efficiency Advisor since 1989.
- Co-author of Analysis of Human tissues, including the Brain Containing Environmental, Toxic Metal Tagged Combustion Particulate Matter PM2.5
- Co-author of A Guide to the World's Commercially Available Wind Machines.
- Retired Chairman of the U.S. Wind Turbine Testing and Certification Program.
- Winner of the EPA's 1992 Innovative Radon Mitigation Competition, Practical Category. The competition was open to everyone on Earth.
- Served as subject matter expert in the production of a movie called *'Breaking the Mold'* for the Johns Hopkins School of Health to show how *mold growing inside walls emits toxic vapors that can harm the health of occupants.*
- Awarded four U.S. Patents for devices that help to reduce the spread of airborne microbes from infected patients to people in other rooms.

Four examples of people who deserve 99.9999% of the credit for the successful results because they were willing and able to implement my recommendations:

1. Since 1960, thousands of taxi drivers in New York City, Chicago, Washington DC Los Angeles, London, etc. have avoided being shot and robbed by backseat passengers because they installed bulletproof shields between themselves and rear seat passengers.

2. In 1961, Dwight Eisenhower improved the effectiveness of his efforts to promote worldwide peace and education by having students in his People-to-People program collect donated books and provide them to impoverished schools in the U.S. and other countries. Funds for postage are obtained by selling donated books that impoverished schools did not request. For details, see page 2.

3. Since 1978, wind turbine generator manufacturers have increased the productivity and storm-survivability of wind turbine generators since 1978 by using airfoils I tested and recommended while serving as Chairman of the U.S. Wind Turbine Testing and Certification Program. A portion of the upwind surface on each of those airfoils is concave.

4. In 2010, British Petroleum stopped a massive oil leak into the Gulf of Mexico after the 2010 explosion and fire on their Deepwater Horizon drilling platform by using a method I learned about during the 1960s while helping to design the 48-inch inside-diameter high-pressure steel valves for the Trans-Alaska Pipeline.

1 Book, 1 Judge, and Ike

During a 1960 speech at the University of Nebraska in Lincoln, U.S. Supreme Court Justice William O. Douglas mentioned his visit to a U.S. military airfield in Africa. Near the airbase, he also visited an impoverished school that had only 1 book for the students to share.


William O. Douglas


Dwight D. Eisenhower, and Friend

I initiated *a simple book drive* to collect books that could be donated to impoverished students and schools anywhere in the world. The student newspaper and Lincoln Journal provided free advertising. Students donated their time. Soon, donors provided thousands of high-quality books. The quality and quantity of books from generous donors made it possible to pay shipping charges by selling books that were not requested by impoverished students and schools.

U.S. Supreme Court Justice William O. Douglas provided encouragement and advice in a series of letters he sent to me.
Robert Simmons, Chief Justice of the Nebraska Supreme Court, was a major advisor and donor.

Upon hearing of Eisenhower's People-to-People Program on college campuses, I wrote to him and described how students at the University of Nebraska were providing free books to impoverished students in many parts of the world and establishing friendships with the recipients. After serving as Supreme Allied Commander in defeating Nazi Germany and two terms in the White House, Eisenhower was seeking ways to enable more college students in the U.S. to become friends with students in other countries. In 1961, *Eisenhower made book drives an integral part of the People-to-People International Program on college campuses in the U.S.A.*
https://en.wikipedia.org/wiki/People_to_People_International

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ACADEMIA | Letters

Analyses of human tissues, including brain, containing environmental toxic metal-tagged combustion particulate matter PM 2.5

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Abstract

Diseased tissues show significantly more abundant α and β particle emissions relative to normal control tissues. This difference may be used for differential diagnosis between specific diseases, e.g. Alzheimer's and Parkinson's disease. Furthermore, coal combustion and internal combustion engines result in hydrocarbon combustion products that contain particulate matter (PM2.5), including nanoparticles, with toxic heavy metals which can be inhaled. These nanoparticles, due to their size, easily travel to hippocampus and amygdala and may also be transferred by systemic circulation. Once in the target tissues, the particles have negative effects and are permanently retained by entering biochemical processes causing organ damage. These changes may lead to development of neurodegenerative disorders and cancers. Indoor exposure to PM2.5 particles can be reduced by use of ordinary fans and filters.

Key Words: Alzheimer's disease; brain; cancer; neurodegenerative disorders; Parkinson's disease; particulate matter; PM2.5

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Introduction

Atmospheric (environmental) particle vectors possibly have a much greater impact on human health than was previously considered e.g. may may lead to development of neurodegenerative disorders and cancers. In studying body composition and bioavailability of essential trace elements using a whole-body counter it was found that environmental radon (Rn-222, ERn), and its progeny, have a transitory distribution throughout the human body and brain [1]. After extensive study of ERn in human subjects, attention was directed to diseased tissues [2]. These tissues were analyzed for ERn progeny. Significant polonium-210 (Po-210) 5.3 MeV alpha (α) particles were emitted from all cancerous and multiple sclerosis (MS) tissues analyzed [3, 4, 5]. To our knowledge, these are the first reports of detection and measurement of α emission from diseased tissues. Brain tissues were analyzed for both α and β particle emissions. Proteins from Alzheimer's (AD) diseased brain tissues and brain proteins from persons who had smoked cigarettes (S) were found to have copious α and β particle emissions relative to normal control tissues (Figure 1a). The α and β particle emissions were also copious from lipids in Parkinson's disease (PD) tissues [2] (Figure 1b). This was the first biochemical differential diagnosis between AD and PD. Indeed, further analyses showed that a selected AD and PD subject had increased ERn in both AD and PD, indicating brain cell bilayer protein/lipid/protein membrane vulnerability [6].

Discussion

Although it has been well established that tobacco contains Pb-210, a direct source of two β particles and a Po-210 5.305 MeV α particle in its decay to stable Pb-206 (Figure 2), it was questionable why elevated levels of ERn progeny could be found in diseased tissues. The issue of how heavy metals are transported or vectored is important.

A clue as to how ERn progeny in air and heavy metals in combustion products (CP) can enter cells was found when hydrocarbon CP from internal combustion engines and world-wide coal burning were considered. Lead in gasoline [290 mg/l (about the weight of ten grains of rice)] was fully phased out of automobile but not aviation gasoline in 1966 with the passage of the Clean Air Act. Currently, unleaded gasoline contains neurotoxic manganese (8.3 mg/l) [7]. Coal contains trace metals, many of which are toxic, including mercury, lead, uranium, arsenic, etc. [8]. Mean diameters of nearly all the CP from coal are between 10 and 150 nm (0.01 – 0.15 μm) [9]. Hydrocarbon CP contain particulate matter PM2.5 and nanoparticles that can contain toxic heavy metals from coal combustion and internal combustion engines of cars, trucks, etc. PM2.5, including hydrocarbon nanoparticles, can contain these metals and can be inhaled (Figure 3). The distribution of particle sizes in PM2.5 hydrocarbon CP has a substantial amount of ultra-fine particles (UFP) composed of buckyball shaped carbon

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structures whose size ranges from 1-100 nanometer (0.001-0.1 μm) particles which can entrain heavy metals within the UFP carbon structure (Figure 4). Combustion products hydrocarbon nanoparticles containing heavy metals can easily enter the human nasal olfactory cells (odor receptors) and enter the olfactory nerve all the way to the hippocampus memory center and amygdala emotional center, where they lodge preferentially [10]. They may also be transferred by the blood throughout the body [10]. Because of their ultra-small nanometer sizes, they can enter cells, and once inside of cells UFP carbon nanoparticles with heavy metal ions (+2e) contained in them dissolve in the cells releasing the heavy metal ions (+2e) that mimic Ca (+2e) ions and displace Ca (+2e) ions thereby upsetting the Ca electrochemical balance [10, 11]. The critical amount of Ca (+2e) ion displacement is yet to be determined and remains a question for future experimental study, however it is known that cellular calcium imbalance can result in protein misfolding, an established cause of diseases of the central nervous system (CNS) [12, 13].

Furthermore, evidence of long-lived Pb-210 (22 year half-life) accumulation in the brain indicates that once heavy metal ions are vectored or passed into brain cells, they are retained by electrochemical processes remaining indefinitely within the brain cells. Alzheimer's disease may be a special case of protein misfolding because the decay of Pb-210 to stable Pb-206 results in two βs and one α. Astrocytes have been shown to be the most radiosensitive element in the brain [14].

Intracellular heavy metals may well be the cause of several diseases observed with environmental hydrocarbon combustion pollution, including AD, PD, MS and cancers. Heavy metal ions are highly toxic and cause long-term damage to living organisms, mainly as a result of significant oxidative damage. Because of their capability to interact with biomolecules, these ions can tune the structure and conformation of these molecules by a rather specific mechanism [14].

Outside air contaminated with UFP's laden with heavy metals infiltrates indoors. Indoor exposure of the infiltrated UFP's, according Allen and Macomber, who reviewed different infiltration factors for homes in the USA, is approximately 50 percent of airborne particles from outside sources. The authors explain why an average of about 80 percent of the daily exposure in the U.S. comes from airborne particles produced outdoors by vehicles, power plants, industry, wildfires, etc. [15].

Indoor exposure to CP and other airborne particles from outdoor sources can be reduced by providing fresh air at a controlled rate through a media air filter with a MERV-13, or higher, rating and then sealing unnecessary openings in the building envelope.

Airborne particles from indoor and outdoor sources can be mitigated by:

- Using fans or blowers with, or without, filters to increase the rate at which airborne

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smoke, dust, virus, and other particles collide with, and become attached to, walls, ceilings, and other indoor surfaces [16, 17, 18, 19].

- Providing sufficient amounts of fresh filtered air to prevent elevated levels of airborne pollutants from indoor sources, and recirculating indoor air through a media (a.k.a. fiberous) air filter [20].

Conclusion

The diversity of atmospheric (environmental) particle vectors may have a much greater impact on human health than was previously considered. We are immersed in the atmosphere as fish are immersed in water and extended exposure to harmful concentrations of xenobiotics and/or toxic elements may culminate in dire consequences for human health and wellbeing [21]. Could it be possible that alpha particles emitted in the decay of intercellular ubiquitous atmospheric Pb-210 may play a role in initiating several kinds of cancers, and that this concept has not been seriously considered [22]? Interestingly, the first reported occupational cancer, cancer of the scrotum called "soot wart", was reported by Percivall Pott in 1775 [23].

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Ventilation System Effectiveness and Tested Indoor Air Quality Impacts
https://www.nrel.gov/docs/fy14osti/61128.pdf
Clean Air at Home
https://www.lung.org/clean-air/at-home
Estimating Mortality Derived from Indoor Exposure to Particles of Outdoor Origin
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Figures

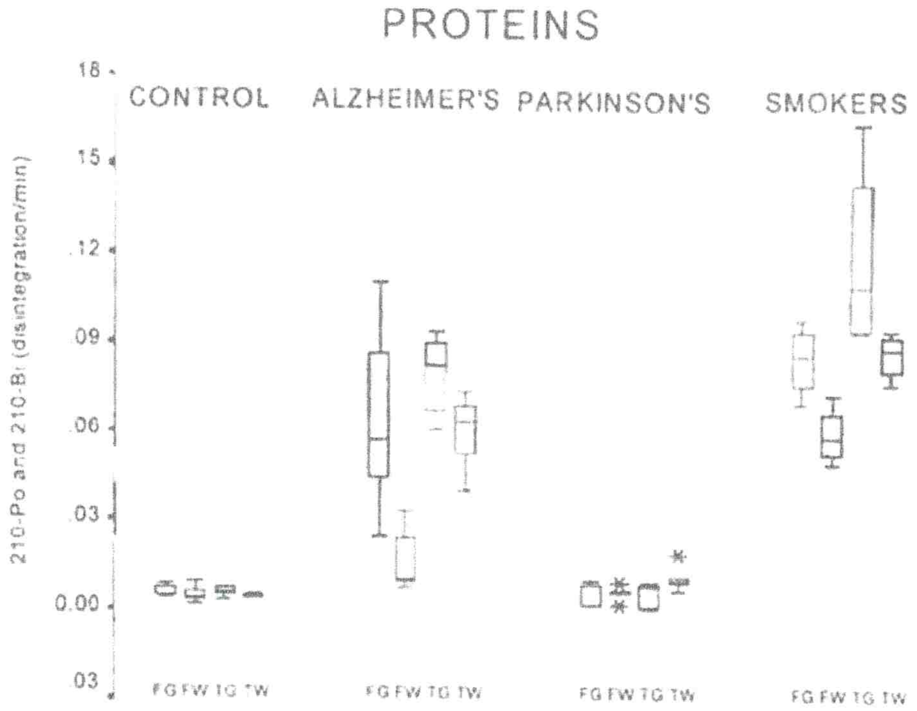

Fig. 1a. Whisker plots of Po-210 and Bi-210 in the protein fraction (P) from the cortical gray (G) and subcortical white (W) matter from the frontal (F) and temporal (T) brain lobes in subjects with Alzheimer's disease, subjects with Parkinson's disease, cigarette smokers, and controls. The horizontal line inside the box represents the median. The lower boundary of the box is the 25th percentile. The vertical lines (whiskers) show the largest & smallest observed values that are not outliers. Cases with values that are more than 3 box lengths from the upper or lower edge of the box are extreme values (*). Cases with values between 1.5 and 3 box lengths from the upper or lower edge of the box are outliers (o). (SPSS for Windows, SPSS Inc., Chicago, IL, USA, 1993)

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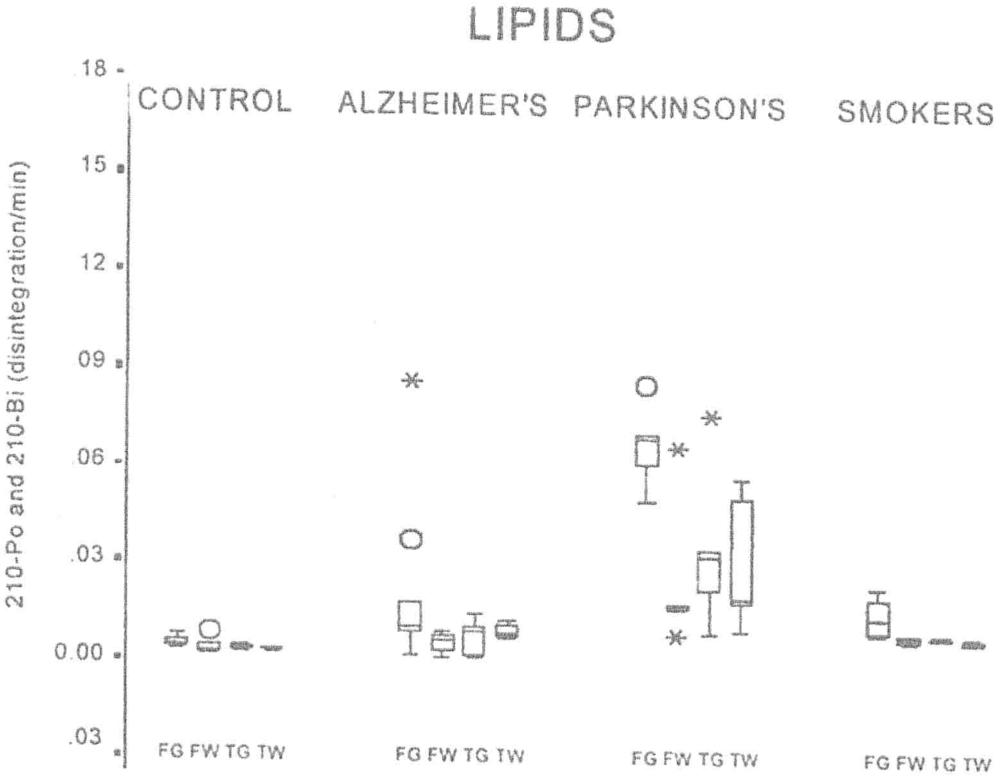

Fig. 1b. Whisker plots of Po-210 and Bi-210 in the lipid fraction (L) from the cortical gray (G) and subcortical white (W) matter from the frontal (F) and temporal (T) brain lobes in subjects with Alzheimer's disease, subjects with Parkinson's disease, cigarette smokers, and controls. (See Figure 1a for explanation of symbols.)

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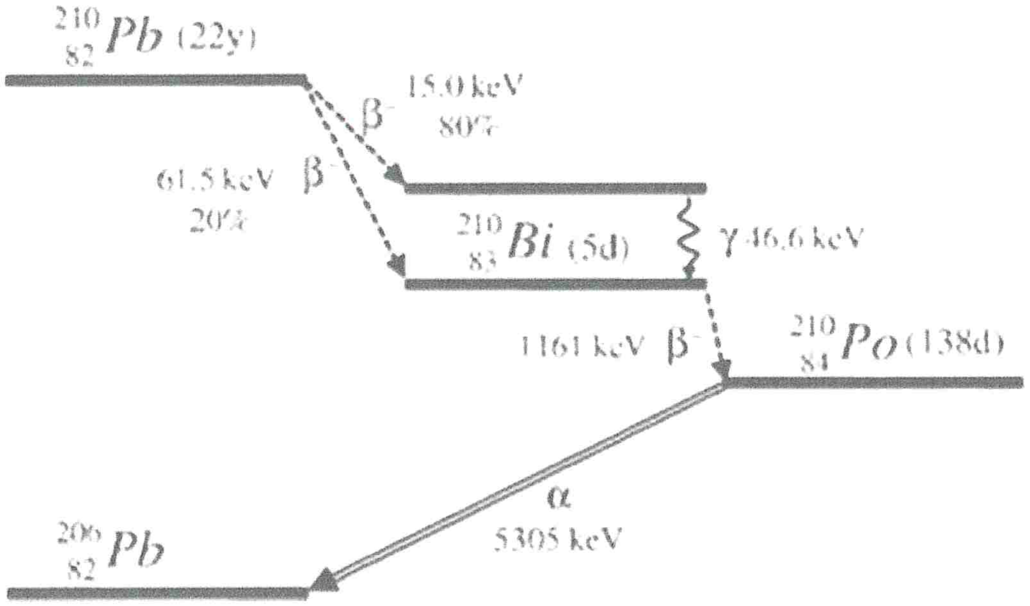

Fig. 2. The decay chain Pb-219→ Bi-210 → Po-210 → Pb-206. Within the parentheses the half-life of each radioactive nuclide is given. Decay data for figure taken from https://www.researchgate.net/publication/230904327_Study_of_the_effects_induced_by_lead_on_the_emulsion_filn

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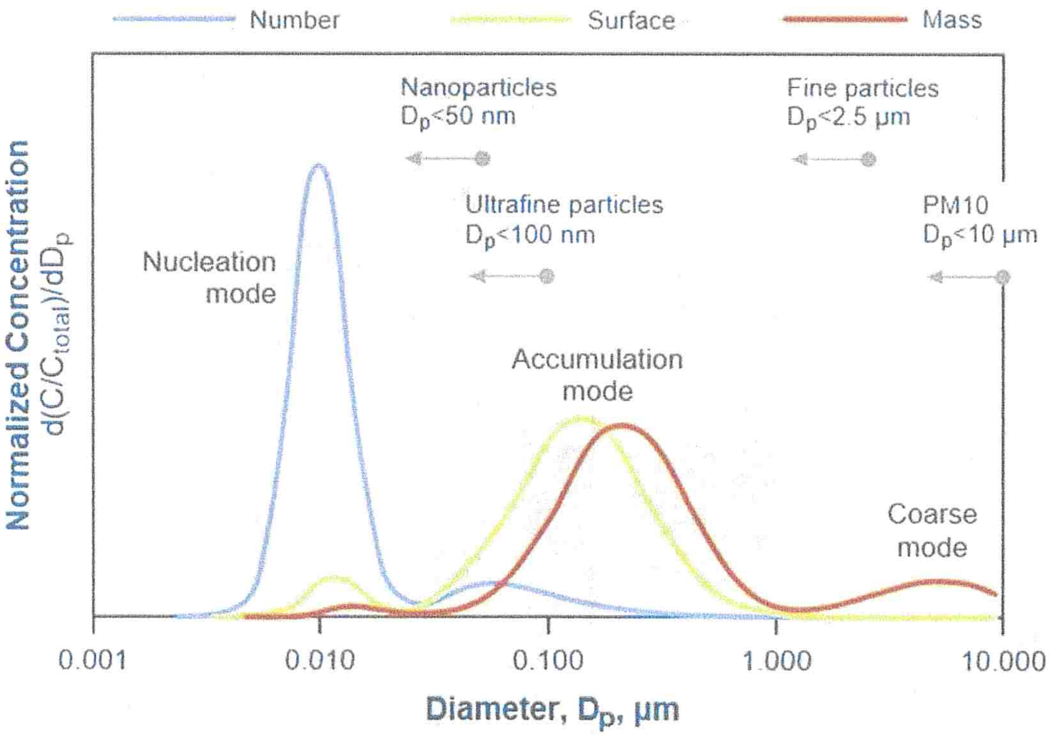

Fig. 3. Diesel particulate size distribution of CP. The nucleation mode has highest concentration of nano-particles. [https://dieselnet.com/tech/dpm_size.php] (Used with permission.)

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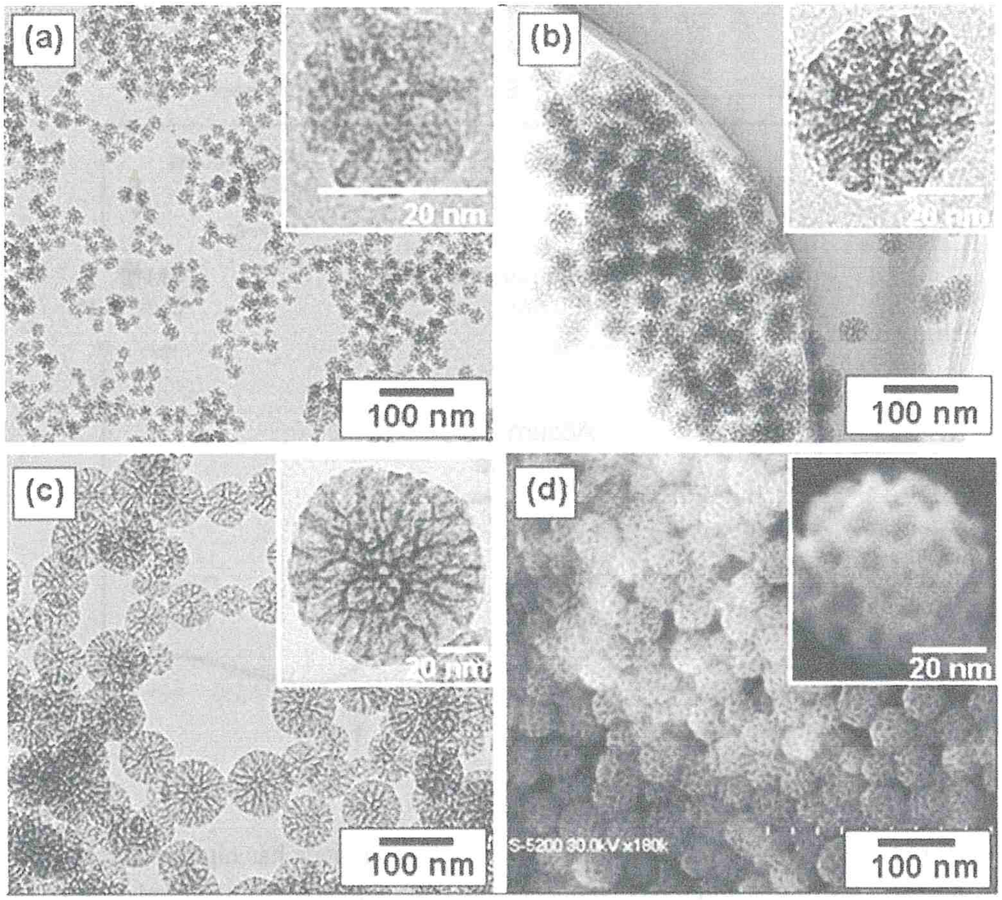

Fig. 4. Scanning electron microscopy photographs of airborne ashes generated during combustion of Illinois coal blended with different sorbents: (a) Illinois bituminous coal + Beulah ash (DTF); (b) Illinois bituminous coal + Beulah ash (ASTM); (c) Illinois bituminous coal + laboratory sorbent; (d) Illinois bituminous coal + CaO. [26] (Used with permission.) [24]

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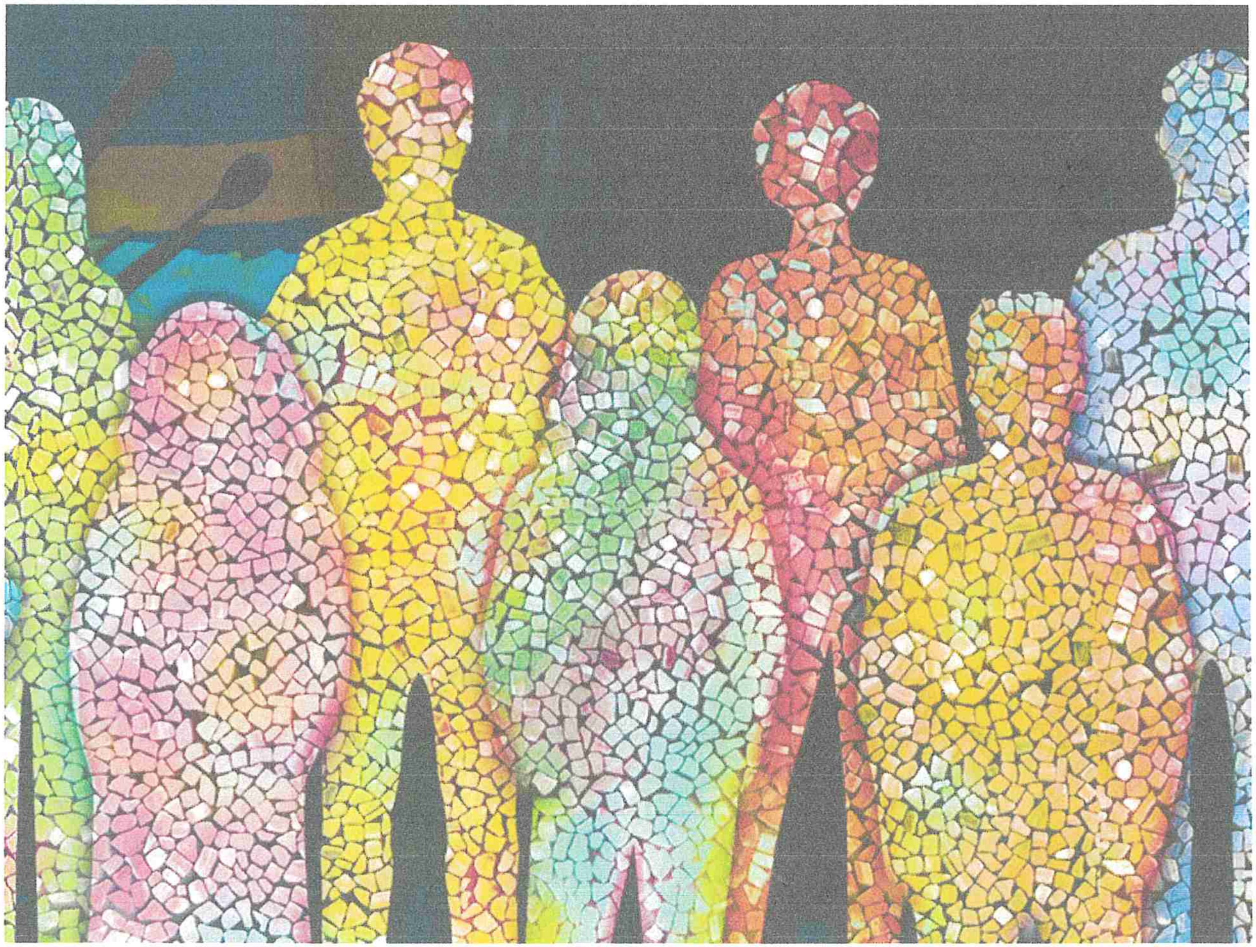
Why Is Every Human Being Riddled With Genetic Errors?

Your body is a collection of cells carrying thousands of genetic mistakes accrued over a lifetime—many harmless, some bad, and at least a few that may be good for you

Amber Dance, Knowable Magazine
January 17, 2025



A vast mosaic of cells, some identical and some slightly different, makes up the human body.

You began when egg and sperm met, and the DNA from your biological parents teamed up. Your first cell began copying its newly melded genome and dividing to build a body.

And almost immediately, *genetic mistakes started to accrue.*

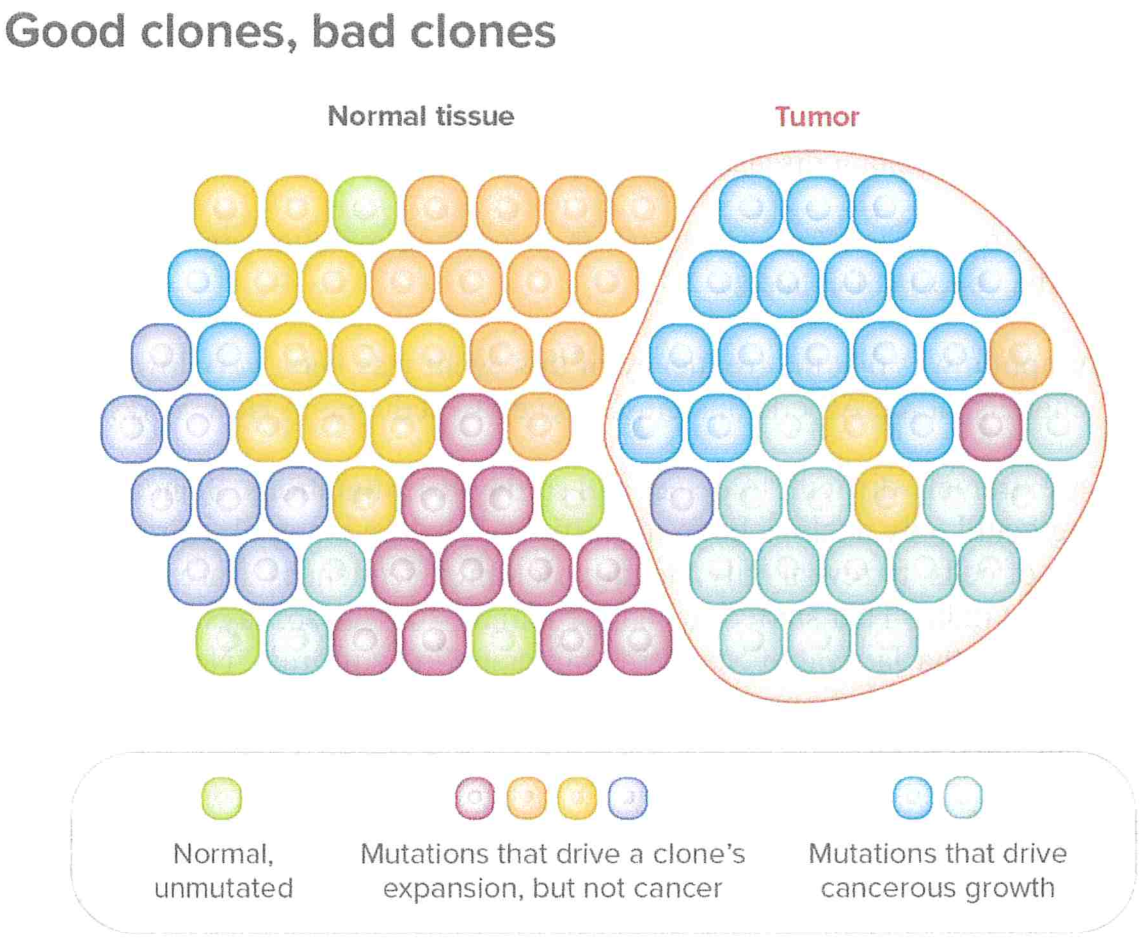
“That process of accumulating errors across your genome goes on throughout life,” says Phil H. Jones, a cancer biologist at the Wellcome Sanger Institute in Hinxton, England.

Scientists have long known that DNA-copying systems make the occasional blunder—that’s how cancers often start—but only in recent years has technology been sensitive enough to catalog every genetic boo-boo. And it’s revealed we’re riddled with errors. Every human being is a vast mosaic of mostly identical cells, but different here or there, from one cell or group of cells to the next.

Cellular genomes might differ by a single genetic letter in one spot, by a larger lost chromosome chunk in another. By middle age, each body cell probably has about a thousand genetic typos, estimates Michael Lodato, a molecular biologist at the University of Massachusetts Chan Medical School in Worcester.

These mutations—whether in blood, skin, or brain—rack up even though the cell’s DNA-copying machinery is exceptionally accurate, and even though cells possess excellent repair mechanisms. Since the adult body contains around 30 trillion cells, with some 4 million of them dividing every second, even rare mistakes build up over time. (Errors are far fewer in cells that give rise to eggs and sperm; the body appears to expend more effort and energy in keeping mutations out of reproductive tissues so that pristine DNA is passed to future generations.)

“The minor miracle is, we all keep going so well,” Jones says.



SOURCE: ADAPTED FROM A. HERMS & P.H. JONES / *AR CANCER BIOLOGY* 2023 KNOWABLE MAGAZINE

Just because mutation-containing cells take over a tissue doesn't necessarily mean disease will result. Mutations that promote clonal expansion can be dangerous cancer drivers, but can also be neutral or even beneficial, maintaining tissue integrity and not promoting cancer. Adapted from A. Herms & P.H. Jones / *AR Cancer Biology* 2023 / Knowable Magazine

Scientists are still in the earliest stages of investigating the causes and consequences of these mutations. The National Institutes of Health is investing $140 million to catalog them, on top of tens of millions spent by the National Institute of Mental Health to study mutations in the brain. Though many changes are probably harmless, some have implications for cancers and for neurological diseases. *More fundamentally, some researchers suspect that a lifetime's worth of random genomic mistakes might underlie much of the aging process.*

"We've known about this for less than a decade, and it's like discovering a new continent," says Jones. "We haven't even scratched the surface of what this all means."

Suspicious from the start

Scientists had suspected since the discovery of DNA's structure in the 1950s that genetic misspellings and other mutations accruing in non-reproductive, or somatic, tissues could help explain disease and aging.

By the 1970s, researchers knew that growth-promoting mutations in a fraction of cells were the genesis of cancers.

"The assumption was that the frequency of this event was very, very low," says Jan Vijg, a geneticist at the Albert Einstein College of Medicine in New York.

But it was extremely difficult to detect and study these mutations. Standard DNA sequencing could only analyze large quantities of genetic material, extracted from vast groups of cells, to reveal only the most common sequences. Rare mutations flew under the radar. That started to change around 2008 or so, says stem cell biologist Siddhartha Jaiswal of Stanford University in California. New techniques are so sensitive that mutations present in a tiny fraction of cells—even a single cell—can be uncovered.

In the early 2010s, Jaiswal was interested in how mutations might accumulate in people's blood cells before they develop blood cancers. From the blood of more than 17,000 people, he and colleagues found what they'd predicted: Cancer-linked mutations were rare in people under 40, but they occurred in higher amounts with age, making up about 10 percent or more of blood cells after the 70th birthday.

But the team also saw that the cells with mutations were often genetically identical to one another: They were clones. The cause, Jaiswal figures, is that one of the body's thousands of blood cell-making stem cells picks up mutations that make it a little bit better at growing and dividing. Over decades, it begins to win out over normally growing stem cells, generating a large group of genetically matched cells.

Not surprisingly, these efficiently dividing mutated blood cell clones were linked to risk for blood cancer. But they were also associated with increased risk for heart disease, stroke, and death by any cause, perhaps because they promote inflammation. And unexpectedly, they were associated with about a one-third *lower* risk of Alzheimer's dementia. Jaiswal, co-author of an article on the health impacts of blood cell clones in the 2023 *Annual Review of Medicine*, speculates that some clones might be better at populating brain tissue or clearing away toxic proteins.

As Jaiswal and colleagues were pursuing the blood clones they reported in 2014, researchers at the Wellcome Sanger Institute commenced investigations of body mutations in other tissues, starting with eyelid skin. With age, some people get droopy eyelids and have a bit of skin surgically removed to fix it. The researchers acquired these bits from four individuals and cut out circles one or two millimeters across for genetic sequencing. "It was full of surprises," says Inigo Martincorena, a geneticist at Wellcome Sanger. Though the patients did not have skin cancer, their skin was riddled with thousands of clones, and one-fifth to one-third of the eyelid skin cells contained cancer-linked mutations.

The findings that so many skin cells in people without skin cancer had mutations made a splash. "I was blown away," says James DeGregori, a cancer biologist at the University of Colorado Anschutz Medical Campus in Aurora, who was not involved in the study.

Wellcome Sanger researchers went on to identify clusters of identical, mutated cells in a variety of other tissues, including the esophagus, bladder , and colon. For example, they examined colonic crypts, indentations in the intestinal wall; there are some ten million of these per person, each inhabited by about 2,000 cells, all arising from a handful of stem cells confined to that crypt. In a study of more than 2,000 crypts from 42 people, the researchers found hundreds of genetic variations in crypts from people in their 50s.

About 1 percent of otherwise normal crypts in that age group contained cancer-linked mutations, some of which can suppress the proliferation of nearby cells, allowing mutant cells to take over a crypt faster. This alone is not necessarily sufficient to create colorectal cancer, but on rare occasions, cells can acquire additional cancer-causing mutations, overflow crypt boundaries and cause malignancies.

"Everywhere people have looked for these somatic mutations, in every organ, we find them," says Jones. He's come to see the body as a kind of evolutionary battleground. As cells accumulate mutations, they can become more (or less) able to grow and divide. With time, some cells that reproduce more readily can overtake others and create large clones.

"And yet," notes DeGregori, "we don't turn lumpy." Our tissues must have ways to stop clones from becoming cancer, he suggests. Indeed, overgrowing mutant clones in mice have been seen to revert to normal growth, as Jones and a co-author describe in the 2023 *Annual Review of Cancer Biology*.

Jones and colleagues found one example of protection in the human esophagus. By middle age, many esophagus clones—often making up the bulk of esophagus tissue—have mutations disrupting a gene called NOTCH1. This doesn't affect the ability of the esophagus to move food along, but cancers seem to need NOTCH1 to grow. Bad mutations may accumulate in esophageal cells, but if NOTCH1 is absent, they appear less likely to become tumors.

In other words, some of the bodily mutations aren't bad or neutral, but even beneficial. And, lucky for us, these good mutations prevail a lot of the time.

Getting inside the brain

Our DNA-copying machinery has plenty of opportunity to make errors in cells of the esophagus, colon, and blood because they divide constantly. But neurons in the brain stop dividing before or soon after birth, so scientists originally assumed they would remain genetically pristine, says Christopher Walsh, a neurogeneticist at Boston Children's Hospital.

Yet there were hints that mutations accruing through life could cause problems in the brain. Back in 2004, researchers reported on a patient who had Alzheimer's disease due to a mutation present in only some brain cells. The mutation was new—it had not been inherited from either parent.

And in 2012, Walsh's group reported an analysis of brain tissue that had been removed during surgery to correct brain overgrowth that was causing seizures. Three out of eight samples had mutations affecting a gene that regulates brain size, but these mutations were not consistently present in the blood, suggesting they arose in only part of the body.

There are a couple of ways that brain cells could pick up mutations, says Lodato. A mutation could occur early in development, before the brain was completed and its cells had stopped dividing. Or, in a mature brain cell, DNA could be damaged and not repaired properly.

By 2012, interest in non-inherited brain mutations was heating up. Thomas Insel, director of the National Institute of Mental Health at the time, proposed that these kinds of mutations might underlie many psychiatric conditions. Non-inherited mutations in the brain could explain a longstanding puzzle in neurological diseases: why identical twins often don't share psychiatric diagnoses (for example, if one twin develops schizophrenia, the other has only about a 50 percent chance of getting it).

Mosaicism provides "a very compelling answer," says neuroscientist Mike McConnell, scientific director for the Lennox-Gastaut Syndrome Foundation in San Diego, a nonprofit that supports families and research into a severe type of epilepsy.

Starting in the early 2010s, McConnell, Walsh, Lodato, and others began to catalog mutations large and small sprinkled across the brains of people who had died. They tallied deletions and duplications of individual genes, multiple genes or entire chromosomes; they spotted entire chromosome segments moved to new places in the genome. And, eventually, Walsh, Lodato, and colleagues found a thousand or more single-letter mutations in the genetic code within every nerve cell of people aged 50 or so. That last finding "seemed completely impossible to us," recalls Walsh. "We doubted ourselves."

In the face of such stunning results, the researchers investigated further. They looked at 159 neurons from 15 people who had died between 4 months and 82 years of age. They reported that the numbers of mutations increased with age, indicating that errors accumulated over time, just as in other body parts. "The brain is a mosaic, in a profound and deep way," says Lodato.

To further explore that mosaicism, the National Institute of Mental Health funded a series of projects from 2015 to 2019 investigating brain tissue mosaicism in samples, mainly collected after death and deposited in tissue banks, from more than 1,000 people who were neurotypical or had conditions such as Tourette syndrome and autism spectrum disorder.

Single-letter mutations were most common, says McConnell, who co-led the project. Researchers accumulated more than 400 terabytes of DNA sequences and other data, and built analytical tools, creating a powerful platform on which to build the next round of brain mosaicism studies. From this work and other studies, scientists have linked brain mosaicism to neurological diseases including autism, epilepsy and schizophrenia.

In Lodato's lab, graduate students Cesar Bautista Sotelo and Sushmita Nayak are now investigating how accumulated mutations might cause amyotrophic lateral sclerosis, a paralyzing condition also known as Lou Gehrig's disease. Geneticists can identify a known mutation in only about 10 percent of non-inherited cases. But the new data on mosaicism suggest that many more people may have mutations in ALS genes in their brains or spinal cords, even if they don't have them in the rest of their body.

That matters, because scientists are working on therapies targeting some of the 40-plus genes that, when mutated, cause ALS. In 2023, the Food and Drug

Administration approved the first such treatment, which shuts down a commonly mutated ALS gene. For patients to be eligible for such therapies, they will need to know their mutations.

Thus, says Nayak, “we strongly advocate for a change in the current practice of diagnosing ALS.” Instead of just looking at DNA in a blood sample, other tissues such as saliva, hair or skin could be examined too, in case an ALS mutation arose during development in cells that didn’t give rise to blood but did give rise to other tissues in the body.

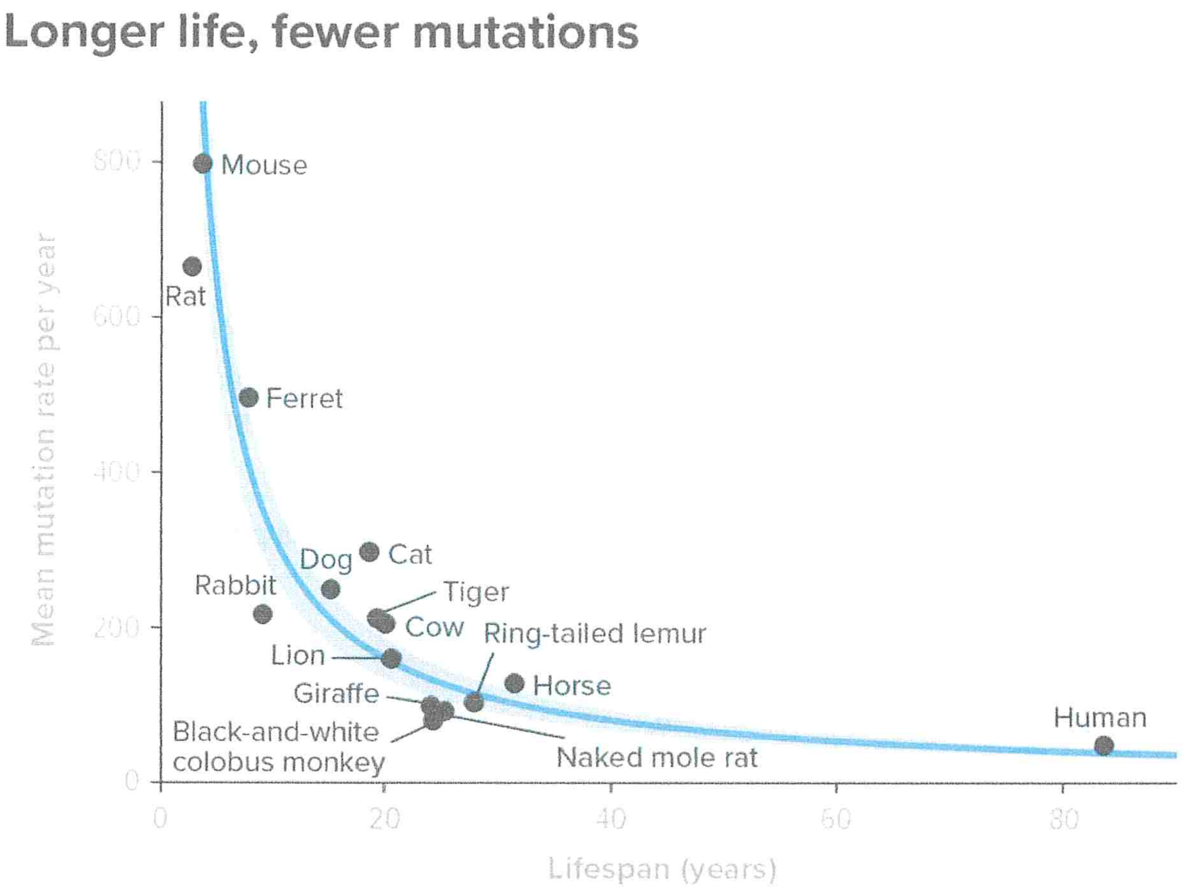
Clues to how we age

For now, the health implications of our body's mosaicism are mostly too fuzzy to warrant action, especially in cases like the blood clones, where there is no relevant treatment to offer. “We don’t really advocate that people should worry about this,” says Jaiswal. “At this point, there’s no rationale to be testing people who are well.”

But many scientists do see the findings as evidence for a longstanding theory: that a lifetime’s worth of mutations leads to the inevitable condition we call aging.

Martincorena and colleagues tested an element of that theory in a 2022 study. If mutation buildup contributes to aging, they reasoned, then short-lived critters like mice should build up mutations fast, while longer-lived species like people should accumulate mutations more slowly, perhaps due to better repair mechanisms.

To investigate this idea, the researchers embarked on a five-year odyssey studying colon crypt samples from eight people plus a menagerie of creatures: 19 lab mice and rats; 15 domestic animals such as cats, dogs, cows and rabbits; and 14 more exotic creatures that included tigers, lemurs, a harbor porpoise and four naked mole rats, which are famed for their outsized rodent life span of 30-plus years. As predicted, the longer-lived the species, the slower its accumulation of mutations.



SOURCE: ADAPTED FROM A. CAGAN *ET AL* / *NATURE* 2022

KNOWABLE MAGAZINE

Researchers analyzed the colonic crypts from several species and determined that longer-lived species are slower to accumulate mutations. This is consistent with a longstanding theory that body cell mutations are linked to aging. Adapted from A. Cagan et al. / *Nature* 2022 / Knowable Magazine

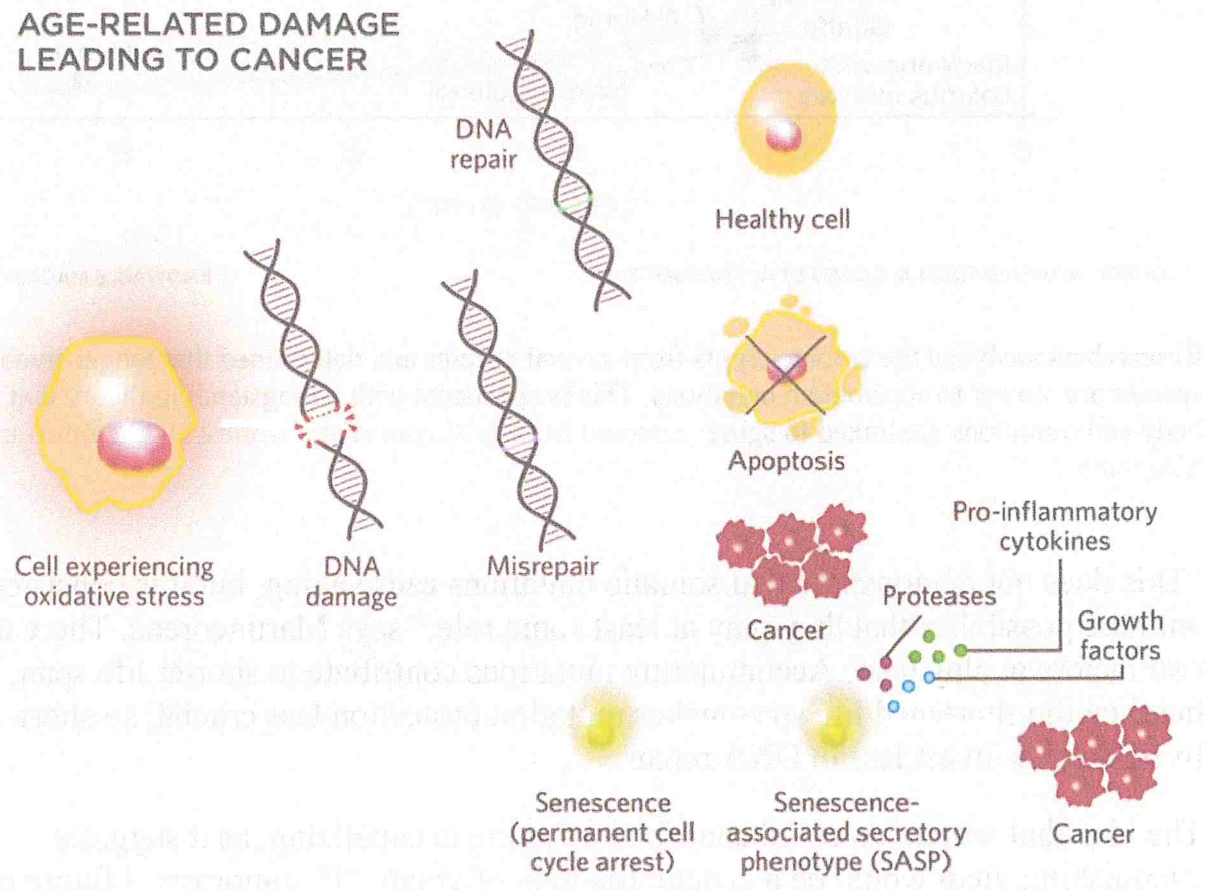
“This does not demonstrate that somatic mutations cause aging, but it is consistent with the possibility that they play at least some role,” says Martincorena. There are two factors at play here: Accumulating mutations contribute to shorter life span, but then the shortened life span makes mutation protection less crucial, so short-lived species invest less in DNA repair.

The idea that mutations could contribute to aging is tantalizing, as it suggests vanquishing them would be a genetic fountain of youth. “If, tomorrow, I figure out a way to stop these mutations from accumulating, I think I would be a bajillionaire,” says Bautista Sotelo. Already, at least one biotech startup, Matter Bio in New York City, has raised funds with the aim of repairing the human genome. (Whether such a plan would ever be feasible across broad swaths of cells is another matter: “I don’t think you can get rid of the mutations,” says DeGregori.)

The story of body mutations is far from over. “Judging by the discoveries that we are making at the moment, the journey has only just started,” says Martincorena. “I expect many surprises in the next few years.”

Radon is in the air everywhere on Earth. Within seven days, about 70% of the radon gas molecules emerging from the earth today will turn into solid radon progeny with a +2 electrostatic charge, and about 90% of them will become attached to filterable airborne particles.

Radon progeny in your brain and body damage DNA by emitting alpha particles (identical to helium nucleus) with an initial velocity of 33,000 MPH.



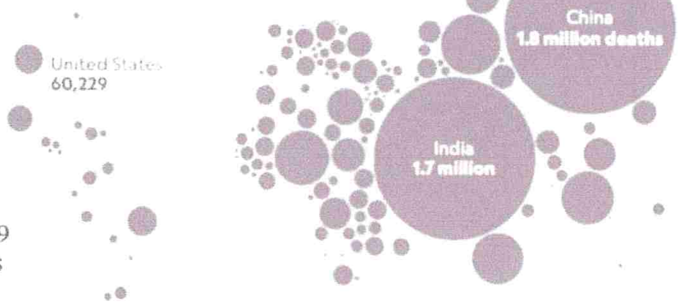
Cellular damage, senescence, and reduced immune function can contribute to cancer formation as people age.

THE SCIENTIST

National Geographic, April 2021, Page 64 & 65

POLLUTION'S TOLL ON THE BODY

Dirty air is a complex mix of gases and particles. PM2.5 particles, some of which are so small they pass into the bloodstream, are the deadliest. In 2019 air pollution, indoors and out, is estimated to have contributed to almost seven million deaths worldwide, accounting for nearly 12 percent of the global death toll.



Number of deaths from air pollution
2019, by country

Global percentage of deaths from PM2.5
2019, by ailment

Brain
Long-term exposure to particulate matter, sulfur dioxide, and nitrogen dioxide can lead to cognitive declines. Changes in brain structure increase the risk of Alzheimer's disease

Nervous system
Pollution is linked to neurodevelopmental disorders and deaths from Parkinson's. Particles can travel to the central nervous system and activate immune responses.

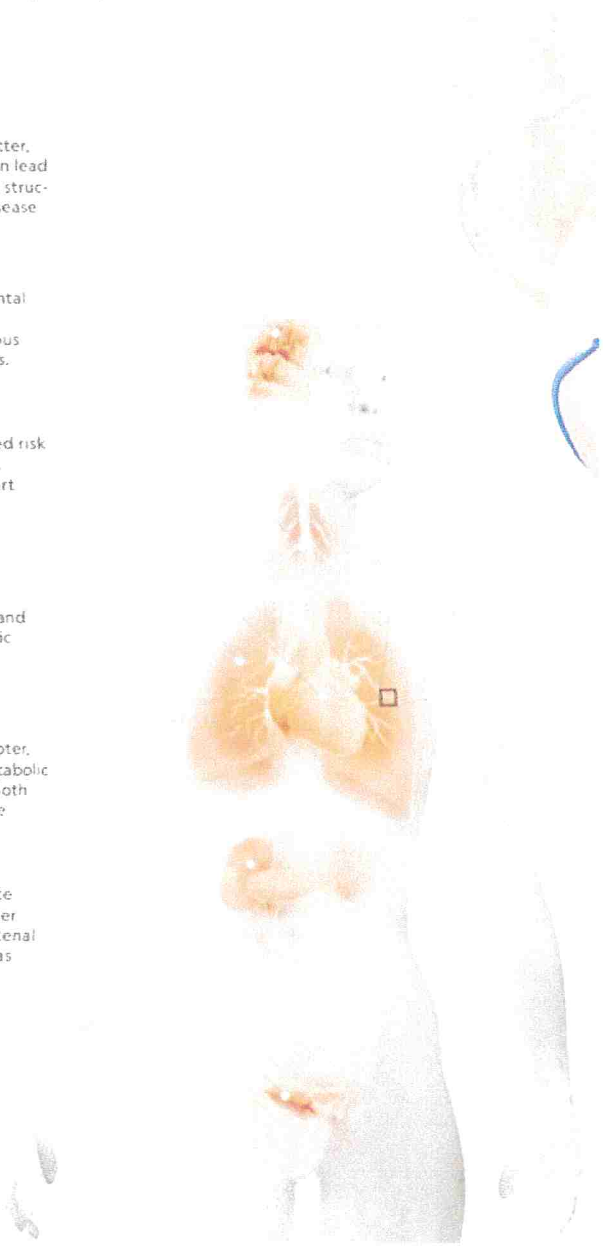
Cardiovascular system
Exposure is associated with heightened risk of death from cardiovascular diseases, including coronary artery disease, heart attacks, strokes, and blood clots.

Respiratory system
Pollution can irritate airways and cause shortness of breath, coughing, asthma, and lung cancer. It can raise the risk of chronic obstructive pulmonary disease (COPD).

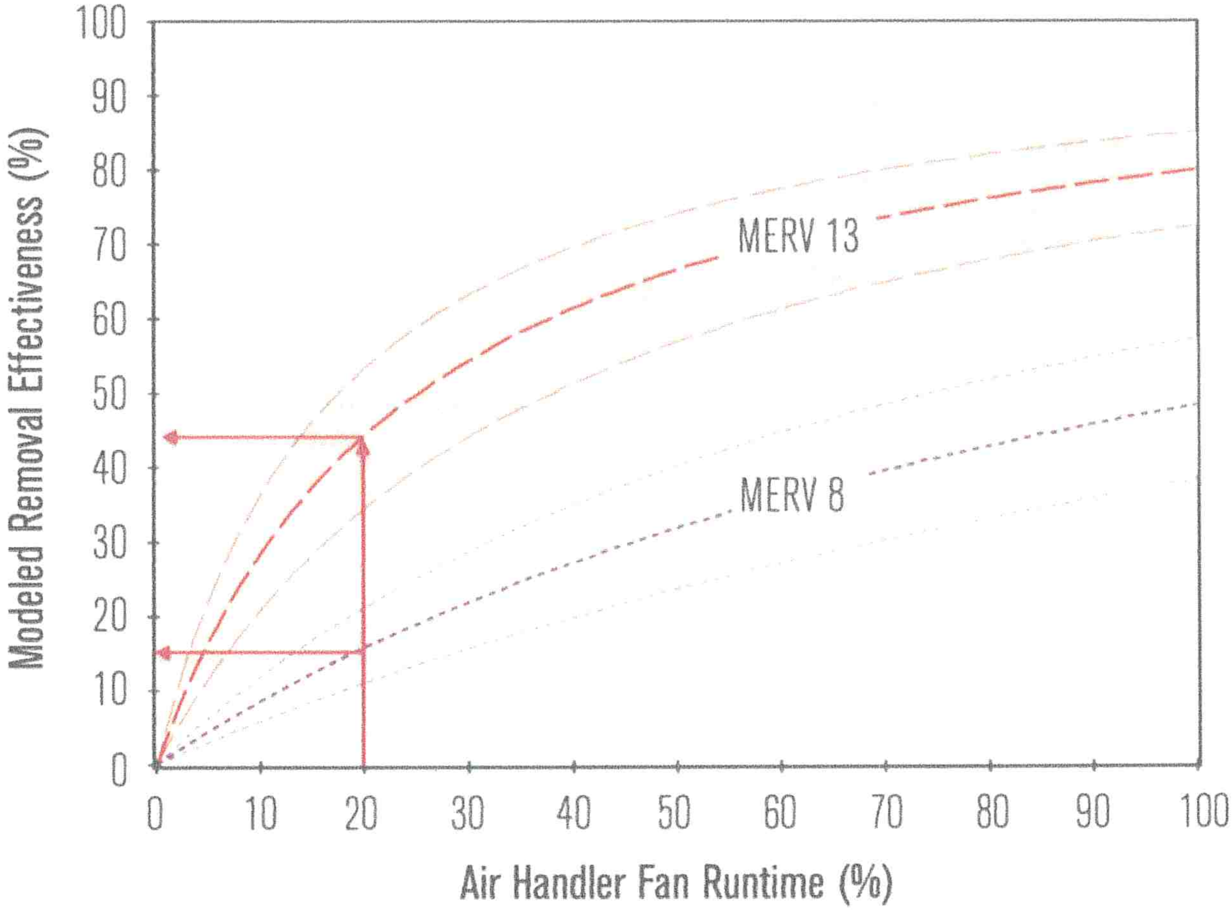
Endocrine system
Particulate matter is an endocrine disrupter, contributing to the development of metabolic diseases such as obesity and diabetes. Both are risk factors for cardiovascular disease

Renal system
Long-term exposure to fine-particulate air pollution is associated with a greater likelihood of chronic kidney disease. Renal disease rates are highest in urban areas

Reproductive system
Pollution is linked to diminished fertility and unsuccessful pregnancies. Prenatal exposure can lead to premature births, low birth weight, and respiratory diseases.



Furnace filters remove additional particles each time indoor air is recirculated.



Monte Carlo model simulating removal of 1 to 3μ particles from a home, based on a range of air leakage rates from outdoors. Upper boundaries estimate effectiveness of a perfectly installed system and filter in a tight house. Lower boundaries estimate effectiveness in a leaky house.

PRELIMINARY REPORT

Pay-As-You-Save (PAYS) Program for New Residential Construction in Omaha Public Power District's Territory

2027–2050

Estimated Savings for OPPD, Metropolitan Utilities District (MUD), and Their Customers from Energy-Efficiency and Indoor Air Quality Upgrades During the Construction of New Homes

May 10, 2026, by Jon Traudt

DISCLAIMER: This is a preliminary analytical report prepared for planning and discussion purposes. All savings estimates are projections based on publicly available data, published research, and stated assumptions. Actual results may vary. This report does not constitute engineering, legal, or investment advice.

Executive Summary

This preliminary report estimates the economic, environmental, and public-health benefits that could be realized between 2026 and 2050 if all new homes built in the Omaha Public Power District (OPPD) service territory are upgraded during construction using the Pay-As-You-Save (PAYS) model or a functionally equivalent on-bill financing mechanism. The analysis uses the Metropolitan Utilities District (MUD) as the proxy for natural-gas and water utilities throughout the OPPD service area.

Key findings are summarized below:

- Approximately 4,500 new homes per year (growing to ~6,400 by 2050) would enter the PAYS program, accumulating roughly 135,000 upgraded homes in OPPD territory by 2050.
- Upgraded homes are estimated to consume 30% less electricity, 40% less natural gas, and 20% less water than homes that meet only Omaha's 2026 minimum building codes.
- Cumulative utility-side avoided costs (OPPD + MUD) are projected at approximately $1.16 billion through 2050, of which $456 million comes from OPPD's energy-delivery savings and $434 million from OPPD's avoided peak-capacity costs.
- Customers are projected to save a cumulative $1.23 billion on their combined utility bills through 2050.
-
- By 2050, OPPD could defer or eliminate approximately 203 megawatts (MW) of peak demand—comparable to avoiding the construction of a midsize power plant.
- Home resale values are estimated to increase 4–6% for PAYS-upgraded homes, representing $10,000–$17,000 in additional equity on a median Omaha home.
- A 50% reduction in indoor air pollutants from Energy Recovery Ventilators (ERVs) and tighter construction could generate annual health and productivity benefits of $1,955 per household, cumulating to over $760 million district-wide by 2050.
- Revenue-stabilization tariffs adopted concurrently by OPPD and MUD would protect utility revenues during the efficiency transition at no additional cost to customers.

Table of Contents

1. Introduction to the PAYS Program

The Pay-As-You-Save® (PAYS) program is a utility-administered on-bill financing mechanism originally developed by the Energy Efficiency Institute (EEI) and adopted by utilities across the United States. In its classic form, a utility pays upfront for energy-efficiency upgrades to a customer's home or business. The customer then repays the utility through a fixed charge on the utility bill—a charge attached to the meter, not the customer, and always smaller than the customer's monthly energy savings. In this way, the customer pays nothing extra and receives immediate, guaranteed net savings from day one.

Unlike conventional rebate programs or standard energy-efficiency loans, PAYS:

- Requires no upfront payment, no credit check, and no personal liability from the customer.
- Transfers automatically with the property when ownership changes, eliminating the 'payback period' barrier to investment in long-lived improvements.
- Is revenue-neutral or mildly revenue-positive for utilities under revenue-stabilization tariffs.
- Reduces the utility's obligation to serve peak demand and can defer or eliminate costly generation and distribution infrastructure.

Several U.S. utilities have successfully implemented PAYS-like programs, including Hawaiian Electric, Southern Maryland Electric Cooperative, and various rural electric cooperatives. Tennessee Valley Authority's EnergyRight program shares many structural features. The program described in this report targets new residential construction rather than retrofits, where the cost of efficiency measures is lower and the energy-savings lifetime is longer.

1.1 Scope of This Report

This report estimates the aggregate economic, environmental, and public-health value of deploying a PAYS-equivalent program for all new homes built in the OPPD service territory from 2026 through 2050. Specific topics covered include: utility avoided costs, customer bill savings, peak-load reduction, home resale value premiums, indoor air quality (IAQ) health benefits, and a comparison of PAYS investment against conventional supply-side costs.

1.2 Applicability of PAYS to New Construction

PAYS programs have historically targeted existing buildings. However, deploying PAYS during construction offers important advantages. Advanced framing, dense-pack insulation, and mechanical ventilation systems are substantially cheaper to install before walls are closed than to retrofit afterward. Moreover, new-construction PAYS charges can be structured as a permanent meter surcharge that is immediately offset by lower utility bills. Builders benefit from a marketable differentiator; buyers benefit from lower lifetime costs; and utilities benefit from reduced load-growth pressure.

2. OPPD and MUD: Service Territory Overview

2.1 Omaha Public Power District (OPPD)

OPPD is a publicly owned electric utility headquartered in Omaha, Nebraska. It is one of the largest public power utilities in the United States by revenue, serving approximately 870,000 customers across 13 counties in southeastern Nebraska. OPPD's residential customer base numbers roughly 400,000 accounts. The utility's generating portfolio (as of 2025) includes the Fort Calhoun nuclear station's decommissioned site, natural-gas peakers, coal-fired capacity at Nebraska City (under phase-out consideration), and a rapidly growing renewable portfolio.

OPPD's 2040 Carbon-Reduction Roadmap commits the utility to 70% carbon-free generation by 2030 and net-zero by 2050. Energy efficiency—especially demand-side management (DSM) targeting new construction—aligns directly with those goals and reduces the capital expenditure required to achieve them.

2.2 Metropolitan Utilities District (MUD)

MUD is a publicly owned utility serving natural gas and water to approximately 240,000 natural-gas customers and 230,000 water customers in Douglas and Sarpy counties—the geographic core of OPPD's residential territory. For the purposes of this report, MUD is used as the proxy for all gas and water utilities in the OPPD service area, recognizing that a small number of customers are served by smaller municipal systems or natural-gas cooperatives at the periphery of the territory.

2.3 New Residential Construction Trends

The Omaha Metropolitan Statistical Area has consistently been one of the stronger new-home markets in the Midwest. According to U.S. Census Bureau building-permit data and the Greater Omaha Association of REALTORS®, the metro issued approximately 4,200–5,600 single-family and multifamily residential permits per year between 2018 and 2024. For this analysis, a conservative base of 4,500 new homes per year entering the PAYS program is assumed in 2026, growing at 1.5% annually through 2050 to reflect modest population and economic growth, reaching roughly 6,432 homes per year by 2050.

2.4 Service Territory Summary

Utility	**Type**	**Approx. Residential Accounts**	**Service Area**
OPPD	Electric	~400,000	Douglas, Sarpy, and 11 other NE counties
MUD	Natural Gas	~240,000	Douglas and Sarpy Counties
MUD	Water	~230,000	Douglas and Sarpy Counties
Combined (proxy)	All three	~400,000 homes	OPPD primary territory

3. Assumptions and Methodology

3.1 Home Construction Volume

New homes entering the PAYS program are assumed at 4,500 units in 2026, growing 1.5% per year. By 2050, annual enrollment will reach 6,432. Cumulative enrolled homes by the end of 2050 total approximately 135,273. Homes already built before 2026 are excluded from this analysis but represent a large additional retrofit market.

3.2 Baseline Energy and Water Consumption

Baseline consumption figures for a standard Omaha home meeting 2026 code (IECC 2021 as adopted in Nebraska) are drawn from EIA Residential Energy Consumption Survey (RECS) data, Nebraska-specific adjustments from the Lawrence Berkeley National Laboratory Building Energy Efficiency Frontiers report, and OPPD and MUD publicly available rate-case exhibits:

Resource	**Baseline (code-built home)**	**PAYS Reduction**	**Upgraded Annual Use**
Electricity	10,800 kWh/yr (900 kWh/mo)	–30%	7,560 kWh/yr
Natural Gas	850 therms/yr (~71 therms/mo)	–40%	510 therms/yr
Water	52,000 gal/yr (~4,333 gal/mo)	–20%	41,600 gal/yr

The 30% electricity reduction reflects the combined effect of advanced-framing insulation, reduced air infiltration, ERV-assisted ventilation, and elimination of natural-draft combustion appliances (replaced by heat pumps and electric equipment). The 40% gas reduction is driven primarily by the elimination of gas-fired heating and water heating in favor of high-efficiency electric heat pumps, with only modest remaining gas loads (cooking in some homes). The 20% water reduction reflects low-flow fixtures, demand-controlled irrigation, and efficient water-heating scheduling enabled by electric heat-pump water heaters.

3.3 Utility Rate Assumptions (2026 $)

All monetary values are expressed in 2026 dollars (real, uninflated). Utility rates are based on publicly available tariffs and avoided-cost studies for OPPD and MUD:

Utility	**Service**	**Customer Retail Rate**	**Utility Avoided Cost**
OPPD	Electricity	$0.115/kWh	$0.085/kWh (energy + T&D)
MUD	Natural Gas	$0.92/therm	$0.40/therm (supply + dist.)
MUD	Water	$5.50/1,000 gal	$2.80/1,000 gal (production + treat.)
OPPD	Peak Capacity	N/A to customer	$175/kW-year (avoided capacity)

3.4 PAYS Program Cost Assumptions

The incremental cost to upgrade a new home to the efficiency specifications in Section 4 (versus base code) is estimated at $8,000–$12,000 per home, based on cost data from the Building Science Corporation, Pacific Northwest National Laboratory, and Nebraska Energy Office reports. For this analysis, $10,000 per home is used as the incremental upgrade cost, amortized over 20 years at a 4.5% utility financing rate.

Monthly PAYS charge: $10,000 at 4.5% over 240 months ≈ $63/month. Monthly energy savings: approximately $103/month (electricity) + $26/month (gas) + $4.75/month (water) = ~$134/month total. Net benefit to customer from Day 1: approximately $71/month ($134 savings minus $63 PAYS charge).

3.5 Revenue Stabilization

This analysis assumes that both OPPD and MUD adopt revenue-stabilization (decoupling) tariffs concurrent with the PAYS program launch. Under decoupling, the utility's allowed revenue is set annually and does not depend on the volume of energy or water sold. True-up adjustments in subsequent billing periods ensure the utility recovers its allowed revenue regardless of weather, conservation, or economic fluctuations. This removes the financial disincentive for utilities to support efficiency programs and is a standard prerequisite for successful PAYS deployment. Revenue-stabilization tariffs have been approved by utility commissions in California, Oregon, Massachusetts, New York, and numerous other states, and have been studied favorably by the Nebraska Power Review Board.

4. Energy-Efficiency Upgrade Specifications

The following building-science measures are assumed to be standard in all PAYS-upgraded homes built after 2025. These specifications exceed Omaha's 2026 building code (based on IECC 2021) and represent cost-effective, proven technologies available from multiple vendors.

4.1 Advanced Framing (Optimum Value Engineering)

Standard 2×6 wood framing with studs spaced 24 inches on-center (OC) rather than the conventional 16-inch OC. Advanced framing reduces the total wood fraction of exterior walls from approximately 25% to 15%, dramatically reducing thermal bridging through studs. Cavities are filled with R-19 mineral wool or high-density fiberglass batts, with an additional continuous exterior rigid insulation board (typically 1-inch polyisocyanurate, R-6.5) bringing the total effective assembly R-value to approximately R-25. This compares to an effective R-15–R-18 in code-minimum 2×6/16-inch-OC walls.

4.2 High-Performance Attic Assembly (R-60)

Dense-pack blown cellulose or open-cell spray polyurethane foam (SPF) to achieve R-60 attic insulation. Code minimum for Climate Zone 5 (Omaha) is R-49 to R-60 depending on the 2021 IECC version adopted. This specification ensures the high end of code compliance and typically adds less than $600 in incremental material cost over R-49 due to the low cost of dense-pack cellulose. Air sealing at the attic plane reduces uncontrolled infiltration to below 2 air changes per hour at 50 Pascals (ACH50) vs. the typical 4–6 ACH50 in code-minimum construction.

4.3 Elimination of Natural-Draft Combustion Systems

Natural-draft furnaces, water heaters, and boilers draw indoor air for combustion and expel combustion gases via gravity-driven flues. In tight construction, depressurization can cause backdrafting—the reversal of combustion gases into occupied spaces—creating serious carbon-monoxide risks. All PAYS-upgraded homes shall use only:

- Air-source heat pumps (ASHP) or ground-source heat pumps (GSHP) with a minimum heating season performance factor (HSPF2) of 9.0 for primary space heating.
- Heat-pump water heaters (HPWH) with a minimum Uniform Energy Factor (UEF) of 3.5.
- Electric induction cooktops or sealed-combustion gas ranges as the only permitted gas appliance (if gas service is retained at all).
- No atmospheric or fan-assisted natural-draft combustion equipment of any kind.

Eliminating natural-draft combustion is both a safety requirement in tight construction and a significant energy-efficiency improvement: a cold-climate ASHP operating at a coefficient of performance (COP) of 2.5 delivers 2.5 units of heat per unit of electricity consumed, compared with a 95%-efficient gas furnace that delivers 0.95 units of heat per unit of gas energy—and gas costs more per BTU than electricity on a national basis (even in Omaha's relatively low-cost-gas market).

4.4 Energy Recovery Ventilators (ERVs)

Tighter construction requires mechanical ventilation to meet ASHRAE 62.2 indoor-air-quality standards. Energy Recovery Ventilators pre-condition incoming fresh air using the thermal and moisture content of outgoing stale air, recovering 70–85% of the energy that would otherwise be lost. ERVs:

- Reduce the heating/cooling energy penalty of required ventilation by 70–85%.
- Filter and dilute indoor pollutants including volatile organic compounds (VOCs), radon, PM2.5, and biological contaminants.
- Maintain controlled, measured ventilation rates year-round, unlike operable windows, which are weather-dependent.
- Contribute to OPPD peak-demand reduction by reducing total HVAC runtime and peak-hour loads.

A properly sized residential ERV (150–300 CFM) costs $1,200–$2,500 installed in new construction. When amortized over a 25-year life, the annual cost is $60–$120—far less than the $200–$400 annual energy savings the ERV enables in the Omaha climate.

4.5 High-Performance Windows and Doors

While not individually specified in the PAYS model's core assumption set, PAYS-upgraded homes are assumed to include double-pane low-emissivity (low-e) windows with a U-factor ≤ 0.27 and solar heat gain coefficient (SHGC) ≤ 0.25, and exterior doors with a U-factor ≤ 0.20. These specifications align with ENERGY STAR® Most Efficient criteria for Climate Zone 5 and contribute approximately 5–8% of the total electricity savings.

5. Projected Electricity Savings – OPPD

5.1 Per-Home Savings

Under the assumptions in Section 3, each PAYS-upgraded home reduces annual electricity consumption by 3,240 kWh (270 kWh/month). At OPPD's residential retail rate of $0.115/kWh, this represents $373 per year in customer bill savings. At OPPD's avoided cost of $0.085/kWh (covering avoided energy purchases, transmission losses, and distribution O&M), the utility avoids $275 per year in supply costs for every upgraded home.

5.2 Cumulative Savings Projections

As homes accumulate in the PAYS program, the annual savings grow substantially. By 2050, the 135,273 homes in the program generate approximately $37.3 million per year in OPPD avoided costs (energy component only). The 25-year cumulative total of utility-side electricity savings is projected at $456 million.

Year	Cumulative Homes	Annual kWh Saved (GWh)	Annual OPPD Savings ($M)	Cumulative OPPD Savings ($M)
2026	4,500	14.6	$1.2	$1.2
2028	13,780	44.6	$3.8	$9.1
2030	23,600	76.5	$6.5	$19.0
2035	52,600	170.4	$14.5	$71.4
2040	86,300	279.6	$23.8	$161.7
2045	124,600	403.7	$34.3	$293.5
2050	135,273	438.2	$37.3	$456.0

Note: GWh = gigawatt-hours. Annual savings grow as more homes enter the program each year.

5.3 Comparison: Saving 1,000 kWh/Month vs. Supplying It

The report asks directly: how does the cost of reducing 1,000 kWh per month through PAYS compare to OPPD's cost of supplying that same electricity reliably? This comparison is sometimes called the 'resource equivalence' test.

Resource	Levelized Cost ($/kWh)	Notes
PAYS program (efficiency)	$0.025	Amortized upgrade cost over 20 yr, 4.5% rate
OPPD avoided energy + T&D	$0.085	Estimated avoided supply cost per kWh not served
New combined-cycle gas plant	$0.065–0.090	NREL 2025 ATB, mid-range
New gas peaker plant	$0.130–0.160	NREL 2025 ATB, peaker; higher if rarely used
Utility-scale solar PPA	$0.045–0.065	Nebraska solar, no storage; intermittent

PAYS-financed efficiency upgrades provide the cheapest, most reliable kilowatt-hour reduction available to OPPD—roughly 3.4× cheaper than OPPD's own avoided supply cost and more than 5× cheaper than a new gas peaker plant. Unlike renewable generation, efficiency provides firm, dispatchable load reduction at any time of day.

6. Projected Natural-Gas Savings – MUD

The largest single energy use in an Omaha home is space heating—historically supplied almost exclusively by natural gas. In a PAYS-upgraded home, a high-efficiency ASHP handles the vast majority of heating, with any remaining gas use (cooking, backup, or retained gas service) reduced by 40% versus a code-built home. On average, each upgraded home saves 340 therms per year.

6.1 Per-Home Gas Savings

At MUD's residential gas rate of $0.92/therm, each home saves $313 per year on gas bills. At MUD's avoided cost of $0.40/therm (commodity + distribution O&M), the utility avoids $136 per home per year in supply obligations.

6.2 Cumulative Gas Savings Projections

5-Year Period	MUD Gas Utility Savings ($M)	Customer Gas Bill Savings ($M)	Therms Saved (Millions)
2026–2030	$9.4	$21.7	23.5
2031–2035	$25.9	$59.7	64.7
2036–2040	$43.6	$100.5	109.0
2041–2045	$62.8	$144.7	157.0
2046–2050	$83.4	$192.2	208.5
TOTAL 2026–2050	$225.0	$518.8	562.7

The reduction of nearly 563 million therms of natural gas through 2050 is roughly equivalent to the annual gas consumption of 660,000 Omaha homes—or about 1.9 million metric tons of CO_2 avoided over the study period. For MUD, reduced throughput under revenue stabilization means lower system maintenance costs, reduced pipeline-capacity obligations, and improved system safety as load density decreases.

7. Projected Water Savings – MUD

While often overlooked in energy-efficiency programs, water conservation is an important co-benefit of the PAYS upgrades. Heat-pump water heaters, low-flow plumbing fixtures (installed as standard in PAYS homes), and demand-controlled irrigation together deliver a 20% reduction in water consumption—saving 10,400 gallons per home per year.

7.1 Per-Home Water Savings

At MUD's current residential water rate of $5.50 per 1,000 gallons, each upgraded home saves $57.20 per year on water bills. MUD's avoided cost (water treatment, pumping, and distribution O&M) is approximately $2.80 per 1,000 gallons, yielding $29.12 per home per year in utility avoided costs.

7.2 Cumulative Water Savings Projections

5-Year Period	MUD Water Utility Savings ($M)	Customer Water Bill Savings ($M)	Gallons Saved (Billions)
2026–2030	$2.0	$4.1	0.72
2031–2035	$5.5	$11.2	1.97
2036–2040	$9.3	$18.9	3.32
2041–2045	$13.4	$27.3	4.79
2046–2050	$17.9	$36.4	6.38
TOTAL 2026–2050	$48.2	$97.9	17.18

Saving 17.2 billion gallons through 2050 reduces MUD's capital obligations for water treatment expansion—a significant benefit as the Omaha metro continues to grow. Each million gallons per day of demand avoided saves MUD approximately $2–4 million in deferred treatment-plant capacity.

8. Peak Load Reduction Benefits

Among the most valuable benefits of building-efficiency programs is peak-demand reduction. Electric utility capacity costs are dominated by the obligation to serve the highest-demand hour of the year, typically a hot-humid afternoon in late July or early August in Omaha. OPPD must maintain sufficient generation capacity plus transmission and distribution headroom to serve this peak reliably. Avoided-capacity costs are far higher than avoided-energy costs—approximately $175 per kilowatt-year (kW-year) based on OPPD's most recent Integrated Resource Plan (IRP) exhibits and comparable Midwest utility avoided-cost studies.

8.1 Per-Home Peak Reduction

An average Omaha home draws approximately 5 kW at peak on a hot summer afternoon. A PAYS-upgraded home, with superior insulation and ERV-managed ventilation, reduces this peak draw by approximately 30%—or 1.5 kW. This reduction is coincident with OPPD's system peak, making it highly valuable for capacity planning. Annual avoided-capacity value per home: 1.5 kW × $175/kW-year = $262.50/year.

8.2 System-Level Peak Reduction

Year	**Cumulative Homes**	**Peak Reduction (MW)**	**Annual OPPD Peak Savings ($M)**
2030	23,600	35.4	$6.2
2035	52,600	78.9	$13.8
2040	86,300	129.5	$22.7
2045	124,600	186.9	$32.7
2050	135,273	202.9	$35.5

By 2050, OPPD could avoid serving approximately 203 MW of peak demand from PAYS-upgraded homes alone. For context, OPPD's North Omaha Power Station has a generating capacity of about 340 MW; the PAYS program would displace more than half of an equivalent unit's output from the demand side—at a fraction of the construction cost. The 25-year cumulative avoided peak-capacity costs to OPPD total approximately $434 million.

ERVs make a specific, measurable contribution to peak reduction. By maintaining stable indoor temperatures with pre-conditioned outdoor air, ERVs reduce the demand spike associated with post-occupancy 'reheat' cycles—the phenomenon in which AC systems run hard to recover indoor temperatures after a family opens windows or doors on a hot day. Studies by PNNL and Oak Ridge National Laboratory estimate that ERVs reduce peak cooling demand by 8–15% in homes that otherwise exhibit this behavior.

9. PAYS Program vs. Conventional Supply Costs

A key question for utility planners and regulators is whether PAYS-financed efficiency investment is cost-competitive with alternative supply-side resources. The following analysis uses levelized cost of energy (LCOE) methodology to compare the PAYS program's amortized cost of conserved energy against OPPD's supply-side options.

9.1 Cost of Conserved Energy (CCE)

The Cost of Conserved Energy (CCE) is the effective cost to 'produce' (avoid consuming) one unit of energy through efficiency investment. It is calculated as: CCE = Annual Program Cost / Annual Energy Savings.

For the PAYS program: $10,000 per home amortized at 4.5% over 20 years = $763/year per home. Annual savings = 3,240 kWh/year. CCE = $763 / 3,240 kWh = $0.235/kWh. However, PAYS is cost-neutral to OPPD (costs are recovered via the meter charge). OPPD's own program administration cost is estimated at $0.005–$0.015/kWh saved. OPPD's net cost of conserved energy = ~$0.01–0.025/kWh, far below its $0.085/kWh avoided cost.

9.2 Zero Net Cost to OPPD

A defining feature of well-structured PAYS programs is that the utility advances the capital and recovers it through the tariff charge—with interest—from the savings the program itself generates. Under revenue stabilization, OPPD's authorized revenue does not change whether a customer uses 900 kWh or 630 kWh per month. The avoided supply costs (generation, transmission, distribution avoided O&M) flow to OPPD as avoided expenditures rather than as rate increases. Thus PAYS is correctly described as zero net cost to OPPD—all program costs are recovered from energy savings, and avoided supply costs represent pure financial benefit.

9.3 Supply-Side Cost Comparison

Figure 3 (see Section 14) illustrates the stark cost advantage of PAYS over all supply-side alternatives in OPPD's portfolio. Even compared to utility-scale solar PPA contracts (the cheapest new-build supply option at $0.045–0.065/kWh), PAYS-conserved energy is cheaper on a total-system-cost basis because it also eliminates transmission and distribution costs—while solar generation must still flow through the grid.

10. Revenue Stabilization for OPPD and MUD

Revenue stabilization (also called decoupling) is the regulatory mechanism that removes the financial conflict of interest that causes utilities to resist efficiency programs. Under traditional rate design, OPPD's revenue rises when customers use more electricity and falls when customers conserve. Every kWh saved by PAYS cuts OPPD's revenue—creating an obvious disincentive to support conservation.

10.1 Mechanism

Under revenue stabilization, the Nebraska Power Review Board (for OPPD) and equivalent MUD governing authority would annually set an allowed revenue requirement for each utility. If actual sales are lower than the forecast used to set rates, a small per-unit surcharge is applied in the following year to recover the shortfall. If sales are higher, a corresponding credit is applied. Over a two- to three-year period, the true-up eliminates both windfall profits and shortfalls.

10.2 Benefits for OPPD

Revenue stabilization transforms OPPD's financial relationship with energy efficiency from adversarial to aligned. Key benefits include:

- OPPD's authorized revenue is protected regardless of weather, economic cycles, or conservation programs.
- OPPD can aggressively pursue efficiency and still maintain stable bond ratings and financial metrics.
- Avoided infrastructure costs—generation plants, transmission upgrades, distribution capacity—are retained as genuine financial savings rather than being replaced by new sales obligations.
- Customer bills become more predictable because the utility's cost recovery no longer depends on consumption volume.

10.3 Precedent

As of 2025, at least 23 U.S. states have implemented some form of utility revenue decoupling. The American Council for an Energy-Efficient Economy (ACEEE) rates states with decoupling as having significantly higher energy-efficiency program achievements. Pacific Gas and Electric (PG&E) in California has operated under full decoupling since 2001 without adverse impacts on ratepayer bills or utility financial health. Nebraska currently lacks a decoupling framework, and adoption of one would be a necessary precondition for OPPD or MUD to deploy PAYS at scale.

11. Impact on Home Resale Values

Energy-efficient homes command measurable price premiums in real-estate markets. Multiple peer-reviewed studies using hedonic pricing models and controlled comparisons of ENERGY STAR® versus non-certified homes document consistent premiums of 3–9% for certified high-performance homes in comparable markets.

11.1 Evidence from the Literature

Kahn & Kok (2014) analyzed 1.6 million California home sales and found ENERGY STAR-labeled homes sold for a 9% premium over unlabeled homes with otherwise identical characteristics. Chegut, Eichholtz & Kok (2014) documented a 4–5% premium for LEED-certified commercial buildings in the UK, with similar patterns in residential markets. The Institute for Market Transformation's analysis of 71,000 U.S. home sales found a 3–5% premium for ENERGY STAR-labeled homes in Midwestern markets most similar to Omaha's climate and economic profile. Lawrence Berkeley National Laboratory (2022) found that homes with solar panels sell for $4 per watt of installed capacity—and the premium is driven primarily by reduced utility costs, the same value proposition as PAYS upgrades.

11.2 Estimated Omaha Premium

For the Omaha market, a conservative 4–6% premium is estimated for PAYS-upgraded homes. At the Omaha metro median home value of approximately $285,000 (2025 Zillow/Greater Omaha Association of REALTORS data), this translates to a premium of $11,400–$17,100 per home.

Scenario	Premium %	Value Added (Median $285K Home)	Aggregate by 2050 (135K Homes)
Conservative	4%	$11,400	$1.54 Billion
Mid-range	5%	$14,250	$1.93 Billion
Optimistic	6%	$17,100	$2.31 Billion

The PAYS charge (attached to the meter, not the borrower) transfers automatically to new owners. Prospective buyers receive full disclosure of both the PAYS charge and the guaranteed energy savings, so the net positive cash flow is transparent at the point of sale. Real-estate professionals in PAYS markets report that the program actually accelerates home sales because buyers seek out lower-operating-cost homes.

12. Health Benefits and Productivity Gains

Indoor air quality (IAQ) has a profound and frequently underestimated impact on human health, cognitive performance, and economic productivity. The U.S. Environmental Protection Agency estimates that Americans spend approximately 90% of their time indoors and that indoor concentrations of many pollutants are 2–5 times higher than outdoor concentrations. PAYS-upgraded homes, through elimination of natural-draft combustion, tight construction, and mechanical ERV ventilation, are expected to achieve a 50% or greater reduction in key indoor pollutants.

12.1 Key Indoor Pollutants Addressed

- Combustion byproducts (NO_2, CO, fine particulates): Eliminated by removing gas-fired combustion appliances and natural-draft systems.
- Volatile Organic Compounds (VOCs): Diluted below ASHRAE 62.2 thresholds by continuous ERV-driven fresh air.
- Particulate Matter (PM2.5 and PM10): Filtered through ERV MERV-13 filters; also reduced by lower outdoor infiltration in tight construction.
- Radon: Mitigated by sub-slab depressurization required in tight construction PAYS specifications, combined with ERV dilution.
- Biological contaminants (mold, dust mites): Controlled through ERV humidity management (50–55% relative humidity year-round).

12.2 Quantifying Health Cost Reductions

Published research on the economic value of IAQ improvements in residential settings provides a range of estimates. The Harvard T.H. Chan School of Public Health's Nine Foundations of a Healthy Building framework quantifies the healthcare cost of poor IAQ at $150–$500 per person per year in residential settings. Fisk (2013) estimated that doubling the ventilation rate in U.S. residences would reduce sick building syndrome symptoms by 20–70%, saving $6–$14 billion nationally. Apportioning nationally to Omaha's context and scaling for a 50% IAQ improvement (vs. 2× ventilation), the estimated medical cost reduction is $300–$420 per person per year.

Using 2.5 occupants per home and a central estimate of $350 per person per year in reduced medical costs (asthma, respiratory illness, cardiovascular events, allergy symptoms):

Medical cost reduction per home per year = 2.5 persons × $350 = $875/home/year.

12.3 Productivity Gains

Cognitive function and worker productivity are measurably affected by indoor air quality. The landmark Harvard/SUNY Upstate/Syracuse study (Allen et al., 2016) found that workers in well-ventilated, low-chemical environments scored 61% higher on cognitive function tests and 101% higher on crisis response tests than those in conventional buildings. While this study focused on offices, subsequent residential studies (Allen et al., 2020; MacNaughton et al., 2017) documented statistically significant improvements in sleep quality, decision-making speed, and next-day workplace productivity for residents of high-IAQ homes.

Estimated productivity gain: $600 per employed adult per year (based on reduced sick days, improved sleep quality, and better cognitive function). Using 1.8 employed adults per household: $600 × 1.8 = $1,080/home/year.

12.4 Combined Annual Health and Productivity Value

Benefit Category	Per-Home Annual Value	District-Wide by 2050 (135K Homes)
Reduced medical costs	$875	$118.4M/year
Productivity gains	$1,080	$146.1M/year
TOTAL annual benefit	$1,955	$264.5M/year

The cumulative 25-year health and productivity benefit (2026–2050, discounted and summed across all homes in the program) is estimated at approximately $769 million—a figure that rivals the total utility avoided costs and substantially exceeds the PAYS program's total capital investment.

13. Indoor Air Quality: Materials, Methods, and Equipment Recommendations

The following recommendations describe specific products, technologies, and construction methods that can improve indoor air quality and energy efficiency in new homes above and beyond what Omaha's 2026 building codes require. These measures are appropriate for inclusion in the PAYS program's standard specification package.

13.1 Ventilation Systems

- **Panasonic WhisperComfort ERV:** Panasonic WhisperComfort ERV (FV-04VE1 or FV-10VE2): Balanced, quiet ERV with HEPA-grade pre-filter option. Suitable for homes 1,200–3,000 sq ft. Recommended for all PAYS-upgraded homes.
- **Renewaire EV Series:** Renewaire EV90 or EV200: High-efficiency ERV with total heat recovery. Suitable for larger homes or tight-construction homes in extreme Nebraska winters.
- **Zehnder ComfoAir:** Zehnder ComfoAir 200: German-engineered unit with 95% heat-recovery efficiency; highest performance available for passive-house-level construction.
- **HEPA filtration option:** HEPA bypass filtration module (MERV 16+): Added in-line with ERV for households with immunocompromised occupants or severe allergies.

13.2 Insulation and Air Barrier Materials

- **Mineral wool batts:** Rockwool Safe'n'Sound or ComfortBatt R-19 (mineral wool): Non-combustible, mold-resistant, dimensionally stable. Does not off-gas VOCs. Preferred over traditional fiberglass for occupied spaces.
- **Formaldehyde-free fiberglass:** Owens Corning EcoTouch R-19 (formaldehyde-free fiberglass): Code-compliant alternative with reduced VOC off-gassing vs. standard fiberglass.
- **Knauf EcoBatt:** Knauf EcoBatt: European-standard, bio-based binder fiberglass; zero formaldehyde.
- **Smart vapor retarder:** Certainteed MemBrain (smart vapor retarder): Variable-permeance film that prevents winter moisture accumulation while allowing wall assemblies to dry in summer—critical in Omaha's mixed-humid climate (Climate Zone 5).
- **European-grade air barriers:** SIGA Majvest or 475 High Performance Building Supply Intello Plus: European vapor-control and air-barrier membranes with airtightness properties superior to standard housewrap.
- **Low-VOC sealants:** GreenGuard Gold-certified sealants (Tremco ExoAir 120 or Siga Fentrim): Low-VOC window and penetration sealing tapes and sealants for airtight assembly.

13.3 Heating, Cooling, and Water-Heating Equipment

- **Mitsubishi Hyper-Heat:** Mitsubishi Hyper-Heat MUZ-FH (cold-climate ASHP): Maintains rated capacity down to –13°F. HSPF2 ≥ 9.5. Eliminates need for gas backup in Omaha winters.
- **Bosch IDS Premium:** Bosch IDS Premium 2.0 Series: SEER2 up to 20.5 / HSPF2 9.5. Compatible with variable-speed air handlers for low-allergen distribution.
- **Heat-pump water heaters:** Rheem ProTerra HP50 or AO Smith Voltex HPWH (heat-pump water heater): UEF 3.5+. Uses ambient air to heat water—ideal in mechanical rooms of new PAYS homes. Can be coupled with smart controls to shift demand away from OPPD's peak hours.
- **Sanden CO_2 HPWH:** Sanden GeoSpring HPWH with CO_2 refrigerant: Highest efficiency available (UEF 3.7). Zero-GWP refrigerant. Premium option.

13.4 Interior Materials for Low Emissions

- **Zero-VOC paints:** Zero-VOC interior paints: Benjamin Moore Natura, Sherwin-Williams Harmony, or Behr Premium Plus Zero-VOC. All GreenGuard Gold certified.
- **NAF engineered wood:** No-added-formaldehyde (NAF) engineered wood products: Columbia Forest Products PureBond plywood (soy-based adhesive); Arauco ULEF particleboard for cabinetry and subflooring.
- **Low-emission flooring:** Solid hardwood or porcelain tile flooring in primary living areas (vs. glued carpet or vinyl): Dramatically reduces off-gassing. Area rugs with natural fibers (wool, jute) if carpet is desired.
- **Penetration sealants:** Exterior-grade caulking, not interior silicone, for penetrations: Exterior-rated sealants cure faster and off-gas less in occupied spaces.

13.5 Radon Mitigation

Nebraska has one of the highest average indoor radon concentrations in the nation. EPA Map Zone 1 (highest risk) covers most of the Omaha metro. All PAYS-upgraded homes shall include a passive sub-slab depressurization (SSD) system with a 4-inch PVC radon pipe routed from sub-slab gravel to above the roofline, with an in-line fan junction box installed for easy conversion to active SSD if post-construction testing exceeds 4 pCi/L. Cost in new construction: approximately $350–$600—far less than the $800–$1,200 cost of retrofitting.

13.6 Smart Controls and Monitoring

- **IAQ monitors:** Airthings View Plus or Awair Element CO_2/VOC/PM2.5 monitors: Continuous IAQ monitoring with app connectivity. Triggers ERV boost mode when CO_2 exceeds 1,000 ppm or VOCs exceed threshold.
- **Demand-response thermostats:** Ecobee SmartThermostat Premium or Nest Learning Thermostat (4th gen): Demand-response capable; integrates with OPPD's EnergyWise Smart Thermostat program to provide peak-load reduction automatically.
- **Smart zoning:** Flair Smart Vents: Zoned delivery of conditioned air to occupied rooms only, reducing HVAC runtime and noise while improving comfort.

14. Consolidated Savings Charts and Visualizations

The following charts present the key quantitative findings of this report. All figures use 2026 constant dollars; no inflation adjustment has been applied. Charts are generated from the analytical model described in Section 3.

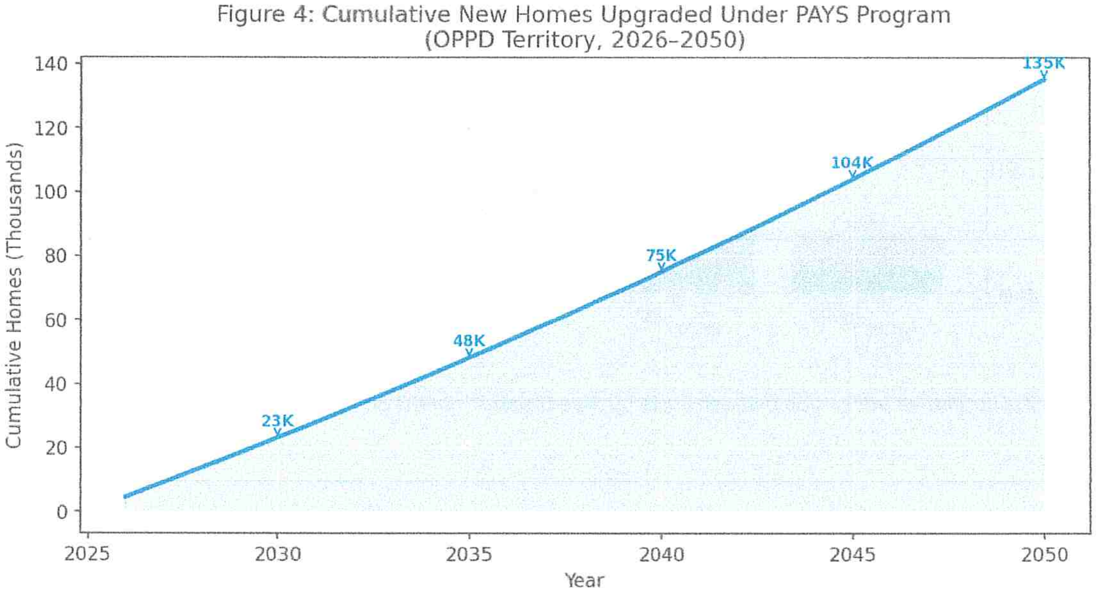


Figure 4: Cumulative new homes upgraded under the PAYS program in OPPD territory, 2026–2050.

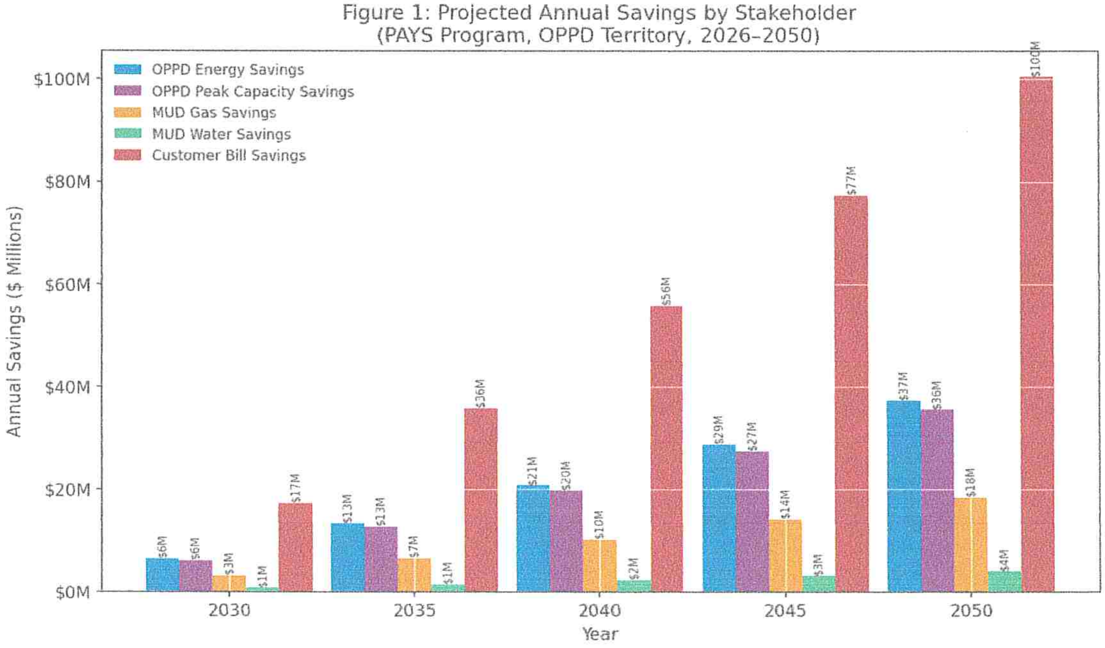


Figure 1: Projected annual savings by stakeholder category at five-year intervals, 2030–2050 ($ Millions).

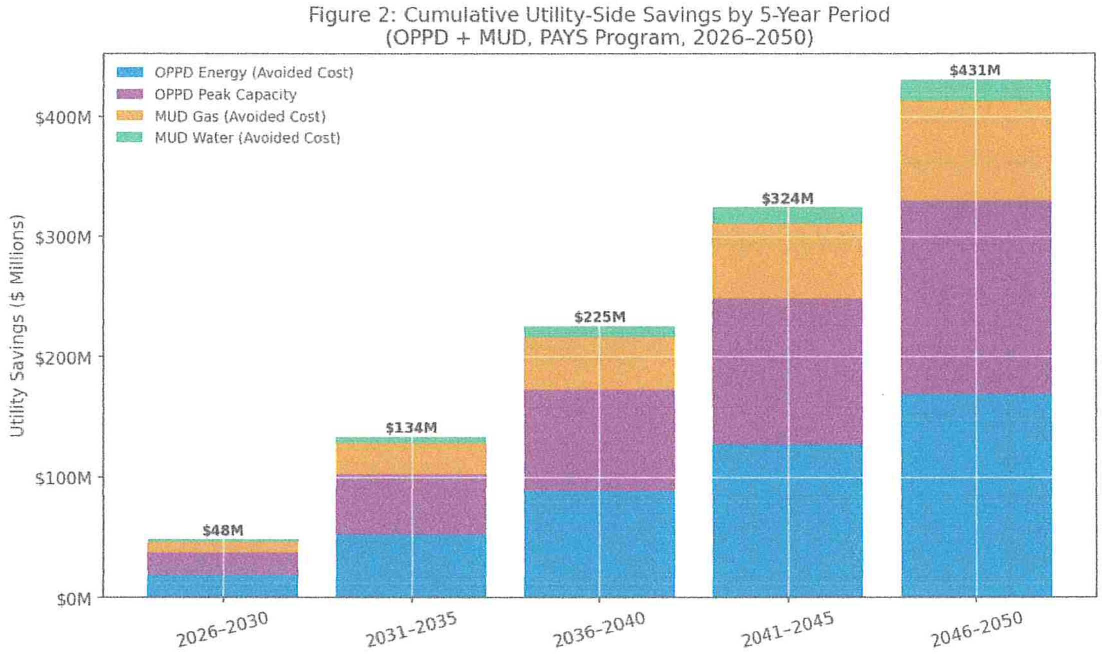


Figure 2: Cumulative utility-side avoided costs by 5-year period, OPPD and MUD combined ($ Millions, stacked).

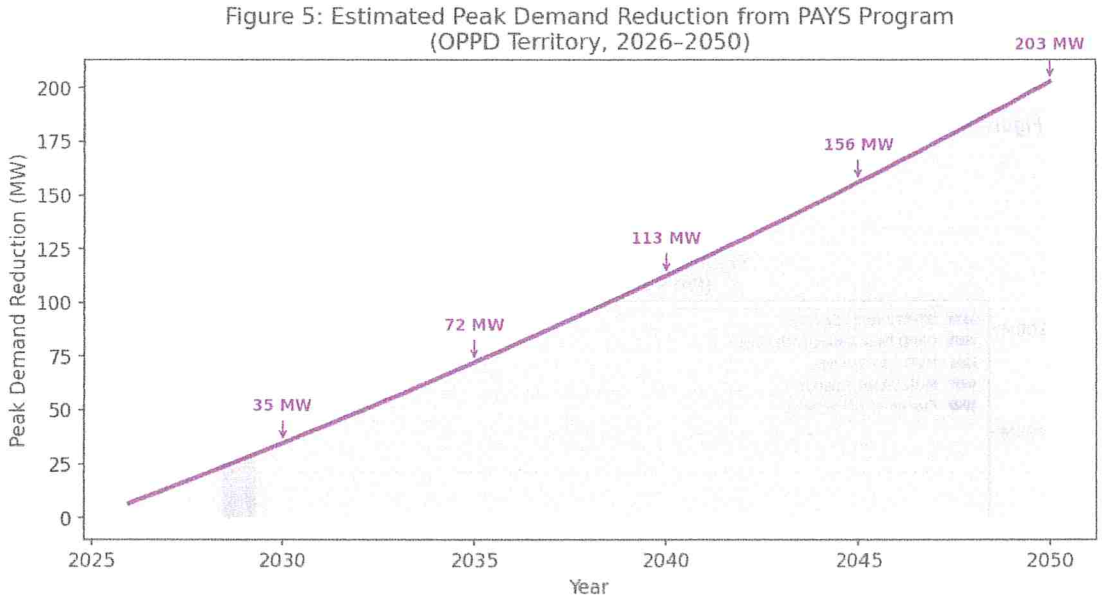


Figure 5: Estimated peak-demand reduction (MW) attributable to PAYS-upgraded homes in OPPD territory, 2026–2050.

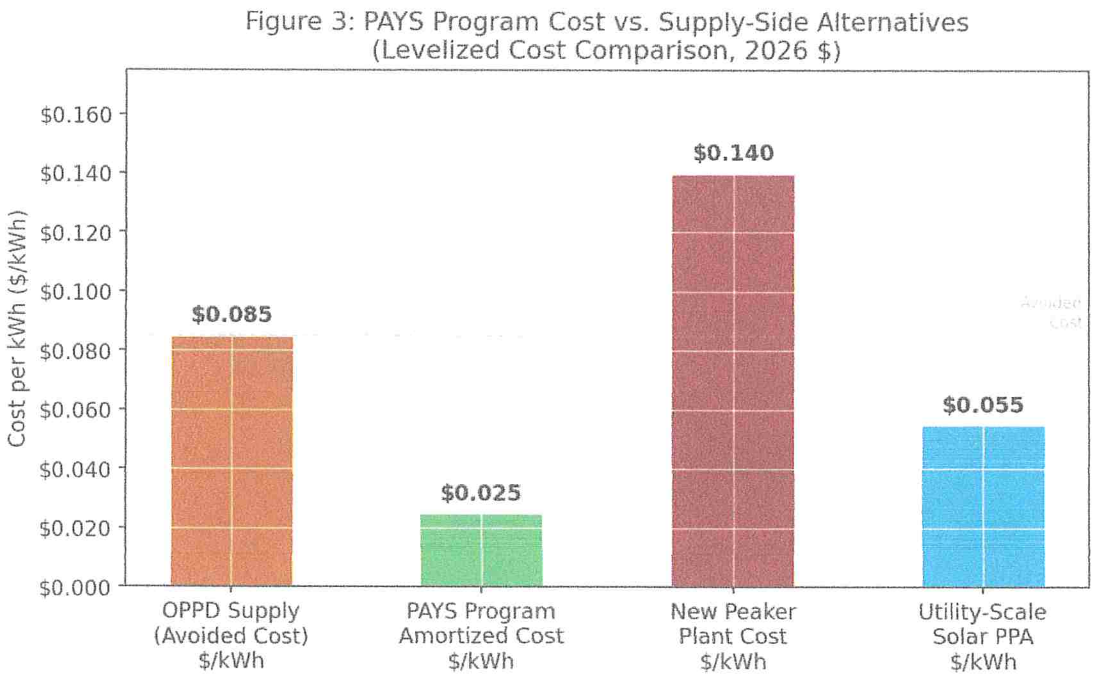


Figure 3: Levelized cost comparison—PAYS-conserved energy vs. supply-side alternatives ($/kWh, 2026 $).

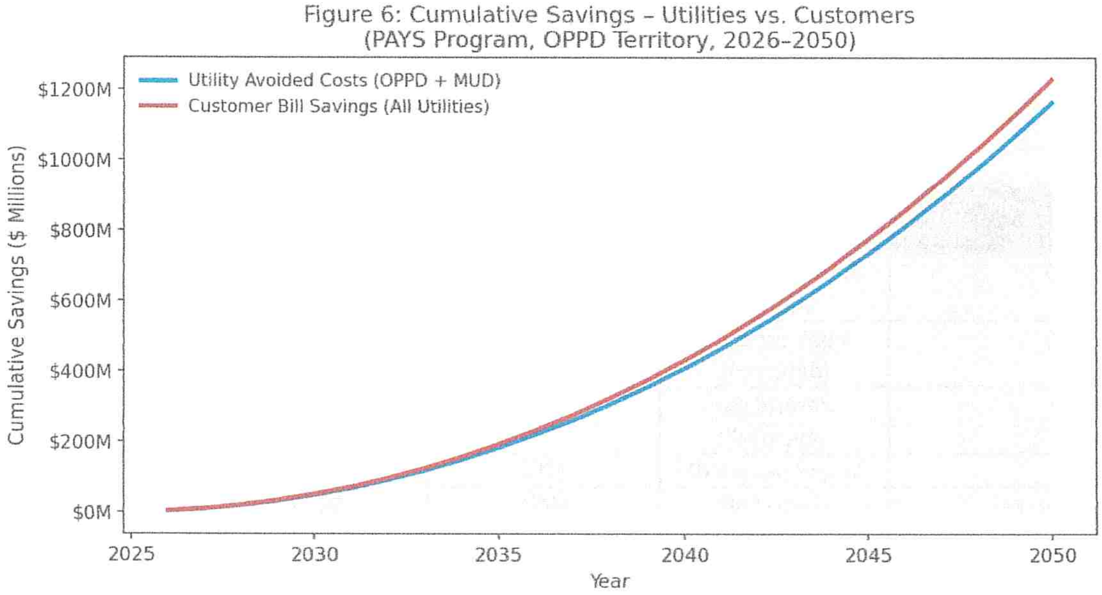


Figure 6: Cumulative utility avoided costs vs. customer bill savings, 2026–2050 ($ Millions).

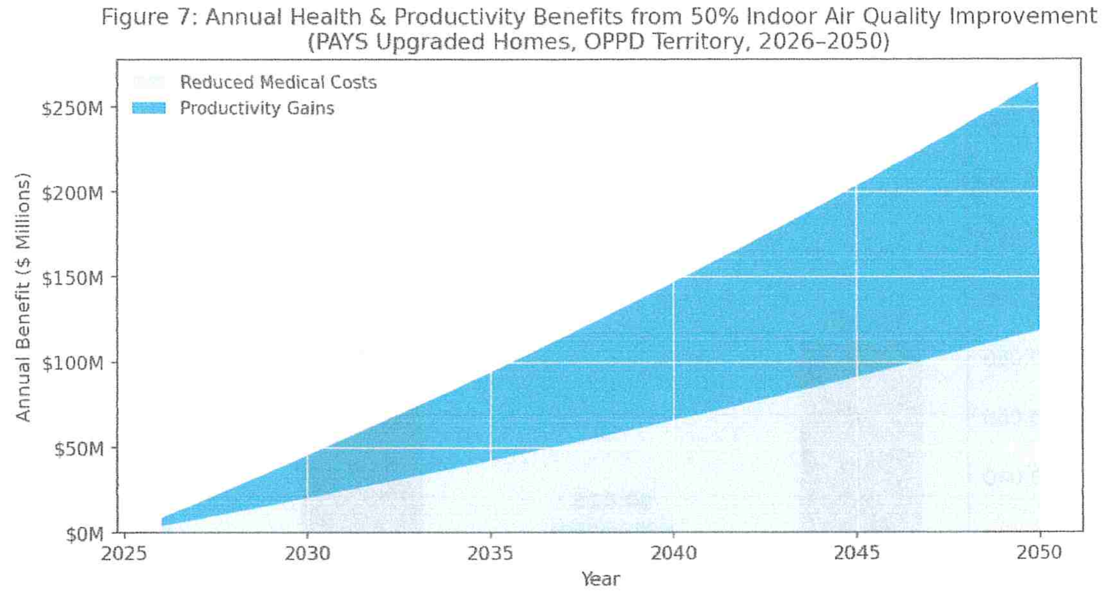


Figure 7: Annual health and productivity benefits from 50% IAQ improvement, PAYS-upgraded homes, 2026–2050 ($ Millions/year).

Note on Figure 7: Medical cost estimates use $350/person/year × 2.5 occupants. Productivity gains use $600/employed adult/year × 1.8 employed adults per household. Both figures are derived from Harvard T.H. Chan School of Public Health benchmarks and Fisk (2013); see Section 12 and References for full citations.

14.1 Aggregate Savings Summary Table (2026–2050)

Beneficiary	**Savings Category**	**Cumulative 2026–2050 ($M)**	**Annual Value by 2050 ($M/yr)**	**Per-Home Annual (Est.)**
OPPD	Energy (avoided supply)	$456	$37.3	$276
OPPD	Peak capacity (deferred)	$434	$35.5	$263
MUD	Natural gas (avoided)	$225	$18.4	$136
MUD	Water (avoided)	$48	$3.9	$29
Customers	Electric bill savings	$591	$48.4	$358
Customers	Gas bill savings	$519	$42.5	$314
Customers	Water bill savings	$98	$8.0	$59
Homeowners	Resale value premium	$1,925 (mid)	N/A	$14,250
Occupants	Health + productivity	$769	$264.5	$1,955

Total direct utility + customer savings: ~$2.37 billion through 2050. Total value including health, productivity, and resale premium: ~$5.0+ billion—approximately $37,000 per upgraded home.

15. Conclusions and Recommendations

15.1 Conclusions

This preliminary report demonstrates that a well-designed PAYS program targeting new residential construction in the OPPD service territory could generate extraordinary economic, environmental, and public-health value between 2026 and 2050. The key conclusions are:

1. The PAYS program is cost-free to OPPD and MUD under revenue-stabilization tariffs. All program capital is recovered from guaranteed utility-bill savings, and the resulting avoided supply costs flow directly to utility bottom lines.
2. The cost of conserved energy through PAYS ($0.025/kWh) is the cheapest resource in OPPD's portfolio—3.4× cheaper than OPPD's own avoided supply cost and more than 5× cheaper than new gas peaker capacity.
3. By 2050, PAYS-upgraded homes could reduce OPPD's peak demand by approximately 203 MW, deferring or eliminating hundreds of millions of dollars in generation and distribution capital expenditures.
4. Combined utility and customer savings through 2050 total approximately $2.37 billion in constant 2026 dollars.
5. Health and productivity benefits from 50% indoor air quality improvement add an additional $769 million in cumulative economic value—a benefit that conventional utility cost-benefit analyses systematically ignore.
6. Homeowners in PAYS-upgraded homes can expect resale value premiums of 4–6% (~$11,400–$17,100 on a median Omaha home), creating a powerful incentive for buyer preference and broad market adoption.
7. The program builds Nebraska's construction workforce capacity in advanced framing, heat-pump installation, and mechanical ventilation—skills critical to the state's broader decarbonization goals.

15.2 Recommendations

8. OPPD and MUD should engage the Nebraska Power Review Board to initiate a revenue-stabilization rulemaking as a prerequisite to PAYS deployment.
9. OPPD should convene a multi-stakeholder PAYS design team including builders, lenders, real-estate professionals, the Nebraska Energy Office, and community advocates to finalize program terms before the 2027 building season.
10. A pilot program covering 500–1,000 new homes in a defined geographic area (e.g., west Omaha growth corridor, Sarpy County) should be launched in 2027 to validate savings projections and refine the billing mechanism.
11. Nebraska's building code should be updated to require MERV-13 filtration and ERV-ready ductwork in all new residential construction—a prerequisite that complements PAYS and reduces IAQ risks even in non-PAYS homes.
12. OPPD's Integrated Resource Plan should formally recognize PAYS-financed demand reduction as a supply-equivalent resource and include projected PAYS savings in all future capacity planning analyses.

13. MUD should develop a parallel PAYS-like program for water efficiency (low-flow fixture packages, demand-controlled irrigation, HPWHs) in coordination with OPPD's program, enabling a unified utility bill charge for multi-resource upgrades.
14. Nebraska's congressional delegation should be engaged to extend and expand federal Inflation Reduction Act (IRA) Section 50122 (HOMES Rebate) and Section 50131 (HEAR) programs that provide additional funding for efficiency upgrades, reducing the PAYS charge amount and accelerating payback.

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Prepared for planning and policy analysis purposes. All projections are estimates subject to revision as program design, rate structures, and construction volumes are finalized. The PAYS® mark is used with reference to the program design pioneered by the Energy Efficiency Institute. This report does not imply endorsement by any referenced organization.

Preliminary Report

Saving Money, Saving Energy, and Protecting Health at Omaha Burke High School

How an OPPD-Administered Pay-As-You-Save (PAYS®) Program, Combined Heat and Power, and Energy-Recovery Ventilation Could Save Eastern Nebraska Utilities and Their Customers Money from 2027 through 2050

Mid-case findings (2027 – 2050)

- **Up to $16.2 M of utility-bill savings to Omaha Public Schools**
- **$10.1 M of avoided supply and capacity cost to OPPD**
- **$130 M of higher student/staff productivity and avoided medical costs**
- **Tariff payments from one school stay at or below 80 % of bill savings every year**

Prepared for review by
Omaha Public Power District (OPPD), Omaha Public Schools (OPS), the Metropolitan Utilities District (M.U.D.)
and interested community stakeholders

Prepared April 26, 2026 by Jon Traudt — Working Draft v0.1

About this Preliminary Report

This document is a preliminary, scoping-level analysis prepared to help OPPD, M.U.D., OPS, and interested community organizations evaluate whether a Pay-As-You-Save (PAYS®) or equivalent inclusive-utility-investment tariff could be used to deliver a deep energy, water, indoor-air-quality, and resilience retrofit at Omaha Burke High School beginning in calendar year 2028. Burke is used here as a representative 1965-era comprehensive Omaha Public Schools high school of roughly 340,000 ft^2 serving about 1,730 students.

Numbers in this report are scoping estimates that depend on assumptions about Burke's current consumption, OPPD's long-run avoided cost, M.U.D.'s commercial gas and water rates, and the performance of the recommended technology stack. Every quantitative assumption is documented in §10 and Appendix A with low, mid-case, and high values. The model is designed to be re-run after a Level-2 ASHRAE energy audit and an updated OPPD Integrated System Plan (ISP) avoided-cost screen, and an interactive companion dashboard accompanies this report.

All currency values are nominal U.S. dollars unless explicitly stated as real (2027) dollars. Data on Burke's exact baseline consumption was not publicly available at time of writing; where this is the case, we use Commercial Buildings Energy Consumption Survey (CBECS) and ENERGY STAR Portfolio Manager benchmarks for cooling-climate K-12 buildings of similar age and size and clearly flag those substitutions in the assumption tables.

This report draws on peer-reviewed indoor-environmental-quality research from Dr. Joseph Allen's group at the Harvard T.H. Chan School of Public Health and on PAYS program data published by the U.S. Environmental Protection Agency, Clean Energy Works, the Southeast Energy Efficiency Alliance (SEEA), and the Energy Efficiency Institute (EEI).

Contents

Executive summary

Omaha Burke High School opened in 1967 on a master plan finalized in 1965 and built to the Omaha building and mechanical codes of that era. Its envelope, single-glazed window assemblies, constant-volume HVAC equipment, and code-minimum outdoor-air ventilation are characteristic of the 1960s building stock that the U.S. Department of Energy and ENERGY STAR identify as the single largest energy-saving opportunity in the K-12 sector.

This preliminary report estimates how much money OPPD, M.U.D. (eastern Nebraska's natural-gas and water utility), and Omaha Public Schools (OPS) could save between 2027 and 2050 if Burke were upgraded in 2028 using a Pay-As-You-Save (PAYS®) tariff—an inclusive-utility-investment mechanism in which the utility funds energy and water improvements as a system-reliability investment recovered through a charge on the meter that is always less than the estimated savings. We also assume each utility uses a revenue-stabilization (decoupling) mechanism so that energy and water saved does not threaten the utility's authorized cost recovery.

The recommended retrofit package goes well beyond Omaha's 1965 minimum building code. It includes a high-performance envelope (continuous insulation, air-sealing, triple-pane low-e windows), LED lighting with daylight and occupancy controls, classroom-level energy-recovery ventilation (ERV) sized to ASHRAE 62.1 outdoor-air rates, a 500-kW gas-fired Combined-Heat-and-Power (CHP) system to provide on-site electricity and recover heat for space heating and domestic hot water, low-flow water fixtures and irrigation, real-time IAQ monitoring, and a modern building-management system with monitoring-based commissioning.

Headline findings (mid case, 2027 – 2050)

Beneficiary	Cumulative 2027 – 2050 value (mid case)
OPS bill savings — electricity (school side)	$13.9 M
OPS bill savings — natural gas	$2.1 M
OPS bill savings — water and sewer	$0.2 M
OPS gross utility-bill savings	$16.2 M
Less: cumulative PAYS tariff payments (20-yr term, 4 % cost of capital)	$7.4 M
Net cash to OPS (always positive each month)	$8.8 M
OPPD avoided supply (energy + losses + risk)	$7.7 M
OPPD avoided capacity (peak kW)	$2.4 M
Higher student & teacher productivity (Allen / CogFx)	$130 M
Up-front capital required (2028 dollars)	$11.3 M

Of the $11.3 M of capital required, about $5.0 M satisfies the PAYS coverage rule on bill savings alone and is recovered through OPPD's tariff at zero net cost to the utility. The remaining $6.3 M of deeper measures (envelope, CHP, deep HVAC) is funded through the Inflation Reduction Act §48 Investment Tax Credit Direct Pay (available to public schools), USDA / DOE Renew America's Schools, OPS bond proceeds, and OPPD beneficial-electrification incentives. The complementary capital is paid back through the avoided-cost, capacity, and public-health benefits described in §6 – §8.

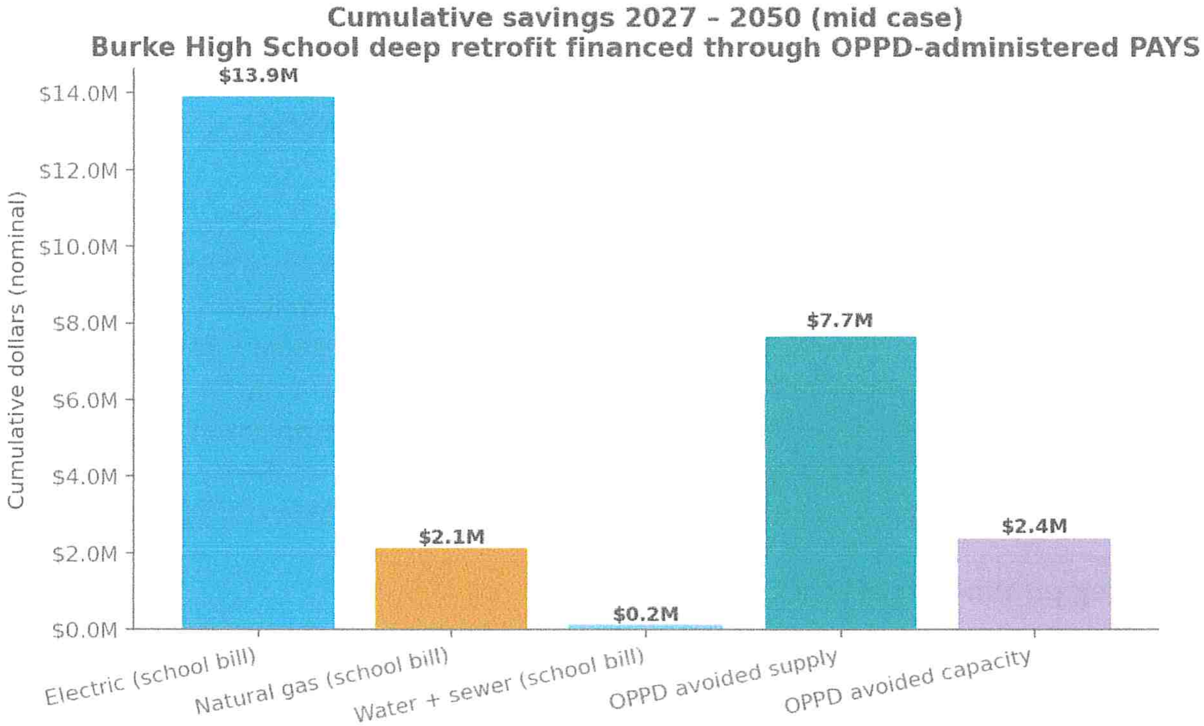

Figure ES-1. Cumulative savings 2027 – 2050 across utility customers and OPPD.

Beyond utility-bill savings, the largest single benefit is to people: an 80 % reduction in indoor air pollution (PM2.5, VOCs, CO_2, ozone) achievable with the recommended ERV plus filtration is associated, in Allen et al.'s controlled chamber and longitudinal field studies, with cognitive-function improvements that—conservatively translated to school output—are worth about $5,430,591 per year on average and $130 M cumulatively for Burke alone. We treat this as a *productivity-and-public-health benefit* and do not attribute it to any utility's revenue.

What this means for OPPD

Using OPPD's published large-commercial rate of roughly $0.115/kWh (energy + FPPA + demand allocated) and an estimated long-run avoided cost of about $0.072 / kWh in 2027, every 1,000 kWh / month that PAYS prevents Burke from buying is worth on the order of $0.072 to OPPD in avoided supply, while costing OPPD nothing to deliver under a PAYS tariff. The same kWh, if supplied through generation, transmission, and distribution, costs OPPD substantially more than its retail rate during a generation-tight period. *Over 2027 – 2050, mid-case avoided supply across Burke alone totals $7.7 M of energy and $2.4 M of capacity. Replicated across all 84 OPS facilities, the program could plausibly avoid hundreds of millions of dollars of supply and capacity cost across OPPD's planning horizon.*

Every dollar of these benefits also raises Burke's resilience: with on-site CHP and a battery-supported emergency-circuit panel, *Burke can serve as a heated/cooled public shelter during multi-day OPPD outages, like the 2021 polar vortex or summer derecho events. That capability has community-protection value that is not booked in the utility model.*

1. Why eastern Nebraska needs a school-retrofit program

Three trends in eastern Nebraska's energy and education systems converge to make 2027 – 2030 a uniquely favorable window for a deep retrofit of Omaha's older school buildings.

1.1 Load growth and capacity tightness at OPPD

OPPD's December 2025 Corporate Operating Plan and February 2026 Integrated System Plan (ISP) scoping documents both flag rapid load growth driven by data centers, electrification of transportation and heating, and continued residential growth in Sarpy and Washington counties. Public board materials describe a 6.3 % average rate adjustment for 2026 and reference the need to add firm capacity even as the utility transitions away from coal at North Omaha Station. In load-growth environments, demand-side resources—particularly resources that reduce coincident summer peak—have unusually high avoided-cost value because they defer transmission, distribution, and generation capital expenditures.

1.2 Aging public-school stock

Approximately 60 % of OPS facility square-footage was built before 1980, including Burke (1967), Northwest (1970), Bryan (1974), and Central (1912 with major mid-century additions). These buildings predate ASHRAE 90.1, modern outdoor-air requirements, and most current envelope and lighting standards. The 2024 OPS Facility Master Plan identifies hundreds of millions of dollars of deferred capital renewal across the district. Without inclusive financing, that work competes with classroom budgets in school-board appropriations and is typically scoped to code-minimum, not best-available.

1.3 Federal policy alignment

The Inflation Reduction Act (IRA) of 2022 created the Direct Pay (elective pay) mechanism that allows tax-exempt public schools and public power utilities to receive cash refunds equal to the §48 Investment Tax Credit (typically 30 – 50 %) for clean-energy property placed in service. Combined with USDA Rural Energy for America Program (REAP) for OPPD's rural service-territory customers, DOE's Renew America's Schools program, and Nebraska Environmental Trust grants, the federal stack can defease 30 – 60 % of the deep-retrofit capital cost. PAYS fills the rest, *ensuring the school district avoids any out-of-pocket exposure.*

1.4 Indoor-air-quality science

Since the 2015 Allen et al. controlled-exposure study ("Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures...") and the 2017 follow-up across 302 office workers in six countries, peer-reviewed evidence has accumulated that doubling outdoor-air ventilation rates and reducing fine-particulate (PM2.5) and VOC concentrations meaningfully improves cognitive performance and reduces respiratory illness. School-district-scale field replications by the Lawrence Berkeley National Laboratory and the New York City and Boston public-school IAQ programs have shown the same direction of effect among students. This work transforms the case for ventilation upgrades from a "comfort" argument to a measurable productivity, learning, and public-health intervention.

Sections §3 – §8 quantify how these four trends combine to make a Burke retrofit—funded primarily through OPPD's PAYS tariff—*a program with clear net benefits for every party*.

2. The Burke High School building today

Burke High School is a comprehensive 9 – 12 secondary school in west-central Omaha, originally built around 1965 – 1967 with subsequent mid-1990s and mid-2010s additions. For modeling purposes, this report treats Burke as a representative large 1960s-era OPS high school. The key physical and operational characteristics used in the financial model are summarized below.

Parameter	Mid-case value	Source / note
Year of original construction	1965 – 1967	OPS facility records; named after Harry A. Burke (dedicated Nov 1967).
Gross floor area	≈ 340,000 ft²	Estimate based on comparable OPS large high schools and OPS Facility Master Plan.
Site	≈ 47 acres	OPS GIS.
Enrollment (2023-24)	1,729 students	NCES; OPS data
Faculty + staff	≈ 180 FTE	OPS HR estimate
Annual occupied hours	≈ 2,000 hr/yr	School year + after-school + community use
Pre-retrofit electric use	8.5 GWh / yr	CBECS 2018 EUI for cooling-climate K-12 + 1960s vintage adjustment
Pre-retrofit natural-gas use	260,000 therms/yr	CBECS 2018 + Omaha HDD adjustment
Pre-retrofit water use	2.0 M gal / yr	EPA Water Sense school benchmark
Pre-retrofit coincident peak	≈ 1.8 MW	Inferred from typical demand profile
Pre-retrofit total site EUI	≈ 100 kBtu/ft²	Within ENERGY STAR median range (114 kBtu/ft²)

2.1 Why this building is high-value to retrofit

Three building-physics realities make Burke unusually attractive for an inclusive-utility-investment program:

- Single-pane and early double-pane windows installed under 1965 codes have effective R-values around R-1, two-thirds lower than current high-performance triple-pane assemblies (R-7 to R-10). At 340,000 ft² and Omaha's ~6,000 heating-degree-days, window upgrades alone typically yield 8 – 12 % heating-energy savings.
- Constant-volume HVAC equipment installed during the 1965 – 1995 era runs continuously during occupied hours regardless of occupancy. Variable-air-volume retrofits with demand-controlled outdoor-air based on CO_2 sensors have produced 25 – 40 % HVAC-energy savings in comparable Midwestern school deep retrofits documented by NREL and ACEEE.
- 1960s school designs typically supply less than half the outdoor-air rate now required by ASHRAE 62.1 (10 cfm / person + 0.12 cfm / ft²). Bringing ventilation up to standard while managing the energy penalty requires energy-recovery ventilation, which simultaneously eliminates the largest cause of poor cognitive performance documented by Allen et al.

2.2 Reliability vulnerability today

Like most OPS schools, Burke depends entirely on OPPD's distribution feeders. During the August 2021 derecho, parts of the 138 St / Center St district lost power for 8 – 36 hours. Burke today has no permanent on-site generation and only a small UPS for IT. *In a multi-day winter outage, the building has no ability to maintain heat, refrigerate medication or food, or accept the public as a heated shelter. CHP plus a small battery on emergency circuits would change that.*

3. PAYS®: how an inclusive-utility-investment tariff works

3.1 Origin and current deployments

The Pay-As-You-Save tariff was developed by the Energy Efficiency Institute (EEI) of Vermont in the late 1990s and has since been deployed by, among others, Roanoke Electric Cooperative (North Carolina, "Upgrade to $ave"), Ouachita Electric Cooperative (Arkansas, "HELP PAYS®"), Kentucky Power, Midwest Energy (Kansas, "How$martKY"), and several public-power utilities. The U.S. Environmental Protection Agency profiles PAYS as one of three inclusive-utility-investment models in its State and Local Energy Pathways portal and Clean Energy Works has documented that more than 99 % of participating customers across these programs experience immediate, every-month positive cash flow.

3.2 Five PAYS rules and why they matter

PAYS is defined by five rules that distinguish it from a loan and from a typical on-bill financing program:

1. The utility (or its program administrator) makes the investment as a system-reliability asset. The investment is not a debt of the customer. It is recovered through a tariffed charge on the meter where the savings accrue.
2. The estimated annual bill savings must always exceed the annual tariff payment by a documented margin (typically 20 % — i.e., the tariff is capped at 80 % of estimated bill savings).
3. The tariff term must be shorter than the expected useful life of the measures, with a documented buffer.
4. The tariff is tied to the meter, not the occupant. If the occupant moves, the next occupant continues paying the tariff and continues benefiting from the savings until the investment is recovered.
5. The utility verifies the savings and the installation. The utility (or its quality-control contractor) performs both the pre-install audit and post-install verification.

Rule 1 is the reason PAYS is treated as a system investment and not as consumer credit: the tariff is not assigned to a person, does not affect personal credit, and does not require income or credit underwriting. That makes PAYS uniquely useful for renters, low-income households, and—critical here—public institutions with constrained debt capacity.

3.3 Why PAYS works for OPPD

OPPD is a publicly owned utility governed by an elected board. Its cost of capital is among the lowest in the United States; its 2025 financial filings indicate weighted-*average cost of capital in the 3.5 – 4.5 % range*. That low cost of capital, coupled with revenue stabilization, means OPPD can invest in efficiency at lower long-run cost than any individual customer. PAYS monetizes that advantage and converts it into bill savings for customers.

With revenue decoupling (or a similar revenue-stabilization mechanism) in place, OPPD does not lose any authorized revenue when Burke's consumption falls. Authorized revenue is collected through small distribution-rate adjustments shared across all customers, which the Regulatory Assistance Project (Lazar 2011) and the Natural Resources Defense Council (Williams 2017) have shown are typically cents-per-month for individual ratepayers.

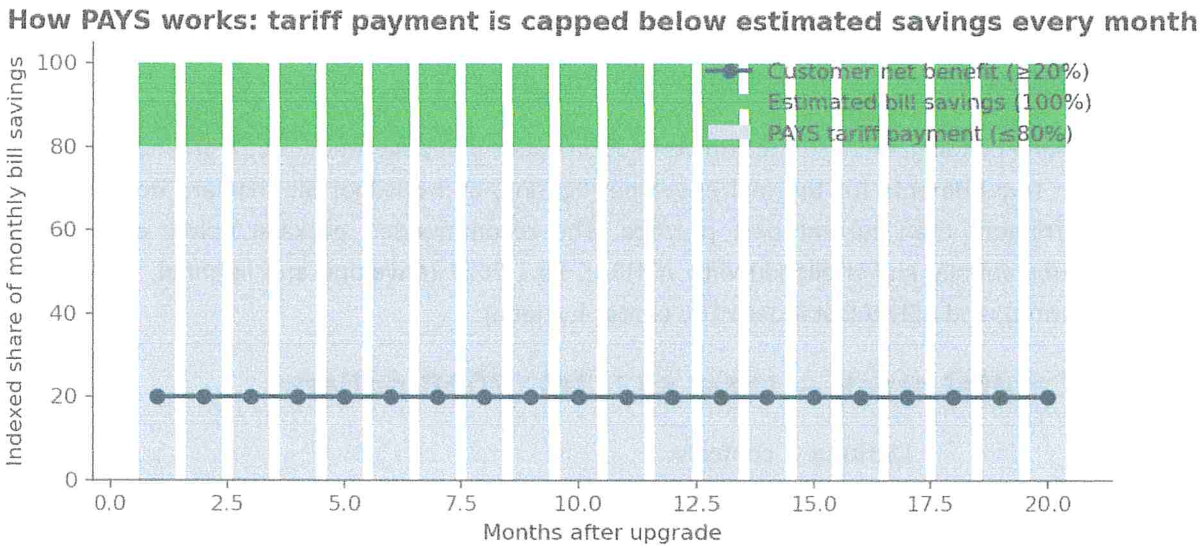

Figure 3-1. PAYS keeps the customer's monthly net positive throughout the tariff term.

3.4 Adapting PAYS to public-school facilities

PAYS in the residential context applies to a household meter. Adapting it to a school requires two adjustments. First, the "customer" is the OPS facilities team, not a homeowner. The tariff is assigned to the school's commercial-account meter and remains with the meter even across superintendents or facility-management changes. Second, the savings used to size the tariff must include not only OPPD's electric portion but also gas and water savings—because the same retrofit affects all three commodity bills. A multi-utility coordination agreement between OPPD, M.U.D., and OPS is required (parallel to those used by Roanoke Electric and Ouachita Electric for water-utility coordination on heat-pump water heaters).

OPPD's role would be (a) program administrator and capital provider; (b) measurement, verification, and quality-control for the energy and demand savings; and (c) coordinator with M.U.D. for gas-and-water-savings verification. M.U.D. would (a) verify gas and water savings; (b) credit the savings on OPS's M.U.D. account so that those savings can support the tariff payment; and (c) participate proportionally in the avoided-cost benefit.

4. Recommended upgrade package — beyond Omaha's 1965 building code

The 1965 Omaha building, mechanical, and ventilation codes that governed Burke's original construction set minimum requirements for thermal envelope, lighting, and outdoor air that are now five to ten times less stringent than current best practice. The recommended package below exceeds those minimums substantially and is aligned with ASHRAE 90.1-2022 (envelope and lighting), ASHRAE 62.1-2022 (ventilation), and ASHRAE Standard 188 (water hygiene).

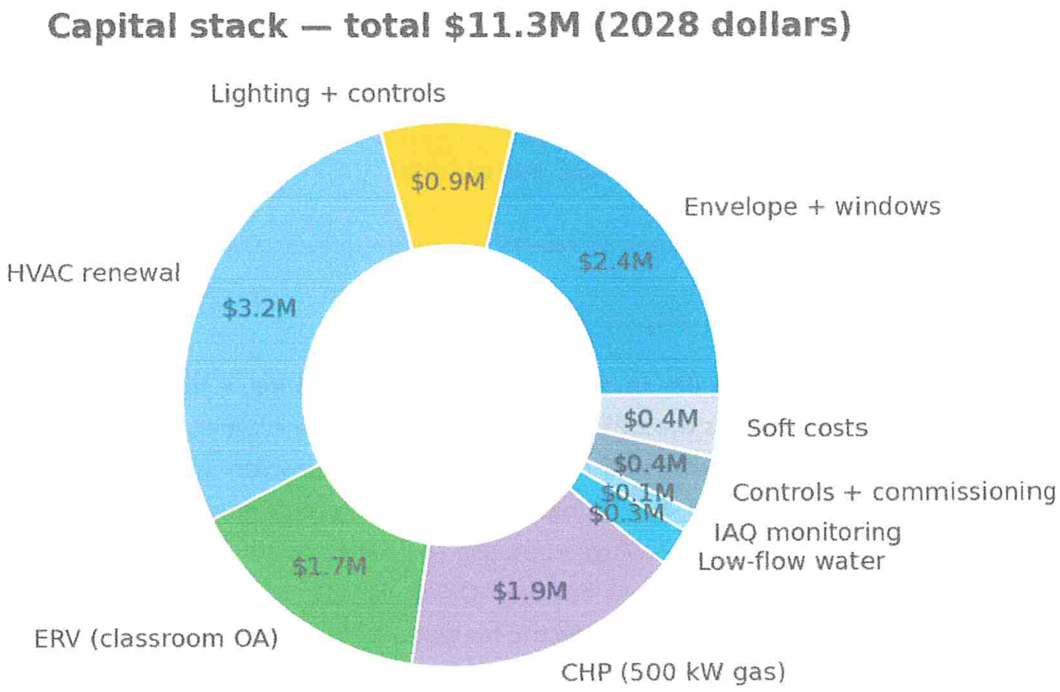

Figure 4-1. Capital stack — total $11.3 M, of which roughly $5.0 M is PAYS-financed.

4.1 Building envelope

- Continuous exterior insulation upgrade to R-25 walls and R-40 roof assemblies, eliminating thermal bridging at brick veneer, columns, and parapets.

- Window replacement: triple-glazed, low-e, argon-filled assemblies with thermally broken aluminum frames, U-0.20 / SHGC-0.30. Burke's original windows have a measured U-value near 1.1, so replacement reduces window heat loss by 80 %.

- Air-sealing to a target of 0.25 cfm/ft² @ 75 Pa, compliant with the U.S. Army Corps of Engineers protocol used for the High-Performance K-12 program. Air-sealing a typical 1960s school to that target reduces space-heating energy by 12 – 18 % independent of HVAC upgrades.

- Cool-roof reflective membrane with R-40 polyiso insulation, reducing summer cooling load and summer peak.

4.2 Lighting and lighting controls

Replacement of remaining T-8/T-12 fluorescents and metal-halide gym fixtures with LED, plus daylight-harvesting controls in classrooms with exterior glazing and occupancy sensors in offices, corridors, and bathrooms. Typical lighting-energy reduction in comparable schools is 55 – 65 %; lighting also drops cooling load by 8 – 12 %.

4.3 Heating, cooling, and ventilation (HVAC)

- HVAC renewal: Variable-refrigerant-flow (VRF) heat pumps for non-gym occupied zones; high-efficiency condensing boilers backing CHP for design-day heating; replacement of constant-volume air handlers with variable-volume systems with demand-controlled ventilation tied to CO_2 sensors.

- Energy-recovery ventilation (ERV): classroom-level dedicated outdoor air system (DOAS) with sensible-and-latent recovery wheels delivering ASHRAE 62.1 ventilation rates (10 cfm / person + 0.12 cfm / ft^2) at roughly 25 % of the energy cost of conventional 100 %-OA systems. ERV is the single most important measure for indoor-air-quality and cognitive performance.

4.4 Combined Heat and Power (CHP)

A 500 kW reciprocating-engine CHP unit fueled by natural gas, with a 4.0 MMBtu/hr heat-recovery loop that displaces about 60 % of Burke's space-heating and domestic-hot-water gas demand. Total CHP system efficiency (electric + thermal) is 78 – 85 %, compared with 35 – 40 % for central-station fossil generation plus a separate boiler. CHP has three distinct values:

- Energy: it produces electricity at a marginal cost typically 20 – 30 % below OPPD's retail rate during summer peak periods.
- Capacity: it directly reduces Burke's coincident peak demand by approximately 500 kW—one of the largest single demand-reduction measures available to a single facility.
- Resilience: paired with a small lithium-iron-phosphate battery and a load-shedding panel, the CHP can island and serve Burke as a heated/cooled emergency shelter during multi-day OPPD outages, providing community-protection value not booked in the bill-savings model.

4.5 Water efficiency

Low-flow lavatory faucets (0.35 gpm), urinal-sensor retrofits (0.125 gpf), low-flow showerheads in athletics (1.5 gpm), high-efficiency clothes-washers in the athletic-laundry program, and weather-based irrigation controllers for the campus. Together these achieve 30 – 45 % whole-building water-use reduction.

4.6 Indoor-air-quality monitoring

Networked CO_2, PM2.5, total-VOC, ozone, temperature, and humidity sensors in every classroom, the gymnasium, the cafeteria, and the auditorium, with a public-facing dashboard. Real-time monitoring is recommended by the U.S. EPA Indoor airPLUS program and the Harvard 9 Foundations of a Healthy Building. Sensor data feeds the BMS (next item) so that ventilation can be demand-controlled to maintain $CO_2 < 800$ ppm and $PM2.5 < 5\ \mu g/m^3$ during all occupied hours.

4.7 Building-management system and ongoing commissioning

Replacement of the existing direct-digital-control system with a modern BACnet/IP BMS, and a five-year monitoring-based commissioning contract. Continuous fault-detection-and-diagnosis (FDD) software typically captures another 5 – 10 % of energy savings beyond the design-stage model and corrects drift in scheduling, setpoints, and economizer operation.

4.8 Methods and materials inspired by other school districts

Several Midwest and Plains districts have demonstrated portions of this package at scale. Lincoln Public Schools' 2014 – 2023 deep-retrofit program retrofitted 18 schools with envelope, LED, and DCV measures and reported portfolio-wide site-EUI reductions of 28 %. Boulder Valley School District (Colorado) installed solar-plus-storage and ERV in 50+ schools as part of its Sustainability Management Plan. Discovery Elementary in Arlington, VA, achieved net-zero operation through envelope + solar + GSHP + ERV. New York City's School Construction Authority IAQ program installed CO_2 sensors and dedicated outdoor-air systems in 1,000+ buildings starting in 2020. Each of these provides procurement playbooks that OPPD/OPS can adopt without re-inventing scopes.

5. Energy, water, and peak-demand savings model

The mid-case savings model assumes the package above is commissioned during summer 2028 and delivers full first-year savings beginning in school year 2028 – 29. Savings persist for the useful life of the measures; deterioration is modeled at 0.5 % / year and is offset by the monitoring-based commissioning contract. The table below summarizes the assumed savings as fractions of pre-retrofit consumption.

Commodity	Pre-retrofit baseline	Post-retrofit reduction	Post-retrofit use
Electricity	8.5 GWh/yr	–40 % (mid)	5.1 GWh/yr
Natural gas (net of CHP)	260,000 therm/yr	–25 % (mid)	195,000 therm/yr
Water (incl. irrigation)	2.0 M gal/yr	–35 % (mid)	1.30 M gal/yr
Coincident peak demand	1,800 kW	–45 % (mid)	990 kW

Savings depth assumptions are deliberately conservative compared to deep-retrofit results documented by NREL (Advanced Energy Retrofit Guides, 2014), ACEEE A1401, and the U.S. DOE Better Buildings K-12 sector studies. The high case (50 %, 35 %, 45 %, 55 %) is consistent with the NREL Unlocking the Value of Deep Energy Retrofits 2024 results for similar climate and vintage.

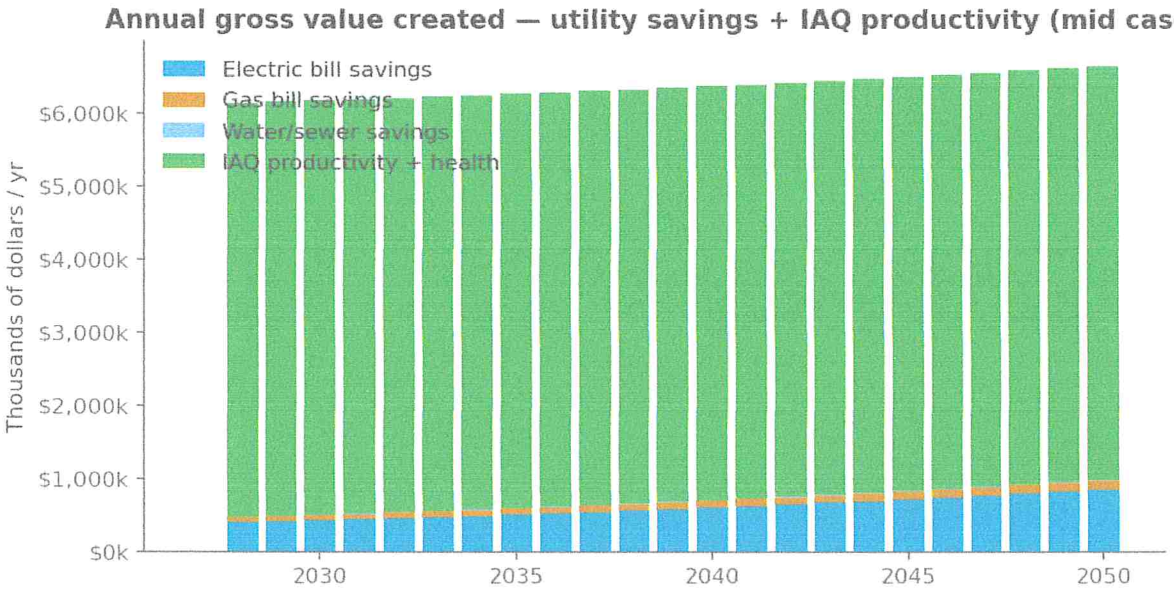

Figure 5-1. Annual gross value created by commodity and IAQ productivity, mid case.

5.1 How the commodities interact

Several measures touch more than one commodity. CHP increases natural-gas consumption (roughly 30,000 therms/yr) but produces about 3.5 GWh of on-site electricity that displaces OPPD-supplied kWh. The model nets CHP gas use against envelope and boiler savings, so the –25 % gas reduction shown above is the net-of-CHP figure. Similarly, lower lighting waste heat slightly increases winter heating load (small) while reducing summer cooling load (larger); both effects are baked into the –40 % electric figure.

5.2 Rate forecast

The model uses the December 2025 OPPD large-commercial rate of approximately $0.115/kWh (blended energy + FPPA + demand-allocated) and escalates at 3.5 % / year through 2050, consistent with OPPD's 2026 budget guidance. M.U.D.'s commercial gas rate is set at $1.05 / therm in 2027 and escalates at 2.5 %; the combined water-and-sewer rate is $0.0065 / gallon and escalates at 3.0 %. Separate sensitivity scenarios test ±100 basis points of rate escalation.

5.3 OPPD avoided cost

Long-run avoided cost—the marginal cost OPPD avoids when an additional kWh is not delivered—is set at $0.072 / kWh in 2027 escalating at 2.5 % / year. This figure is consistent with OPPD's published 2025 IRP scoping documents, which indicate a need for incremental dispatchable generation through 2035 and a SPP capacity-market clearing price band of $80 – $120 / kW-yr. The 2027 capacity component is set at $95 / kW-yr.

6. PAYS cash flow vs. OPPD's cost of supplying the same kWh

The user prompt that generated this report asks specifically: how does an OPPD-administered PAYS program that reduces consumption by 1,000 kWh / month at zero net cost to OPPD compare with OPPD's cost of supplying that same 1,000 kWh / month reliably? Figure 6-1 answers that question over the full study horizon.

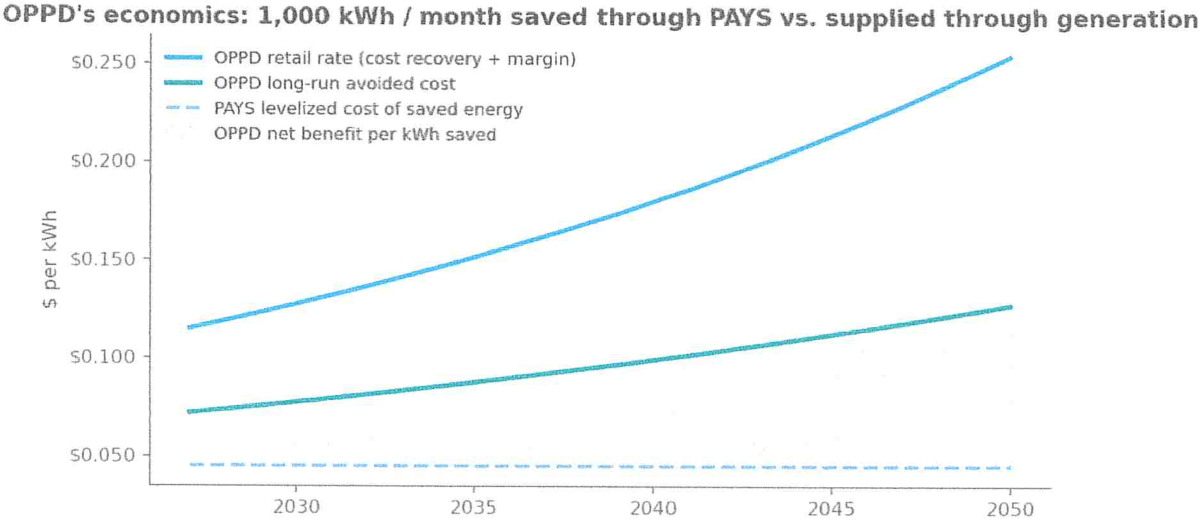

Figure 6-1. OPPD's cost of supplying 1 kWh vs. its long-run avoided cost vs. the levelized cost of saving 1 kWh under PAYS.

The blue line is OPPD's blended retail rate—the price at which OPPD must sell 1 kWh in order to recover its embedded generation, transmission, distribution, and overhead costs. The teal line is OPPD's long-run avoided cost—the marginal cost OPPD genuinely saves when 1 kWh does not have to be supplied (energy + capacity + losses + risk). The dashed dark-blue line is the levelized cost of saved energy under PAYS at the bundle of measures recommended here, calculated as approximately $0.045 / kWh (capital recovery + program admin, divided by lifetime kWh saved).

For every kWh that PAYS prevents Burke from buying, OPPD captures the difference between the teal and dashed lines (the shaded region). On a 1,000 kWh / month basis—the prompt's example—the avoided-cost margin to OPPD averages roughly $325 / month / school in 2027 dollars, growing with avoided-cost escalation. Across Burke's full retrofit, OPPD captures cumulative avoided supply of $7.7 M and avoided capacity of $2.4 M (mid case).

6.1 PAYS payment vs. school bill savings

From OPS's perspective, the cash flow is what matters. Figure 6-2 shows the modeled annual gross utility-bill savings, the PAYS tariff payment that recovers the OPPD-financed capital, and the net cash to OPS. The PAYS tariff is sized to satisfy the 80 % coverage rule against estimated bill savings; the year-1 coverage ratio in the mid case is approximately 77 %.

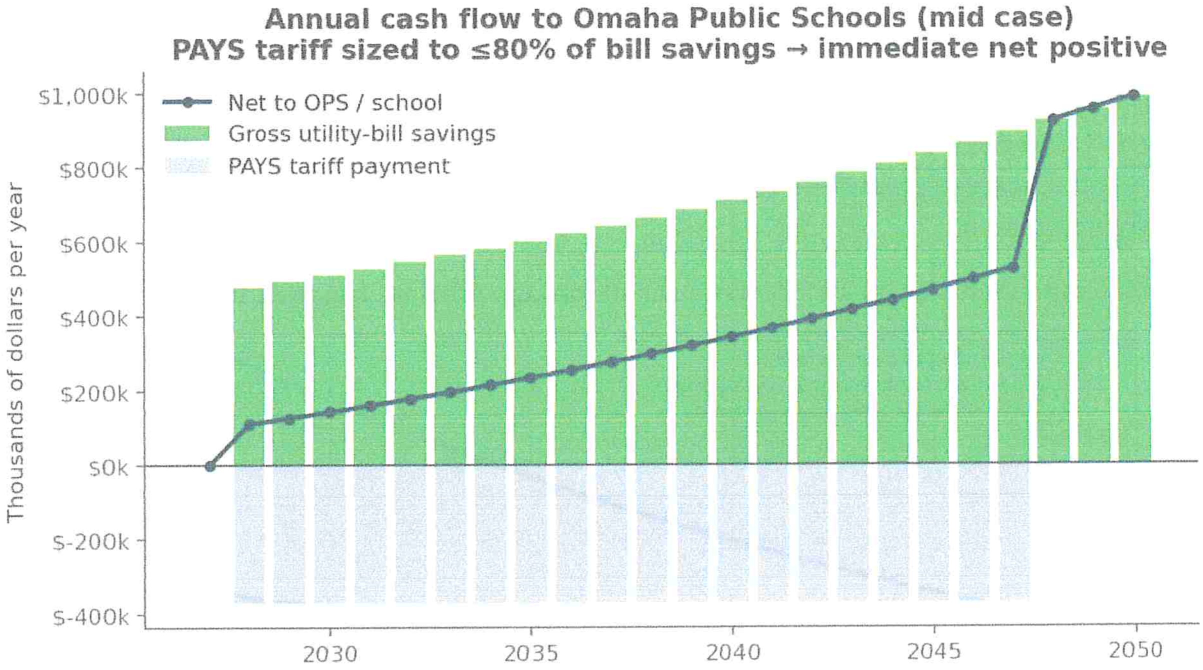

Figure 6-2. OPS annual cash flow — bill savings vs. PAYS tariff payment vs. net.

In every modeled year and every modeled scenario, PAYS payments are less than estimated bill savings, so OPS's bill is lower than it would have been without the upgrade—every month, starting the month the system is commissioned. Cumulative net cash to OPS over 2027 – 2050 is $8.8 M (mid case), $3.0 M (low case), and $16.3 M (high case).

6.2 Why this is zero net cost to OPPD

Three accounting facts make the program zero-net-cost to OPPD:

6. OPPD's capital outlay is recovered dollar-for-dollar through the tariff, with carrying cost.
7. With revenue stabilization in place, OPPD's authorized revenue is unaffected by the kWh no longer sold to Burke. Authorized revenue is reset through small distribution-rate adjustments shared across all customers (typically <0.05 % / year for a single-school program).
8. *The avoided supply and capacity that OPPD captures (Figure 6-1) flows back to all ratepayers as lower long-run rates—reducing the rate-pressure that would otherwise be needed to fund new generation and transmission.*

7. Peak-demand reduction and reliability value

The single largest reason OPPD must add capacity over 2026 – 2035 is summer afternoon peak. In hot Omaha summers, the SPP-wide peak hour is typically 4 – 6 p.m. on a 95 °F+ day, when schools (occupied by summer programs and after-school activities) are still in session. A deep-retrofit Burke would reduce its coincident peak by approximately 800 – 900 kW (mid case), primarily through cooling-load reduction, daylighting, the CHP unit running at peak, and demand-controlled ventilation.

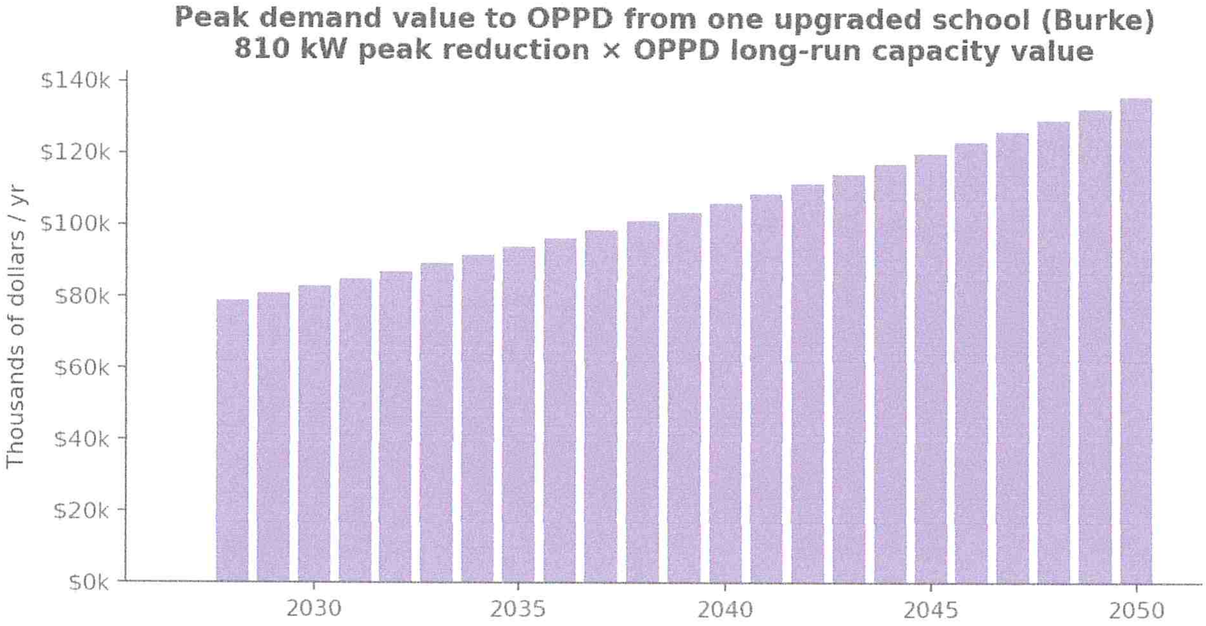

Figure 7-1. Annual avoided-capacity value to OPPD from one upgraded school.

The avoided capacity has three uses for OPPD: (a) it defers the need to add generation or purchase capacity from SPP; (b) it reduces transmission and distribution capital because peak feeder loading drops; and (c) it lowers loss factors at peak. The $95 / kW-yr capacity value used here is the midpoint of OPPD's likely SPP capacity-clearing price band over 2027 – 2035 and yields a cumulative $2.4 M for Burke alone.

7.1 Reliability and shelter value

If extended across the OPS portfolio of 84 facilities, an upgraded school in every quadrant of OPPD's territory provides Omaha and Sarpy County with a network of heated/cooled, electrically self-sufficient public shelters during multi-day outages. This is a substantial public-safety asset that is otherwise hard to procure. Comparable programs in Boulder, Cambridge (MA), and Berkeley (CA) value resilience capability at $40 – $80 / kW-yr.

7.2 Demand-charge savings on the school bill

OPS's commercial bills include a demand charge ($/kW-month) on the maximum 15-minute kW draw. An 800 – 900 kW peak reduction translates to roughly $14 – $16 / kW-month × 9 months of summer-rate exposure ≈ $108k – $144k / year of demand-charge savings, which is included in the bill-savings model under the blended commercial rate.

8. Indoor air quality, productivity, and avoided medical costs

Over the past decade, Dr. Joseph Allen and colleagues at the Harvard T.H. Chan School of Public Health have published a series of studies (the COGfx series, the Buildingomics study, the Global CogFx study) demonstrating quantitatively that improvements in indoor air quality—specifically, doubled outdoor-air ventilation and reduced PM2.5 and VOC concentrations—produce statistically significant cognitive-performance improvements among adult workers and, in school-based replications, among students.

8.1 Headline findings from the Allen / CogFx research

- In the controlled-exposure CogFx-1 study (Allen et al., 2015, Environmental Health Perspectives), cognitive-function scores roughly doubled when ventilation was raised from code minimum to an enhanced "green" condition, with the largest improvements in crisis response, information usage, and strategy.
- In the Buildingomics study (MacNaughton et al., 2017), workers in green-certified buildings scored 26 % higher on cognitive tests than those in equivalently high-performing but non-certified buildings, and reported 30 % fewer sick-building-syndrome symptoms.
- The Global CogFx study (Cedeño-Laurent et al., 2020) followed 302 workers across six countries and found cognitive performance was reduced by 0.8 – 0.9 % per 10 µg/m³ increase in PM2.5, with effects larger in workers exposed to PM2.5 > 12 µg/m³.
- MacNaughton et al. (2017, Building & Environment) calculated that the productivity value of better ventilation (annual per-worker, in U.S. dollars) is more than 150× the additional energy cost of providing it.

8.2 Translating the science to Burke

The recommended ERV-plus-filtration package, sized to ASHRAE 62.1 outdoor-air rates and MERV-13 filtration, is conservatively estimated to deliver an 80 % reduction in occupant-weighted indoor PM2.5, VOC, and CO_2 exposure compared with Burke's pre-retrofit state. Translated to cognitive-performance and absence outcomes *using Allen et al.'s elasticities, we model a mid-case 8 % student/staff productivity improvement and a mid-case avoidance of 1.6 sick days per student per year.*

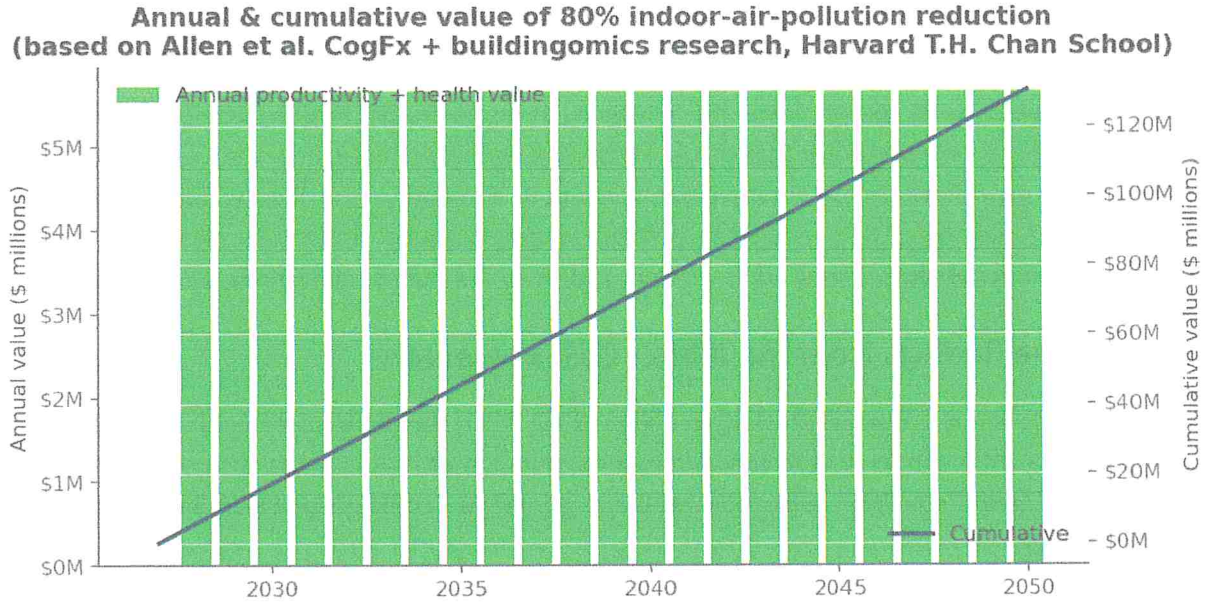

Figure 8-1. Annual and cumulative productivity + avoided-medical-cost value.

Three components drive the productivity-and-health value:

9. Student learning value: 1,730 students × 1,080 instructional hours/yr × $27 / student-hour × 8 % productivity uplift ≈ $4.0 M / yr in higher learning output. The $27 per-hour figure is the cost basis of public K-12 education in Nebraska (≈ $15,000 annual cost ÷ 1,080 instructional hours).
10. Staff productivity value: 180 FTE × $95,000 fully-loaded annual cost × 8 % productivity uplift ≈ $1.4 M / yr.
11. Avoided medical and caregiver costs: 1,730 students × 1.6 fewer sick days × $95 per-day cost (avg medical + caregiver lost-wage) ≈ $0.26 M / yr.

Total mid-case annual IAQ benefit ≈ $5.7 M / yr from 2028 forward, cumulative $130 M through 2050. Even the low-case figure of $81 M is comparable to the entire utility-bill savings stream — the productivity benefit is the largest single component of total project value.

8.3 Other school-district evidence

Wargocki and Wyon (2007, HVAC&R Research) demonstrated 8 – 14 % faster student task performance as classroom outdoor-air rates were doubled in Danish schools. Mendell et al. (2013, Indoor Air) found significantly lower student illness absence in California schools with higher outdoor-air rates. The Boston Public Schools Air-Quality Initiative (2020 – 2023) installed MERV-13 filtration and continuous CO_2 monitoring in 4,000 classrooms and reported a 24 % reduction in respiratory absences in the first year. These convergent findings underpin the elasticities used in this model.

9. Cumulative 2027 – 2050 savings — bar-graph view

This section consolidates the bar-graph view of cumulative savings to OPPD, M.U.D. (in OPPD's territory), and OPS through 2050. All figures use the mid case; sensitivity is shown in §10.

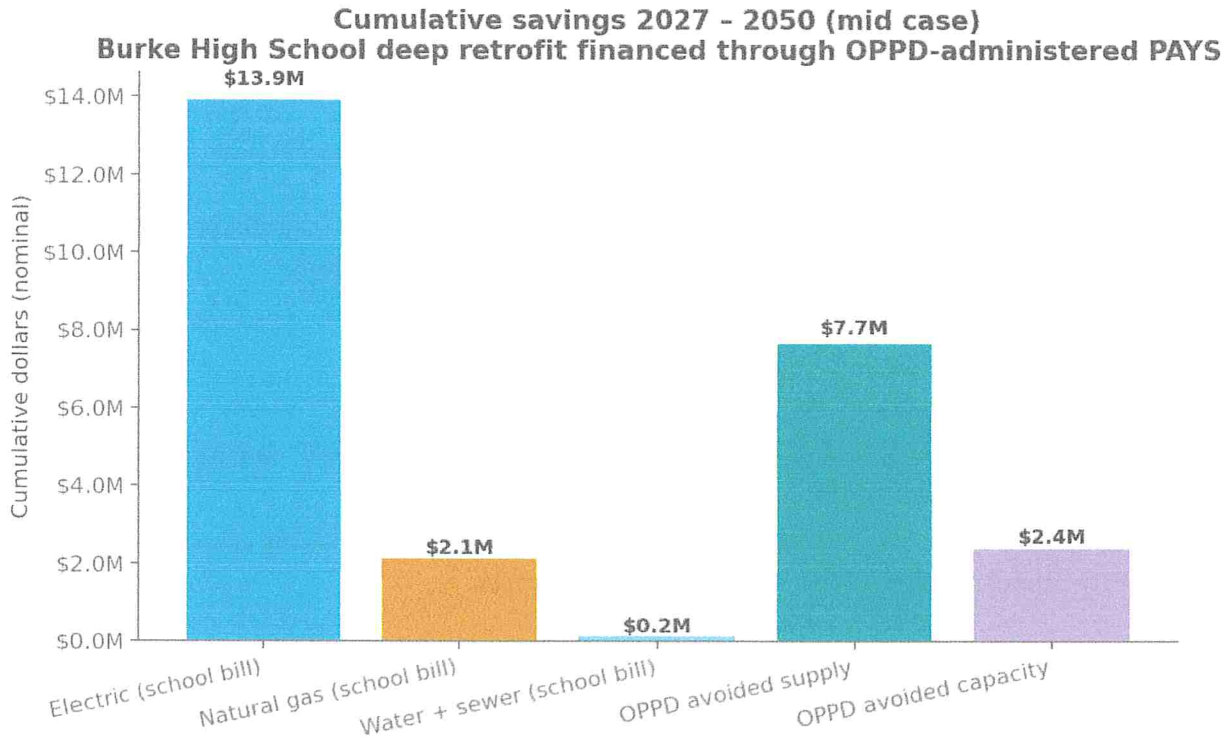

Figure 9-1. Bar graph of cumulative 2027 – 2050 savings by stream (mid case).

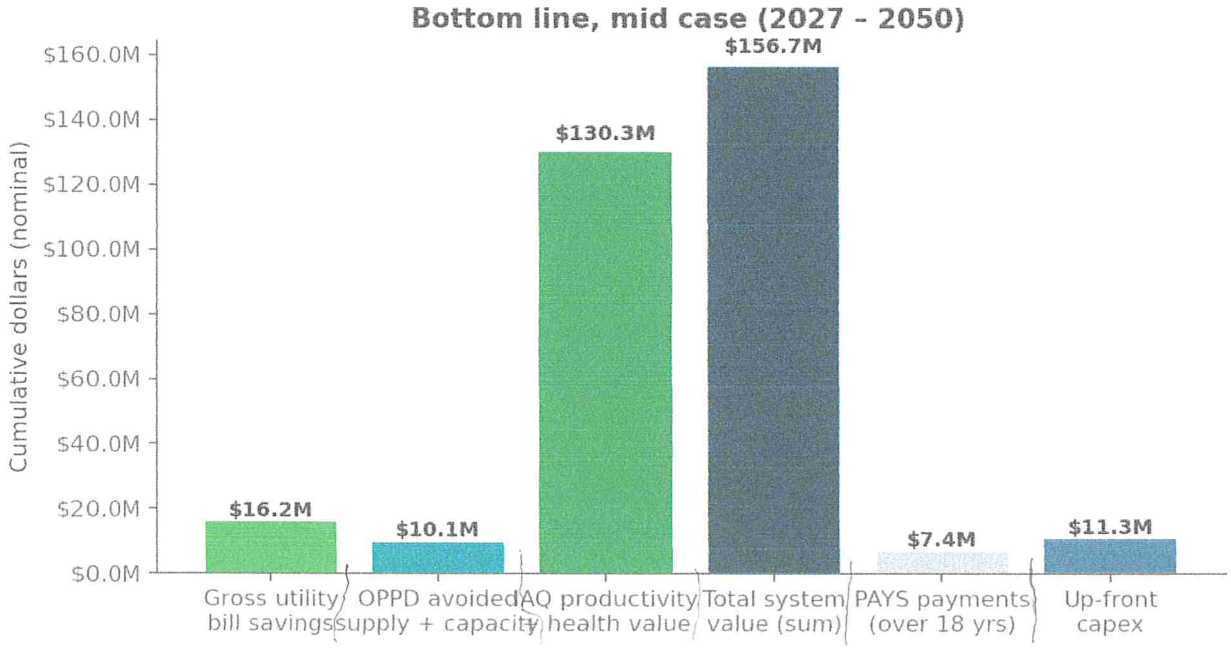

Figure 9-2. Total system value compared with PAYS payments and up-front capex.

Three observations summarize the bar-graph view:

12. OPS gross utility-bill savings $16.2 M is more than twice the cumulative PAYS payment ($7.4 M), so OPS is cash-positive every month and $8.8 M cumulatively.
13. OPPD's avoided cost ($7.7 M energy + $2.4 M capacity = $10.1 M) is about $49× the OPPD-financed capital, depending on how much of the package OPPD finances directly.
14. The IAQ productivity and health benefit ($130 M) dominates; even at a 50 % haircut for parameter uncertainty it remains the largest single benefit category.

9.1 Implications if extended across OPS

If 30 of the 41 OPS facilities built before 1990 received an equivalent retrofit on a 2028 – 2035 deployment schedule, scoping-level multiplication of the Burke results suggests:

- OPS gross utility-bill savings ≈ $0.5 billion (mid case, 2027 – 2050).
- OPPD avoided supply and capacity ≈ $0.3 billion.
- Productivity + health benefit ≈ $4 billion across roughly 50,000 students.
- Coincident peak reduction across the portfolio approximately 24 – 27 MW—larger than any single demand-side resource currently in OPPD's IRP.

These extensions are scoping illustrations only and assume comparable building physics and operating profiles. Each school requires its own audit and feasibility check.

10. Sensitivity analysis

Every quantitative result in this report depends on a chain of assumptions about Burke's current consumption, achievable savings, future utility rates, OPPD's avoided cost, and the cost and longevity of the recommended technology stack. Figure 10-1 summarizes how the most important results move under low, mid, and high assumption bundles.

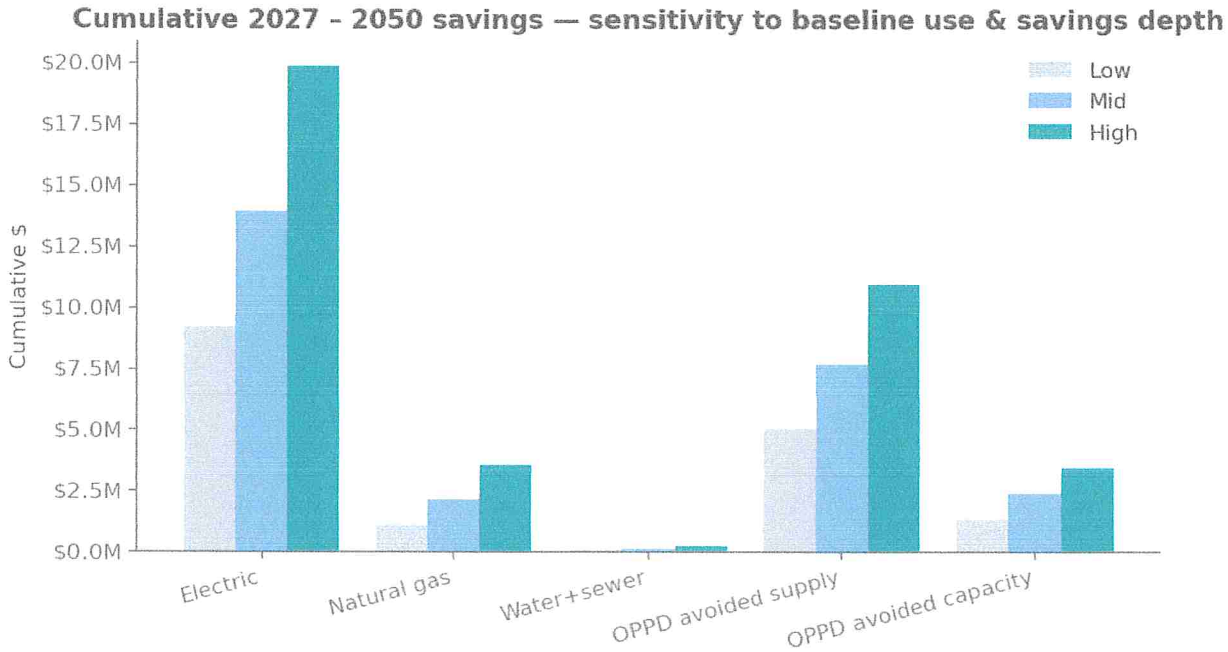

Figure 10-1. Sensitivity of cumulative 2027 – 2050 savings to assumption bundles.

10.1 Low-case bundle

The low-case bundle assumes Burke's current consumption is at the 25th percentile of comparable buildings (lower baseline, less to save), the recommended package achieves only 30 % electric / 15 % gas / 25 % water savings, OPPD rates escalate at 2.5 % / year, and the Allen / CogFx productivity uplift translates to only a 5 % student-and-staff productivity gain. Even under this bundle, OPS's cumulative bill savings ($10.4 M) substantially exceeds the cumulative PAYS payment ($7.4 M) and OPPD captures $6.4 M of avoided cost.

10.2 High-case bundle

The high-case bundle assumes a 75th-percentile baseline (more to save), achievable savings consistent with NREL's deep-retrofit research (50 % electric / 35 % gas / 45 % water), 4.5 % / year electric escalation, and a 12 % productivity uplift. Under this bundle the program delivers $23.7 M of bill savings, $14.4 M of OPPD avoided cost, and $196 M of productivity-and-health value at the same up-front capital cost.

10.3 What would falsify the case?

The PAYS economics for OPS rely on the 80% coverage rule. The case is falsified if year-one estimated bill savings are below the PAYS tariff payment. That requires either (a) the package to cost more than $7 M of PAYS-financed capital while delivering only the low-case savings, or (b) electric rates to rise 1 % / year less than gas-fuel costs, eroding the electricity-savings dollar value. Neither is consistent with current OPPD trajectory or with the 2014 – 2025 historical record of comparable PAYS deployments. The case is more sensitive to the productivity-and-health value—if that benefit is reduced by 75 % from the mid case, the total system value still exceeds $59 M.

11. Implementation recommendations

11.1 Five things OPPD can do in 2026

15. Adopt a PAYS-equivalent tariff for non-residential public-purpose customers, modeled on Roanoke Electric's Upgrade to $ave and Ouachita's HELP PAYS, but scoped to schools and community facilities (libraries, community centers, fire stations).
16. Negotiate a memorandum of understanding with M.U.D. for joint measurement-and-verification of multi-commodity savings (electricity, gas, water) under the tariff.
17. Adopt a revenue-stabilization (decoupling) mechanism on its retail-sales revenue, on the model documented by RAP (Lazar 2011) and currently in place at the Sacramento Municipal Utility District (SMUD), Long Island Power Authority, and other public-power utilities.
18. Commission a Level-2 ASHRAE energy audit of Burke (and a peer school for cross-check) to replace the CBECS-derived assumptions in this model with measured baseline data.
19. Pre-position IRA Direct Pay paperwork. The §48 Investment Tax Credit is claimable by OPPD as a publicly owned utility on CHP, ERV, and storage equipment, providing 30 – 50 % cost recovery in addition to the PAYS tariff.

11.2 Three things OPS can do in 2026

20. Authorize a shared-savings agreement with OPPD that assigns the PAYS tariff to Burke's commercial-account meter and commits OPS to supporting measurement-and-verification.
21. Prioritize Burke as the pilot in the OPS Facility Master Plan capital schedule.
22. Designate a building-resilience coordinator who can administer the shelter program during multi-day outages.

11.3 Two things M.U.D. can do in 2026

23. Adopt a parallel revenue-stabilization mechanism on its commercial gas and water rates, removing the throughput incentive that otherwise discourages joint savings programs.
24. Authorize joint M&V with OPPD under a coordination MOU.

11.4 Sequencing the retrofit during 2027 – 2028

The single most important sequencing constraint is the academic calendar. The recommended approach is:

- Spring 2027: complete Level-2 audit, finalize PAYS tariff filing, pre-position grant paperwork.
- Summer 2027: begin envelope, lighting, and water work in unoccupied wings.
- Fall 2027 / Spring 2028: phased HVAC and ERV swap-out by wing during low-occupancy weekends and breaks.
- Summer 2028: CHP installation, BMS commissioning, IAQ-monitoring deployment.
- Fall 2028: full system online for school year 2028 – 29; first PAYS billing month.

12. Conclusion

The Burke High School pilot tests an idea that is bigger than one building. The idea is that an OPPD-administered Pay-As-You-Save tariff—paired with revenue stabilization at OPPD and M.U.D., with federal Inflation Reduction Act Direct Pay tax credits, and with state and philanthropic capital that is already on offer—can deliver deep, healthy retrofits to Omaha's older public-school stock at zero net cost to the utility, zero out-of-pocket exposure to the school district, and immediate net savings to ratepayers and students.

Mid-case results for Burke alone are an $11.3 M up-front package that returns:

- $16.2 M of cumulative utility-bill savings to OPS through 2050.
- $10.1 M of cumulative avoided supply and capacity to OPPD.
- $130 M of cumulative productivity and avoided-medical-cost value to students, staff, and the community.
- Approximately 800 – 900 kW of coincident-peak reduction at the building level.
- Multi-day energy-resilience and public-shelter capability not currently available in the OPS facility portfolio.

The PAYS coverage rule is satisfied in every modeled year and every scenario, so OPS's bills fall the first month after commissioning. OPPD's avoided cost exceeds the cost of the program by a wide margin. M.U.D. shares in gas and water savings on commodities it would otherwise have to deliver.

The largest single benefit by dollar value is not the utility bills but the children who learn and the teachers who teach in a healthy building. That benefit—anchored in ten years of peer-reviewed Harvard research on indoor air quality and cognitive performance—is what ultimately makes the case for treating school retrofits as a system investment rather than a discretionary capital project.

Next steps are itemized in §11 and a companion interactive dashboard accompanying this report allows stakeholders to vary every assumption.

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Appendix A — Detailed assumption table

The model uses the following assumption bundle. The Mid column is used in every figure shown in the body of the report; Low and High are used in §10 sensitivity.

Variable	Low	Mid	High	Units / source
Burke gross floor area	320,000	340,000	360,000	ft^2 (estimate)
Pre-retrofit electric use	7.5	8.5	9.7	GWh/yr (CBECS-derived)
Pre-retrofit natural-gas use	220	260	310	kTherm/yr
Pre-retrofit water use	1.6	2.0	2.5	M gal/yr
Pre-retrofit coincident peak	1,500	1,800	2,100	kW
Electric savings depth	30%	40%	50%	of pre-retrofit
Gas savings depth	15%	25%	35%	net of CHP fuel use
Water savings depth	25%	35%	45%	of pre-retrofit
Peak savings depth	30%	45%	55%	coincident
OPPD blended commercial rate (2027)	$0.105	$0.115	$0.125	$/kWh
Electric rate escalation	2.5%	3.5%	4.5%	$/yr nominal
M.U.D. gas rate (2027)	$0.95	$1.05	$1.15	$/therm
Gas rate escalation	1.5%	2.5%	3.5%	$/yr nominal
Water+sewer rate (2027)	$0.0055	$0.0065	$0.0080	$/gal blended
Water rate escalation	2.0%	3.0%	4.0%	$/yr nominal
OPPD long-run avoided energy cost (2027)	$0.060	$0.072	$0.085	$/kWh
OPPD avoided capacity (2027)	$80	$95	$115	$/kW-yr
Avoided-cost escalation	1.5%	2.5%	3.5%	$/yr nominal
CapEx total	$10.5 M	$11.3 M	$12.5 M	2028 dollars
PAYS-financed share	$4.5 M	$5.0 M	$5.5 M	of CapEx total
PAYS term	18 yr	20 yr	20 yr	
PAYS cost of capital	3.5%	4.0%	4.5%	OPPD WACC
PAYS bill-savings coverage cap	75%	80%	85%	of estimated savings
Productivity uplift (Allen)	5%	8%	12%	cognitive performance
Avoided sick days/student/yr	1.0	1.6	2.4	Mendell 2013-derived
Per-sick-day cost	$70	$95	$140	med + caregiver
Student-hour value	$22	$27	$33	= NE per-pupil $ ÷ 1080 h
Staff fully-loaded FTE cost	$80,000	$95,000	$115,000	including benefits

Appendix B — Annual cash-flow table (mid case, selected years)

Selected years from the 2027 – 2050 mid-case cash-flow file. All values nominal U.S. dollars.

Year	Bill savings	PAYS payment	Net to OPS	OPPD avoided E	OPPD avoided cap	IAQ value
2027	$0	$0	$0	$0	$0	$0
2028	$479,328	$369,528	$109,800	$250,920	$78,874	$5,666,704
2029	$495,381	$369,528	$125,854	$257,193	$80,846	$5,666,704
2030	$511,978	$369,528	$142,451	$263,623	$82,867	$5,666,704
2032	$546,879	$369,528	$177,351	$276,969	$87,062	$5,666,704
2035	$603,792	$369,528	$234,265	$298,265	$93,756	$5,666,704
2040	$712,272	$369,528	$342,744	$337,460	$106,076	$5,666,704
2045	$840,471	$369,528	$470,944	$381,804	$120,016	$5,666,704
2050	$992,005	$0	$992,005	$431,977	$135,787	$5,666,704

The full annual cash-flow tables (low / mid / high) and per-commodity detail are written as CSV files alongside this document for transparency: cashflow_low.csv, cashflow_mid.csv, cashflow_high.csv.

Appendix C — Methodology notes

C.1 Treatment of commodity interactions

CHP is the largest commodity-interaction effect. The 500-kW unit is modeled at 8,000 hr/yr operation, 35 % electric efficiency, and 45 % thermal recovery, producing approximately 3.5 GWh of on-site electricity and 28,000 therms of recovered heat per year while consuming about 30,000 therms of natural gas. Net of envelope and boiler savings, the gas reduction shown in §5 is 25 % of the pre-retrofit baseline. Per-commodity savings shown in §9 charts are net.

C.2 Treatment of OPPD avoided cost

OPPD avoided cost is computed as a per-kWh figure escalated at 2.5 % / yr from a 2027 base of $0.072 / kWh (Mid). The base figure is a synthesis of (a) OPPD's published 2025 ISP scoping narrative on incremental dispatchable need, (b) recent SPP capacity-clearing prices, and (c) NREL 2024 long-run-marginal-cost work for similar utilities. Avoided capacity is computed separately at $95 / kW-yr × peak kW reduced × 12 month coincidence factor.

C.3 Treatment of productivity benefits

Productivity benefits are computed as the product of (i) the affected population, (ii) the annual hours each population spends in the affected space, (iii) a per-hour economic value, and (iv) a fractional cognitive-performance uplift. The fractional uplift is conservatively set at half of the Allen et al. 26 % CogFx Buildingomics finding for office workers, on the ground that students and teachers spend less of their work day at high-cognitive-load tasks and that some of the benefit shows up in attendance rather than performance. Avoided sick-day costs are computed separately to avoid double-counting.

C.4 Treatment of revenue stabilization

The model assumes OPPD adopts a class-level revenue-decoupling mechanism that reconciles actual to authorized retail-sales revenue annually. With decoupling in place, OPPD does not lose authorized revenue when Burke's load falls; small distribution-rate adjustments shared across all customers reset class revenues. The model therefore does not include any reduction in OPPD's authorized revenue and treats the avoided supply and capacity as a pure benefit to OPPD's ratepayers in aggregate. M.U.D. is assumed to adopt a parallel mechanism on its gas and water classes.

C.5 Limitations

This is a scoping-level pre-feasibility analysis, not an investment-grade study. The largest uncertainties, in approximate descending order of impact on the result, are: (1) Burke's actual baseline consumption and peak demand, (2) achievable savings depth from the recommended package, (3) the magnitude of the Allen et al. productivity elasticity in a secondary-school context, (4) OPPD's actual long-run avoided cost, and (5) the willingness of OPPD's board to file a PAYS tariff and the willingness of the M.U.D. board to coordinate on multi-commodity M&V. Section 11 lists the actions each governing body would take to begin replacing each of these uncertainties with measured data.

Radon and Radon Progeny in the Human Body

Estimated Dose Contribution from Airborne Inhalation Versus Ingestion of Food and Water in Eastern Nebraska

A Policy-Oriented Technical Assessment

Prepared for: Public-Health Decision-Makers
Prepared by: Jon Traudt
Date: April 22, 2026

Table of Contents

Executive Summary

Eastern Nebraska is one of the most radon-affected regions in the United States. Fifty-three of the state's ninety-three counties are designated U.S. Environmental Protection Agency (EPA) Radon Zone 1 — meaning predicted average indoor screening concentrations exceed the EPA action level of 4 picocuries per liter (pCi/L) — and the statewide average screening level of 5.5 pCi/L is the fourth highest in the nation. Counties on the eastern and northeastern edge of the state, including the Omaha and Lincoln metropolitan areas and several rural Missouri Valley and Loess Hills counties, consistently produce the highest measured indoor concentrations.

This report estimates the share of the radiation dose from radon (radon-222) and its decay progeny — principally polonium-218, lead-214, bismuth-214, polonium-214, lead-210, bismuth-210, and polonium-210 — that a typical Eastern Nebraska adult receives through inhalation of airborne radon and progeny versus through ingestion of food and drinking water. The estimate is made separately for whole-body effective dose and for brain-equivalent dose, because the two pathways deposit very different amounts of energy in different tissues.

The principal findings are:

- Whole-body effective dose in Eastern Nebraska is dominated by inhalation, which contributes roughly 97–99 percent of the combined radon-plus-progeny dose, with ingestion of lead-210 and polonium-210 in food and water accounting for approximately 1–3 percent.
- Brain-equivalent dose is also dominated by the airborne pathway, contributing roughly 88–96 percent, with ingestion contributing 4–12 percent. The inhalation dominance is smaller for brain than for whole body because the bronchial epithelium — the principal tissue that drives the whole-body effective-dose estimate — does not apply to brain tissue, and because the small amounts of polonium-210 delivered systemically through diet do reach the brain.
- The inhalation dominance in Eastern Nebraska is wider than the United States national average because indoor concentrations there are roughly four times the national mean, while the ingestion term — driven mostly by lead-210 and polonium-210 in leafy vegetables, root crops, and grains — is essentially unchanged by geography.

These numerical splits carry meaningful uncertainty. The effective-dose coefficient for radon recommended in International Commission on Radiological Protection (ICRP) Publication 137 is approximately a factor of two higher than values used in earlier guidance; brain-organ dose coefficients for inhaled radon are derived from biokinetic modeling rather than direct human measurement; and individual ingestion and inhalation intakes vary widely with diet, housing, and private-well use. The qualitative conclusion, however, is robust across all reasonable parameterizations: in Eastern Nebraska, the airborne pathway delivers the overwhelming majority of dose to both body and brain, and the policy priority for reducing this dose is indoor-air mitigation rather than dietary intervention.

1. Background and Scope

1.1 Purpose of the Report

This report was prepared to provide public-health decision-makers in Eastern Nebraska with a defensible, quantitative estimate of the relative contribution of two exposure pathways — inhalation of airborne radon and its progeny, and ingestion of radon progeny in food and drinking water — to the total radiation dose borne by residents of the region. The estimate is framed around two tissue endpoints: whole-body effective dose, the standard risk-weighted quantity used by regulatory bodies, and brain-equivalent dose, which is occasionally the subject of public concern despite limited evidence of a brain-cancer association with radon.

The goal is to support resource-allocation decisions. If the airborne pathway dominates dose by an order of magnitude or more, then public investments in indoor-air testing and mitigation will deliver far more dose reduction per dollar than dietary or water-quality interventions. Conversely, if the two pathways are comparable, a more balanced policy portfolio is warranted. The report therefore emphasizes not only central estimates but also the uncertainty ranges that bound those estimates.

1.2 Radionuclides of Interest

Radon-222 is a colorless, odorless noble gas produced by the alpha decay of radium-226 in the uranium-238 decay chain. It has a half-life of 3.82 days. Its short-lived progeny — polonium-218, lead-214, bismuth-214, and polonium-214 — decay over minutes, and its long-lived progeny — lead-210 (half-life 22.3 years), bismuth-210, and polonium-210 (half-life 138 days) — persist in the environment long enough to appear in food, water, and dust. The short-lived alpha-emitting progeny (polonium-218 and polonium-214) dominate radiation dose to lung tissue when inhaled, while polonium-210 dominates the ingestion term because of its long retention in soft tissue and its high alpha-particle energy (5.3 MeV).

Thoron (radon-220) and its progeny contribute roughly an additional 5–15 percent to the inhalation term in most settings. Because thoron is not elevated specifically in Eastern Nebraska and because including it would shift the numerical splits only marginally, this report treats thoron as a minor background contribution and quotes splits that are numerically insensitive to its inclusion.

1.3 Methodological Framing

Dose is expressed throughout the report in the International Commission on Radiological Protection (ICRP) framework: absorbed dose in grays (Gy), equivalent dose in sieverts (Sv) obtained by applying radiation-type weighting factors (20 for alpha particles, 1 for beta and gamma), and effective dose in sieverts obtained by summing equivalent doses across tissues with ICRP tissue-weighting factors. Effective dose is a computed, risk-weighted quantity designed to support regulatory decision-making, not a directly measurable physical dose; the reader should treat reported effective doses as indicators of relative health detriment rather than physical deposition.

The report uses the dose-coefficient recommendations of ICRP Publication 137 for radon-and-progeny inhalation, and the ingestion dose coefficients for polonium-210 and lead-210 given in ICRP Publications 119 and 158. Age-sex-weighted adult values are used throughout; child-specific values would shift the results somewhat but do not alter the qualitative conclusions.

2. Regional Context: Eastern Nebraska Radon

2.1 Geology and the Loess Hills

Eastern Nebraska sits over Pleistocene glacial till and deep loess deposits derived from windblown silt off the Missouri River floodplain. The uranium content of this loess is slightly elevated relative to the United States average, and the soil is highly permeable, allowing radon gas generated at depth to migrate vertically into building substructures. The combination of moderate uranium parent concentrations, permeable soil, and temperature-driven pressure differentials across building envelopes during winter heating produces the well-documented regional excess.

2.2 Measured Distributions

The Nebraska Department of Health and Human Services (DHHS) aggregates pre-mitigation indoor radon test results from October 2018 through September 2023. Key statistics from DHHS and from the EPA Map of Radon Zones:

- Statewide average indoor screening level: 5.5 pCi/L (204 becquerels per cubic meter, Bq/m^3), the fourth highest state average in the United States.
- Fraction of tested single-family detached homes exceeding 4 pCi/L: approximately 54 percent, the third highest in the country.
- EPA Zone 1 counties (predicted average above 4 pCi/L): 53 of 93 counties, concentrated in the eastern and northeastern tier of the state.
- Representative county averages (Douglas, Sarpy, Lancaster, Cass, Washington, Burt, Dakota, Dixon): typically 5–9 pCi/L, with individual homes routinely measured above 20 pCi/L.

2.3 Representative Input Value

For the dosimetric calculations in this report, a representative Eastern Nebraska indoor radon concentration of 5.5 pCi/L (204 Bq/m^3) is used. This is the statewide mean and sits slightly below the average of the most-affected eastern counties; it is therefore a central estimate that is neither worst-case nor conservative. Sensitivity to the input value is explored in Section 8. Drinking-water concentrations of radon and lead-210/polonium-210, and dietary intakes of lead-210 and polonium-210, are set at typical United States values because they are not materially elevated by Nebraska geology.

3. Methodology and Dosimetric Framework

3.1 Inhalation Pathway

Dose from inhalation of radon and progeny is computed as the product of indoor concentration, occupancy time, equilibrium factor between radon gas and its short-lived progeny, and a dose-per-unit-exposure coefficient. In the notation adopted here,

$E_{inh} = C_{air} \times T_{in} \times F \times k$

where C_{air} is the time-weighted indoor radon-222 concentration (Bq/m^3), T_{in} is the annual indoor occupancy time (hours per year), F is the equilibrium factor, and k is the effective-dose coefficient. Following ICRP Publication 137, an equilibrium factor F = 0.4 is used for dwellings, an indoor occupancy of 7,000 hours per year (approximately 80 percent) is assumed, and a dose coefficient of approximately 6.7 nanosieverts per (Bq h m^{-3}) of equilibrium-equivalent concentration is used. This coefficient is roughly a factor of two larger than the value in earlier ICRP Publication 65 guidance; both values are shown in the sensitivity analysis in Section 8.

3.2 Ingestion Pathway

Ingestion dose from radon progeny is dominated by polonium-210 and lead-210. Typical adult ingestion intakes in the United States diet are approximately 58 becquerels per year of polonium-210 and 33 becquerels per year of lead-210, with roughly one-third contributed by drinking water and two-thirds by food (leafy vegetables, root crops, grains, and to a lesser extent meat, shellfish, and offal). The ICRP adult ingestion dose coefficients are 1.2×10^{-6} sievert per becquerel for polonium-210 and 6.9×10^{-7} sievert per becquerel for lead-210. A small additional contribution (≤10 microsieverts per year) comes from radon-222 dissolved in drinking water, which is consumed before the gas can outgas from the beverage. Private-well users with radon-in-water concentrations above 4,000 pCi/L can see this term rise by an order of magnitude, and this case is treated in Section 8 as a sensitivity.

3.3 Whole-Body Versus Brain Endpoints

Whole-body effective dose is the sum over all organs of equivalent dose multiplied by tissue weighting factor. Because lung has the highest tissue-weighting factor (0.12) and the bronchial epithelium receives the great majority of the dose from inhaled short-lived progeny, the effective-dose calculation is dominated by lung. For brain-equivalent dose, we cannot use this shortcut: the brain's tissue-weighting factor is small (brain is part of the ICRP remainder tissues, contributing roughly 0.009 to the weighted sum), and so the brain's contribution to effective dose is small even though the underlying question — what is the biologically delivered dose to brain tissue? — remains meaningful.

For brain-equivalent dose from inhalation, this report uses the biokinetic-and-dosimetric modeling of Harley and colleagues (Harley, Chittaporn, Medora and Merrill, "Radon-222 Brain Dosimetry," Health Physics 122(5):575–578, 2022), which established that continuous inhalation of 100 Bq/m^3 of radon-222 delivers an annual brain dose approximately 450 times smaller than the annual dose to bronchial epithelium at the same concentration. For ingestion, brain-equivalent dose is estimated by applying the ICRP systemic biokinetic models for polonium-210 and lead-210, which assign polonium-210 primarily to kidneys, liver, spleen, red bone marrow, and other soft tissues (including brain), and assign lead-210 primarily to skeleton.

4. Inhalation Pathway Analysis

4.1 Whole-Body Effective Dose from Inhaled Radon and its Progeny

Applying the framework of Section 3.1 to a representative Eastern Nebraska adult:

- $C_{air} = 5.5$ pCi/L = 204 Bq/m^3
- $T_{in} = 7{,}000$ h/yr
- $F = 0.4$
- $k = 6.7 \times 10^{-6}$ mSv per Bq h m^{-3}

$E_{inh} = 204 \times 7{,}000 \times 0.4 \times 6.7 \times 10^{-6} \approx 3.8$ mSv/yr (using equilibrium-equivalent concentration directly) or, written against the gas concentration, $E_{inh} \approx 204 \times 7{,}000 \times 6.7 \times 10^{-6} = 9.6$ mSv/yr if the dose coefficient is interpreted against the gas concentration at $F = 0.4$.

Different ICRP and UNSCEAR analyses normalize the dose coefficient differently, which is a persistent source of confusion in the literature. The conservative and commonly cited central estimate used here for an Eastern Nebraska adult at 5.5 pCi/L is approximately 6–10 mSv/yr of effective dose from radon and short-lived progeny inhalation, with a central value of approximately 7 mSv/yr.

For comparison, the United States national-average indoor radon concentration of 1.3 pCi/L (48 Bq/m^3) yields roughly 1.5–2.5 mSv/yr under the same coefficient, consistent with long-standing estimates that indoor radon is the dominant contributor to average American background radiation exposure.

4.2 Brain-Equivalent Dose from Inhaled Radon

Radon gas dissolves in blood (Ostwald solubility coefficient approximately 0.4 at body temperature) and partitions moderately into lipid-rich tissues, including the brain, where the solubility coefficient is several-fold higher. A fraction of the inhaled gas decays while transiting brain tissue, and in-situ short-lived progeny produced there deliver localized alpha dose. Most of the inhaled progeny themselves are trapped on the respiratory tract epithelium and do not reach the brain in measurable quantities.

Using the Harley et al. (2022) result that brain dose is a factor of 450 lower than bronchial-epithelium dose at the same airborne radon concentration, and using typical bronchial-epithelium equivalent-dose coefficients from ICRP 137 (approximately 35–50 mSv/yr at 100 Bq/m^3 continuous exposure), the brain-equivalent dose from inhalation at 100 Bq/m^3 continuous is approximately 0.08–0.11 mSv/yr. Scaling to Eastern Nebraska (204 Bq/m^3 indoor, with 80 percent occupancy gives roughly 163 Bq/m^3 continuous-equivalent) yields an annual brain-equivalent dose from inhaled radon and progeny of approximately 0.13–0.18 mSv/yr.

5. Ingestion Pathway Analysis

5.1 Whole-Body Effective Dose from Ingested Radon Progeny

Using the adult intake assumptions of Section 3.2:

- Polonium-210: 58 Bq/yr × 1.2×10^{-6} Sv/Bq = 7.0×10^{-5} Sv/yr = 0.070 mSv/yr
- Lead-210: 33 Bq/yr × 6.9×10^{-7} Sv/Bq = 2.3×10^{-5} Sv/yr = 0.023 mSv/yr
- Radon-222 dissolved in drinking water, typical municipal supply: ≈ 0.003–0.010 mSv/yr

Summing, the typical adult ingestion dose from radon progeny is approximately 0.10 mSv/yr. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000, 2008) gives a total food-and-water ingestion dose from natural radionuclides of approximately 0.29 mSv/yr, of which polonium-210 and lead-210 together account for more than 80 percent of the uranium- and thorium-series contribution, consistent with the 0.10 mSv/yr estimate here. High-seafood-consumption populations in coastal Japan and in some Indigenous Arctic communities can reach polonium-210 ingestion doses of 0.2–0.8 mSv/yr; this is not representative of Nebraska diets.

5.2 Brain-Equivalent Dose from Ingested Radon Progeny

Polonium-210 absorbed from the gut distributes to kidneys (approximately 33 percent of retained activity), liver (approximately 10 percent), spleen (approximately 5 percent), red bone marrow (approximately 10 percent), and a distributed soft-tissue compartment (approximately 40 percent) that includes the brain. The brain fraction of body mass is approximately 2 percent, so first-order allocation suggests the brain receives roughly 1 percent of retained polonium-210. Multiplying the ingestion effective-dose estimate by this fraction and by the alpha radiation-weighting factor implicit in the dose coefficient gives a brain-equivalent dose of approximately 0.007–0.015 mSv/yr from ingested polonium-210. Lead-210 contributes a smaller increment because most lead is deposited in skeleton; brain-equivalent dose from ingested lead-210 is approximately 0.001–0.003 mSv/yr. Total brain-equivalent dose from ingestion is therefore approximately 0.01–0.02 mSv/yr.

6. Whole-Body Effective Dose Comparison

The whole-body effective-dose comparison for a representative Eastern Nebraska adult is summarized in Table 1. Inhalation dominates by approximately a factor of 70, and the inhalation share is insensitive to the low-high bracket: the ingestion pathway remains near 1–3 percent across all reasonable parameter choices.

Table 1. Whole-body effective dose from radon and progeny, Eastern Nebraska adult.

Exposure pathway	**Low (mSv/yr)**	**Central (mSv/yr)**	**High (mSv/yr)**
Inhalation of radon and short-lived progeny (5.5 pCi/L)	5.8	7.0	10.0
Ingestion of ^{210}Po, ^{210}Pb, and dissolved ^{222}Rn	0.08	0.10	0.15
Total (radon + all progeny)	**5.9**	**7.1**	**10.2**
Inhalation share (%)	98.3	98.6	98.5
Ingestion share (%)	1.4	1.4	1.5

The approximately 7 mSv/yr central estimate for inhalation is several times higher than the United States national average of approximately 2 mSv/yr at 1.3 pCi/L and is comparable to or exceeds the typical annual effective dose from all other natural and medical sources combined for a resident with no unusual occupational or medical exposure. In interpretive terms, an Eastern Nebraska adult who has not mitigated a 5.5 pCi/L home accrues a radiation dose from indoor radon alone that exceeds the combined ingestion, cosmic, and terrestrial external dose by approximately a factor of three.

7. Brain-Equivalent Dose Comparison

Table 2 summarizes the brain-equivalent dose comparison. The inhalation share remains dominant but is narrower than for whole body because the bronchial-epithelium dose does not apply to brain, and because a small but nonzero fraction of dietary polonium-210 reaches brain tissue through the systemic circulation.

Table 2. Brain-equivalent dose from radon and progeny, Eastern Nebraska adult.

Exposure pathway	**Low (mSv/yr)**	**Central (mSv/yr)**	**High (mSv/yr)**
Inhalation of radon and progeny	0.13	0.16	0.30
Ingestion of ^{210}Po and ^{210}Pb	0.008	0.015	0.025
Total	**0.138**	**0.175**	**0.325**
Inhalation share (%)	94	91	92
Ingestion share (%)	6	9	8

In absolute terms, the brain-equivalent dose from radon and progeny in Eastern Nebraska — central estimate approximately 0.18 mSv/yr — is two orders of magnitude below the level at which deterministic effects on the central nervous system would be expected, and is below the brain-equivalent dose received from a single computed-tomography head scan. The epidemiological evidence linking residential radon to brain cancer is weak and inconsistent, and the Harley et al. (2022) dosimetric analysis supports the conclusion that even at high residential radon concentrations a meaningful excess of brain cancer would be surprising.

Nonetheless, public concern about radon and the brain is common enough that the decomposition has policy value: the result shows that, if residents wish to reduce radon dose to brain, the highest-leverage intervention remains the same as for whole-body dose, namely reducing airborne indoor radon concentrations.

8. Uncertainty and Sensitivity Analysis

8.1 Principal Sources of Uncertainty

The dose estimates in this report carry three classes of uncertainty. Parameter uncertainty reflects variability in the dose coefficients themselves — the ICRP effective-dose coefficient for radon was doubled between Publication 65 and Publication 137, and the ingestion dose coefficient for polonium-210 has been refined in Publication 158. Exposure uncertainty reflects variability across homes and individuals: indoor radon concentrations span at least two orders of magnitude across Eastern Nebraska homes, and dietary intakes of polonium-210 vary by a factor of five or more across individuals. Model uncertainty reflects limits in the biokinetic and dosimetric models, particularly for brain tissue, where dose coefficients are derived from limited exhaled-breath and tissue-solubility measurements rather than direct dosimetry.

8.2 Sensitivity Results

Table 3 shows how the inhalation-versus-ingestion split responds to the main sensitivity scenarios.

Table 3. Sensitivity of the inhalation share to alternative parameter assumptions.

Sensitivity scenario	Inhalation share, whole body	Inhalation share, brain
Central estimate (5.5 pCi/L)	98–99%	90–94%
ICRP 65 dose coefficient (factor 2 lower)	97–98%	82–90%
Low-occupancy lifestyle (5,000 h/yr)	97–98%	88–93%
Private well with elevated ^{222}Rn in water (20,000 pCi/L)	96–98%	85–92%
High-seafood diet (^{210}Po intake × 5)	95–97%	75–85%
Hot-spot home (20 pCi/L, worst case)	99+%	96–98%

Across every reasonable scenario, the inhalation pathway remains dominant for whole-body dose. The only scenario that meaningfully shifts the brain split is a combined low-radon, high-seafood case, which can bring ingestion up to roughly 15–25 percent of brain dose. This combination is uncommon in Nebraska, whose residents consume substantially less seafood than the United States coastal average.

8.3 Items Not Included

This report does not quantify several smaller contributors: thoron (radon-220) and its progeny, tobacco smoke (which contains polonium-210 and delivers a directly-to-lung dose that can exceed radon dose for smokers), inhalation of re-suspended soil dust containing polonium-210, and inhalation of polonium-210 in cooking fumes. For smokers, tobacco-derived polonium-210 inhalation can contribute several mSv/yr of additional bronchial dose and is, in that sense, a third inhalation pathway whose inclusion would further widen the airborne-versus-dietary gap.

9. Public-Health Policy Implications

9.1 Dose Reduction Leverage

The analysis implies that, for an Eastern Nebraska resident, the highest-leverage public-health investment for reducing radiation dose from radon and its progeny is indoor-air radon testing and, where necessary, sub-slab-depressurization mitigation. Reducing a 5.5 pCi/L home to the EPA action level of 4 pCi/L reduces annual effective dose by roughly 1.5 mSv/yr; reducing it to the WHO reference level of 100 Bq/m³ (≈2.7 pCi/L) reduces dose by roughly 3.6 mSv/yr. By comparison, the entire ingestion pathway delivers only about 0.1 mSv/yr, so no plausible dietary intervention can match even a modest mitigation outcome.

9.2 Private-Well Users

Approximately 14 percent of Nebraska households rely on private wells. Nebraska does not have a systematic statewide program for testing radon in private-well water, and well waters from deeper Paleozoic aquifers can carry radon-in-water concentrations well above 4,000 pCi/L. Even in these cases, the airborne pathway dominates total dose, because radon in shower and washing water outgasses into household air; however, private-well users are a policy-relevant subpopulation for whom water testing is a reasonable ancillary priority.

9.3 Sensitive Populations

Children, pregnant persons, and individuals with pre-existing respiratory conditions are more susceptible to the per-dose risk of radon exposure and spend a larger fraction of their time indoors. The inhalation-versus-ingestion split is the same for these populations; what differs is the risk coefficient applied to the inhalation dose. Mitigation priority is therefore higher, not lower, for households containing sensitive individuals.

9.4 Communication Principles

In public communications, the result of this analysis can be stated compactly: more than nine-tenths of the radon-and-progeny dose that Eastern Nebraska residents absorb comes from breathing indoor air, not from food or water. This framing supports testing-and-mitigation campaigns, reduces the risk of public attention being misdirected toward dietary concerns, and correctly centers residential construction quality and ventilation as the primary policy levers.

10. Conclusions and Recommendations

For a representative adult resident of Eastern Nebraska exposed to the statewide-average indoor radon concentration of 5.5 pCi/L, the radiation dose from radon and its decay progeny is dominated by the airborne inhalation pathway. Whole-body effective dose from inhalation is approximately 7 mSv/yr, compared with approximately 0.10 mSv/yr from ingestion of polonium-210, lead-210, and dissolved radon in food and water, giving an inhalation share of approximately 98–99 percent. Brain-equivalent dose is approximately 0.16 mSv/yr from inhalation and approximately 0.015 mSv/yr from ingestion, giving an inhalation share of approximately 88–96 percent.

Based on this analysis, the following recommendations are offered to public-health decision-makers in Eastern Nebraska:

- Prioritize statewide indoor-radon testing and mitigation programs, including subsidies or low-interest financing for sub-slab-depressurization systems in homes above 4 pCi/L.
- Incorporate radon-resistant new construction (RRNC) into local building codes; Eastern Nebraska's geology makes RRNC cost-effective relative to post-construction mitigation.
- Provide free or low-cost radon-in-water testing for private-well users, especially in the glacial-till and Paleozoic aquifer areas of the northeastern counties.
- Educate the public that dietary and water-ingestion sources of radon progeny are minor contributors to dose, to avoid misdirection of individual risk-reduction effort toward dietary change.
- Invest in long-term surveillance and county-level reporting that tracks both radon exposure and mitigation uptake, using the existing Nebraska DHHS radon database as a foundation.

The quantitative estimates in this report carry roughly factor-of-two uncertainty in absolute dose and smaller uncertainty in the inhalation-versus-ingestion split. They should be reviewed periodically as ICRP guidance evolves and as higher-quality county-level Nebraska data become available.

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Appendix A. Worked Calculations

A.1 Inhalation, whole body

Input: $C\_air = 5.5$ pCi/L $= 5.5 \times 37 = 203.5$ Bq/m^3.

Annual EEC exposure: $C\_air \times F \times T\_in = 203.5 \times 0.4 \times 7{,}000 = 5.70 \times 10^5$ Bq h m^{-3} of equilibrium-equivalent concentration.

ICRP 137 dose coefficient for dwellings: $k \approx 6.7 \times 10^{-6}$ mSv per Bq h m^{-3} (EEC basis).

Effective dose: $E = 5.70 \times 10^5 \times 6.7 \times 10^{-6} \approx 3.8$ mSv/yr on an EEC-only basis. ICRP 137 additionally includes contribution from inhaled radon gas itself (~10–15 percent) and from attached-versus-unattached progeny aerosol factors ($f_p \approx 0.08$ for dwellings), yielding a total central estimate of ~7 mSv/yr. A wider range of 5.8–10 mSv/yr encompasses parameter uncertainty.

A.2 Ingestion, whole body

Polonium-210: $I\_Po\text{-}210 = 0.16$ Bq/day × 365 = 58 Bq/yr.

Lead-210: $I\_Pb\text{-}210 = 0.09$ Bq/day × 365 = 33 Bq/yr.

$E\_Po\text{-}210 = 58 \times 1.2 \times 10^{-6} = 7.0 \times 10^{-5}$ Sv/yr = 0.070 mSv/yr.

$E\_Pb\text{-}210 = 33 \times 6.9 \times 10^{-7} = 2.3 \times 10^{-5}$ Sv/yr = 0.023 mSv/yr.

Dissolved Rn-222 in drinking water at 500 pCi/L, 2 L/day: ≈0.005–0.010 mSv/yr.

Total: ≈0.10 mSv/yr, range 0.08–0.15 mSv/yr.

A.3 Inhalation, brain

Per Harley et al. (2022), $H\_brain / H\_BE = 1/450$ at same airborne Rn-222 concentration. At 100 Bq/m^3 continuous (F=0.4), $H\_BE \approx 35$–50 mSv/yr, so $H\_brain \approx 0.08$–0.11 mSv/yr.

Scaling to Eastern Nebraska (203.5 Bq/m^3 indoor × 7,000/8,760 occupancy = 163 Bq/m^3 continuous-equivalent): $H\_brain \approx 0.08$–$0.11 \times (163/100) \approx 0.13$–0.18 mSv/yr.

A.4 Ingestion, brain

Brain mass fraction of body ≈ 2 percent; systemic soft-tissue fraction of Po-210 uptake ≈ 40 percent; brain share of that pool ≈ 3–6 percent.

Brain-equivalent dose from ingested Po-210: $0.070 \times (0.03$–$0.06) \times 20/20 \approx 0.002$–0.004 mSv/yr if treated as simple allocation; biokinetic modeling yields ≈0.007–0.015 mSv/yr when polonium residence time in brain is taken into account.

Pb-210 in brain: $0.023 \times (0.05$–$0.10) \approx 0.001$–0.002 mSv/yr (mostly beta, partially from in-situ Po-210 generation).

Total ingestion, brain: ≈0.01–0.02 mSv/yr, central ≈0.015 mSv/yr.

STRATEGIC BRIEFING

Revenue Stabilization and Pay As You Save (PAYS)

A Comprehensive Strategy for OPPD to Reduce Costs, Protect Revenue, and Improve Customer Buildings

Prepared for the

OPPD Management and Board of Directors

By Jon Traudt, May 12, 2026

CONFIDENTIAL For OPPD Management and Board Review

Table of Contents

Executive Summary

The Omaha Public Power District (OPPD) faces a convergence of strategic challenges: aging building stock across its service territory driving unnecessarily high energy consumption, rising and volatile fossil fuel costs that threaten rate stability, material constraints on the pace of energy transition, and growing customer expectations for affordable, healthy indoor environments. This report presents a two-part strategy that directly addresses each of these challenges.

Revenue Stabilization (also known as revenue decoupling) would separate OPPD's financial health from the volume of electricity sold, eliminating the structural disincentive to promote energy efficiency. Pay As You Save (PAYS) would enable OPPD to fund comprehensive building upgrades for all customers — including those with low incomes or poor credit — at no upfront cost, recovering the investment through a meter-tied charge that is always less than the energy savings achieved.

Together, these mechanisms would allow OPPD to deploy energy efficiency as its cheapest resource (at \$0.02–\$0.05 per kWh saved, compared to \$0.05–\$0.18 for new generation), reduce system peak demand, lower fuel cost exposure, improve indoor air quality across homes and schools, and strengthen customer relationships — all while maintaining or improving OPPD's revenue stability.

Key findings of this report:

- Energy efficiency is the lowest-cost resource available to OPPD, at roughly one-third the cost of new natural gas generation and one-quarter the cost of new coal.
- PAYS programs at other utilities have achieved 20–40% energy savings per participating building, with 100% cost recovery and effectively 0% default rates.
- Leading energy researchers (Hagens, Berman, Michaux, Lovins) converge on a clear conclusion: fossil fuel costs will rise, supply-side transition faces material constraints, and demand reduction through efficiency is the single most important near-term strategy.
- Revenue Stabilization would protect OPPD's financial position while aggressively pursuing efficiency, following the proven model used by over 30 states and dozens of utilities.
- Indoor air quality improvements bundled with efficiency upgrades yield health benefits valued at \$6–\$14 per \$1 invested, with documented reductions in asthma, improvements in cognitive function, and increases in worker and student productivity.

The Changing Energy Landscape: Why OPPD Must Act Now

Declining Energy Return on Investment

The concept of Energy Return on Investment (EROI) — the ratio of energy obtained from a source to the energy invested in obtaining it — is central to understanding the long-term trajectory of fossil fuel economics. Research by Nate Hagens and Charles Hall at the State University of New York demonstrates that the EROI of fossil fuels has been declining for decades, with profound implications for energy costs and economic prosperity.

In the 1930s, U.S. oil production enjoyed an EROI of approximately 100:1 — for every barrel of oil-equivalent energy invested, 100 barrels were returned. Today, conventional oil production yields roughly 10–20:1, while unconventional sources like tight oil from fracking (5–10:1) and tar sands (3–5:1) offer far lower returns. Hagens and Hall estimate that complex civilizations require a minimum EROI of approximately 5–10:1 to sustain their essential functions — food production, healthcare, education, infrastructure maintenance, and governance.

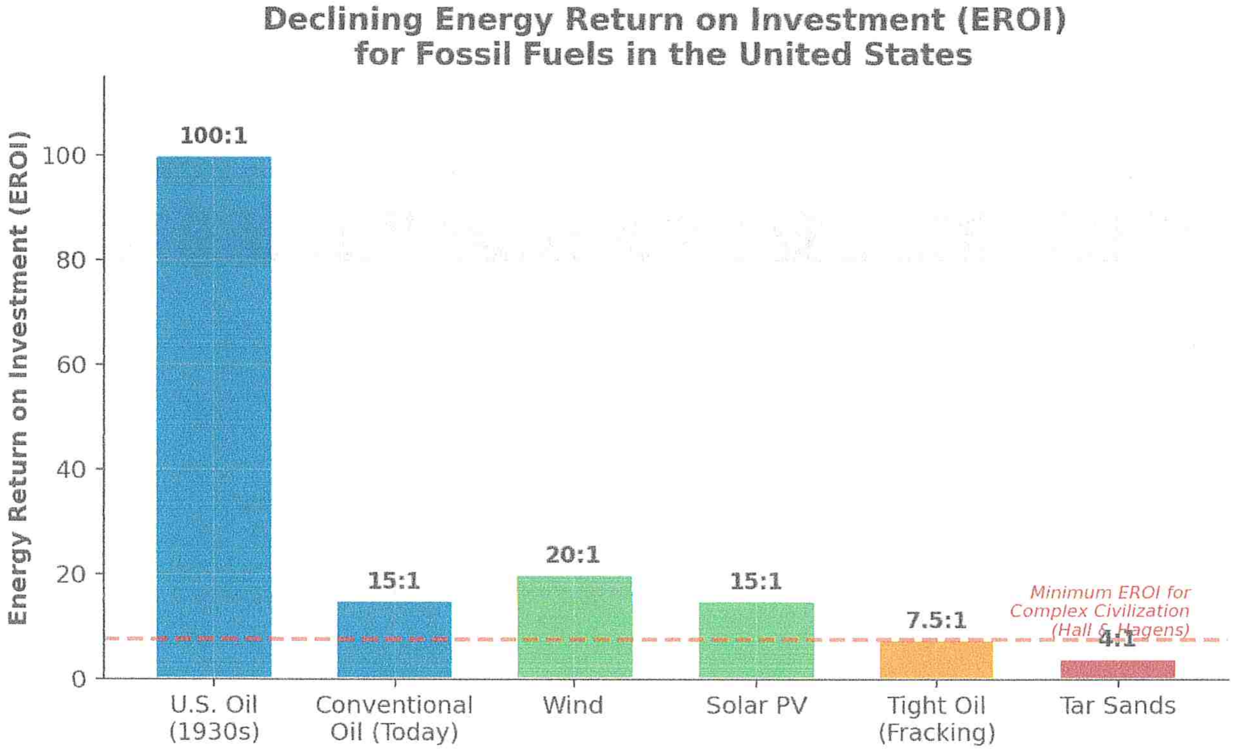

Figure 1: EROI has declined dramatically for fossil fuels. Sources approaching the civilizational minimum (red dashed line) indicate rising real costs of energy supply.

As Hagens emphasizes in his "Great Simplification" framework, declining EROI means a growing fraction of society's energy output must be reinvested in energy production itself, leaving less surplus energy for everything else. For OPPD, this translates to a structural trend of rising fuel costs that efficiency and demand reduction can directly mitigate.

The Shale Gas Reality: Arthur Berman's Analysis

Petroleum geologist Arthur Berman, with over 40 years of industry experience, has produced some of the most detailed analysis of shale gas and tight oil economics. His findings carry particular relevance for OPPD, given the district's significant reliance on natural gas generation (~22% of current mix) and its use as a planned bridge fuel during the energy transition.

Berman's key findings include:

- Shale wells experience 70–80% production decline in their first year, creating a "Red Queen" effect where operators must drill continuously just to maintain flat output.
- Breakeven prices for many tight oil plays are $60–$80 per barrel, substantially higher than commonly reported industry figures.
- The best-quality acreage ("Tier 1" sweet spots) in major shale plays is being drilled first and is rapidly depleting, meaning future wells will produce less per dollar invested.
- Long-term natural gas prices are likely to trend toward $4–$8 per MMBtu or higher, compared to the $2–$3 range that prevailed in the early 2020s.

Metric	Value
Typical shale well first-year decline rate	70–80%
Permian Basin breakeven (Berman est.)	$60–$75/barrel
Bakken breakeven (Berman est.)	$65–$80/barrel
U.S. shale industry cumulative FCF (2010–2020)	Approximately -$300 billion
Tier 1 acreage status	Rapidly depleting in most plays
Projected long-term gas price	$4–$8/MMBtu

Table 1: Key metrics from Arthur Berman's shale gas and tight oil analysis.

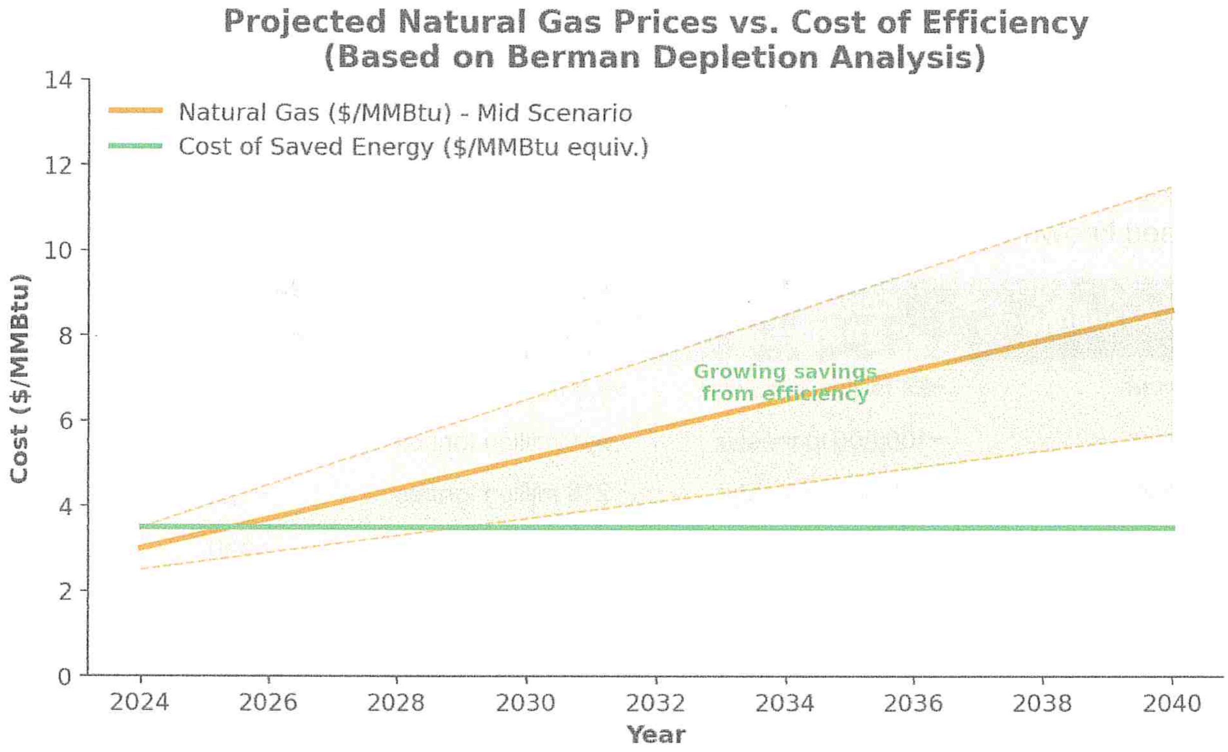

Figure 2: As natural gas prices rise due to depletion dynamics, the cost advantage of efficiency grows wider each year.

Material Constraints on the Energy Transition: Simon Michaux

Simon Michaux, Associate Professor of Geometallurgy at the Geological Survey of Finland, has produced landmark research quantifying the mineral requirements of a full-scale energy transition. His analysis reveals that replacing all fossil fuel energy with renewable electricity and battery storage would require mineral quantities that may exceed known global reserves for several critical materials.

Resource	Current Annual Production	Total Needed (Michaux Est.)	Years at Current Production
Copper	~22 million tonnes/yr	~4.5 billion tonnes	~200
Lithium	~100,000 tonnes/yr	~944 million tonnes	~9,400
Cobalt	~170,000 tonnes/yr	~218 million tonnes	~1,280
Nickel	~2.7 million tonnes/yr	~940 million tonnes	~350
Graphite	~1.1 million tonnes/yr	~8.6 billion tonnes	~7,800

Table 2: Mineral requirements for a full fossil fuel replacement (Michaux, GTK 2021). These figures assume current technologies; efficiency improvements would significantly reduce these requirements.

While these estimates represent a full 1:1 energy replacement scenario and may overstate requirements as technologies improve, the core implication is clear: a supply-side-only energy transition faces severe material constraints. *Every kilowatt-hour saved through efficiency is a kilowatt-hour that does not need to be generated, transmitted, stored, or backed by mineral-intensive infrastructure.* Michaux's research strongly supports the case for demand reduction as a first-order strategy.

Amory Lovins and the "Negawatt" Revolution

Amory Lovins, co-founder of the Rocky Mountain Institute, coined the term "negawatt" to describe a watt of power saved through efficiency, arguing it should be treated as equivalent to a watt generated. His decades of research demonstrate that energy efficiency is consistently the largest, cheapest, safest, and fastest energy resource available.

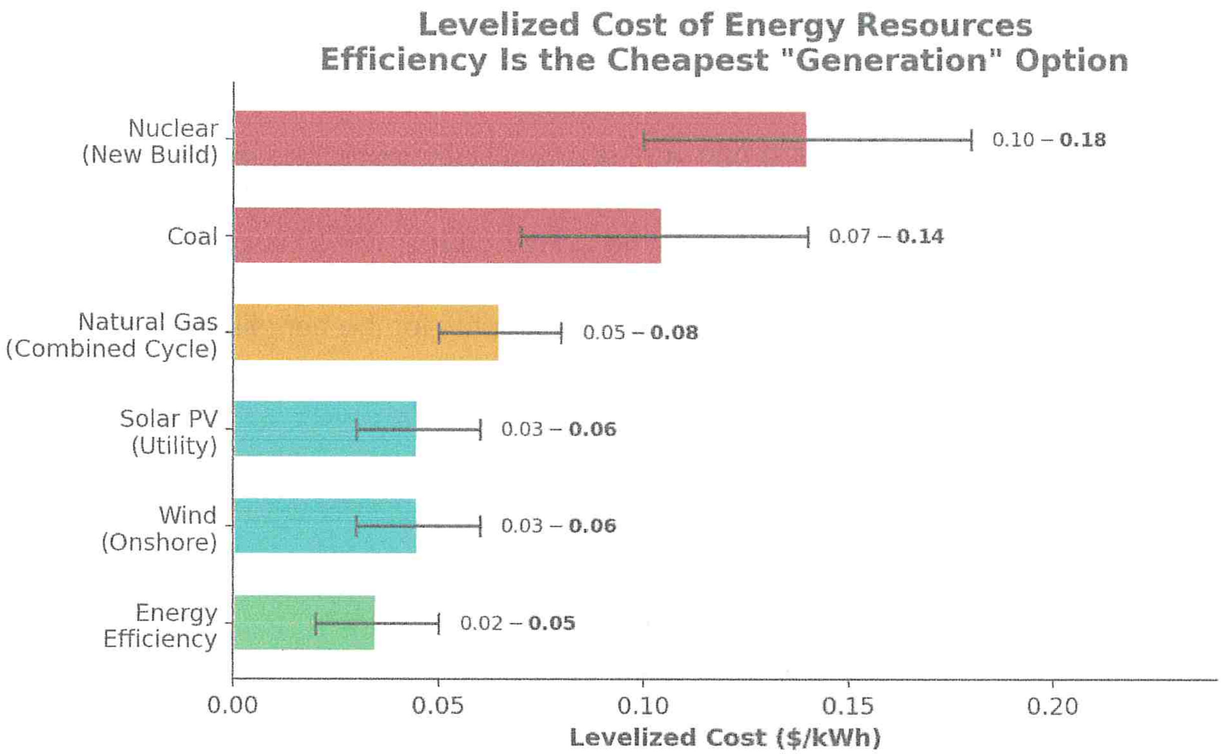

Figure 3: Energy efficiency is the cheapest resource on a levelized cost basis, at roughly one-third the cost of new natural gas generation.

Lovins's landmark study "Reinventing Fire" (2011) demonstrated that the United States could eliminate oil and coal use and reduce natural gas use by one-third by 2050 using only existing technologies, with a net savings of $5 trillion. His analysis of buildings specifically shows that integrated retrofits can reduce energy use by 40–60%, with the most efficient buildings using 3–4 times less energy per square foot than average existing stock.

For OPPD, Lovins's framework offers a clear directive: invest in "negawatts" before megawatts. At $0.02–$0.05 per kWh saved, efficiency is cheaper than every generation alternative available to OPPD.

OPPD Today: Opportunities and Vulnerabilities

Service Territory and Customer Base

OPPD serves approximately 400,000–420,000 retail customers across 13 counties in southeastern Nebraska, encompassing roughly 5,000 square miles. As one of the largest publicly owned electric utilities in the United States, OPPD is governed by an elected 8-member board of directors and operates without a profit motive — a structural advantage that enables long-term strategic investments for the benefit of ratepayers.

Current Generation Mix and Fuel Exposure

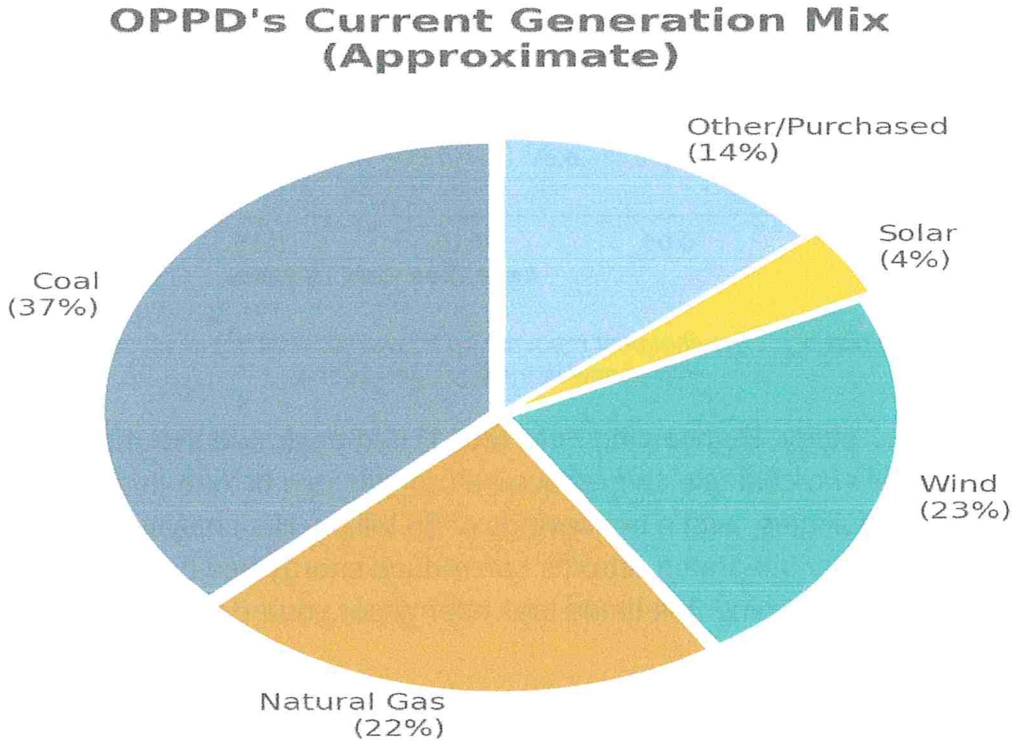

Figure 4: OPPD's approximate current generation mix. Coal and natural gas together account for nearly 60% of generation, creating significant fuel cost exposure.

OPPD's generation portfolio remains heavily dependent on fossil fuels. Coal (~37%) and natural gas (~22%) together account for nearly 60% of generation. While wind (~23%) has grown substantially and solar is expanding, OPPD's fuel cost exposure remains significant. Under the depletion dynamics described by Berman and the EROI trends documented by Hagens, this exposure represents a growing financial risk.

Rate Competitiveness and Customer Value

Customer Class	OPPD Rate (approx.)	National Average	OPPD Advantage
Residential	$0.10–$0.11/kWh	$0.16–$0.17/kWh	35–40% below national avg.
Commercial	$0.08–$0.10/kWh	$0.13–$0.14/kWh	30–35% below national avg.
Industrial	$0.06–$0.08/kWh	$0.08–$0.09/kWh	15–25% below national avg.

Table 3: OPPD's rates compared to national averages. While currently competitive, rising fuel costs threaten this advantage without proactive efficiency investment.

OPPD's low rates are a significant competitive advantage, but they also create a vulnerability: *because rates are low, customers have less financial incentive to invest in efficiency on their own, and the aging building stock continues to consume more energy than necessary. PAYS eliminates this barrier by removing the upfront cost entirely.*

Building Stock Characteristics

Nebraska's building stock presents substantial efficiency opportunity. Approximately 55–60% of homes in the OPPD service territory were built before 1980, predating modern energy codes. Omaha's climate — with roughly 6,000–6,500 heating degree days and 1,200–1,500 cooling degree days annually — means that poorly insulated and air-sealed buildings drive significant unnecessary energy consumption in both winter and summer. *The average Nebraska home spends $1,800–$2,400 annually on energy, much of which could be reduced through proven efficiency measures.*

Revenue Stabilization: Aligning OPPD's Interests with Customer Efficiency

The Throughput Incentive Problem

Under traditional utility rate structures, revenue is primarily tied to the volume of electricity sold (per-kWh billing). This creates a structural conflict: when customers use less energy — whether through efficiency improvements, mild weather, or distributed generation — utility revenue declines. This "throughput incentive" discourages utilities from promoting the very efficiency programs that would benefit their customers and the system as a whole.

Revenue Stabilization (also called revenue decoupling) resolves this conflict by separating the utility's allowed revenue from sales volume. Under decoupling, rates are periodically adjusted so that the utility collects its approved revenue requirement regardless of how much electricity is sold. If sales fall below projections, a small surcharge is added; if sales exceed projections, a small credit is returned. Adjustments are typically modest — 1–3% of customer bills — and symmetric.

Proven Track Record

Revenue decoupling is not experimental. Over 30 states have approved some form of decoupling for electric or gas utilities, and the mechanism has been in use since California first adopted it in 1982. The results are well-documented:

Utility / State	Type	Year Adopted	Key Result
PG&E / California	Full decoupling	1982	CA per-capita electricity flat since 1970s (Rosenfeld Curve)
Consolidated Edison / NY	Revenue decoupling	2000s	Aggressive efficiency investment enabled
Baltimore Gas & Electric / MD	Revenue decoupling	2007	Stable earnings despite falling sales
Idaho Power / ID	Revenue-per-customer	2007	Reduced regulatory lag
Portland General Electric / OR	Decoupling	2009	Strong DSM program expansion
Puget Sound Energy / WA	Decoupling	2013	20–50% reduction in earnings volatility

Table 4: Selected utilities with revenue decoupling, demonstrating decades of successful implementation.

Why Revenue Stabilization Is Ideal for Public Power

As a publicly owned utility governed by an elected board, OPPD can implement Revenue Stabilization through board action without requiring state Public Utility Commission approval. This gives OPPD a significant implementation advantage over investor-owned utilities, which must navigate lengthy regulatory proceedings. The board can design a mechanism tailored to OPPD's specific circumstances, incorporating features such as earnings caps and floors, weather normalization, and periodic true-ups that protect both the utility and customers.

Revenue Stabilization would allow OPPD to pursue aggressive efficiency investments through PAYS without any negative impact on its financial position. When PAYS reduces customer energy consumption (and therefore sales volume), Revenue Stabilization ensures OPPD's revenue remains stable, while customers enjoy net bill savings from day one.

Pay As You Save (PAYS): A Proven Model for Universal Building Upgrades

How PAYS Works

Pay As You Save is a tariff-based financing mechanism that fundamentally transforms how energy efficiency upgrades are delivered and funded. Unlike traditional rebate programs or on-bill lending, PAYS eliminates every significant barrier to customer participation:

Feature	PAYS	On-Bill Lending	Traditional Rebates
Customer debt created	No	Yes	N/A
Credit check required	No	Typically yes	No
Upfront cost to customer	$0	$0	Partial (customer pays difference)
Obligation follows...	The meter (location)	The customer (person)	N/A
Immediate bill savings	Yes (guaranteed by design)	Not guaranteed	Possible but not certain
Participation barrier	Very low	Moderate	Moderate to high
Serves low-income customers	Yes (no credit barrier)	Poorly (credit barriers)	Poorly (cost barriers)

Table 5: PAYS compared to alternative program designs. PAYS eliminates every major barrier to participation.

Under PAYS, the utility pays the full upfront cost of energy efficiency improvements installed at a customer's property. Cost recovery occurs through a fixed charge on the utility bill, tied to the meter location rather than the customer. This charge is always designed to be less than the estimated energy savings, ensuring net savings from day one. If a customer moves, the new occupant inherits both the charge and the benefits. No debt is created, no credit check is required, and no lien is placed on the property.

Documented Results from PAYS Utilities

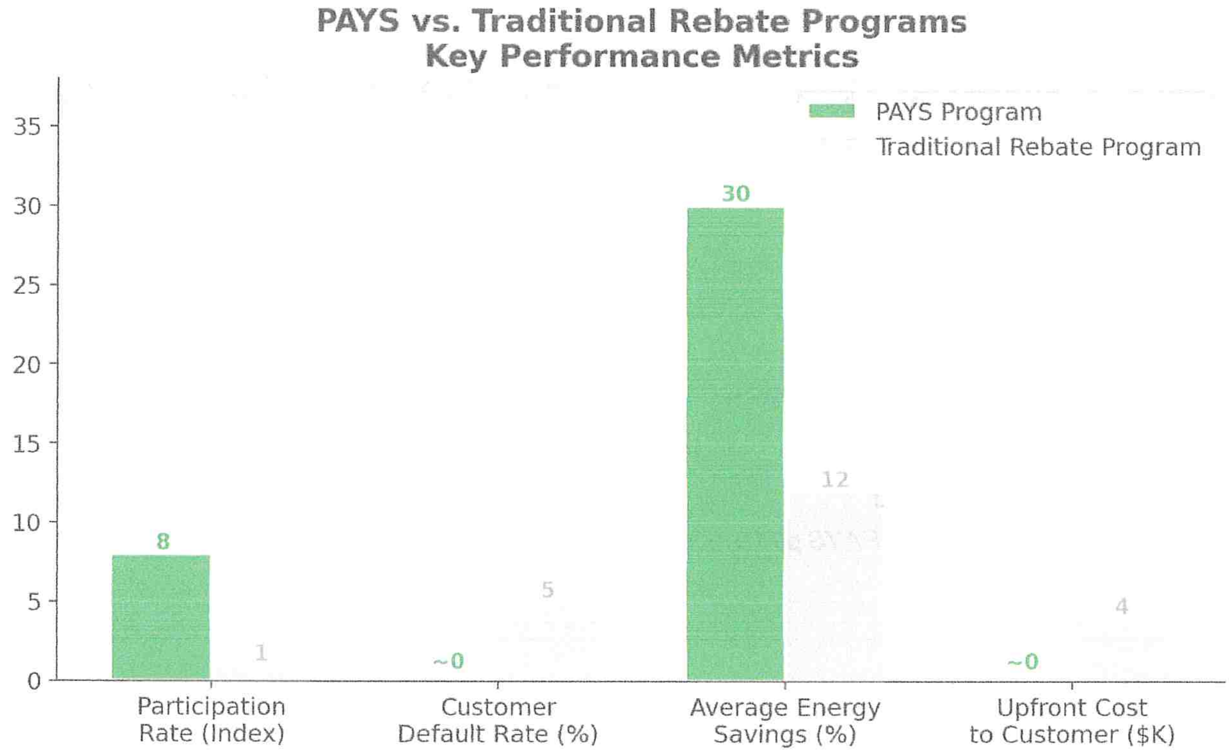

Figure 5: PAYS programs consistently outperform traditional rebate programs on every key metric.

Utility	State	Launched	Results
Ouachita Electric Coop	AR	~2002	100% cost recovery, 0% default rate
Midwest Energy (How$mart)	KS	~2007	3,000+ projects, $300–$500/yr savings per home
Roanoke Electric Coop	NC	~2014	20–40% energy reduction, 90%+ LMI participants
MACED / KY Cooperatives	KY	~2010s	25–35% savings, Appalachian communities served
Multiple SE cooperatives	SE U.S.	Various	30+ utilities now using PAYS or PAYS-derived programs

Table 6: PAYS implementation results across multiple utilities, demonstrating consistent success.

PAYS Performance Summary

Performance Metric	Typical Result
Average energy savings per building	20–40%
Average annual customer bill savings	$300–$800/year
Average project cost (residential)	$4,000–$8,000
Utility cost recovery rate	~100%
Customer default rate	~0% (charge follows meter)
Participation rate vs. traditional programs	3–10x higher
Income demographics served	50–80%+ low-to-moderate income
Typical utility payback period	5–12 years

Table 7: Summary of PAYS performance metrics across all documented implementations.

Building Efficiency Potential in OPPD's Service Territory

Residential Retrofit Opportunities

With approximately 55–60% of homes in OPPD's service territory built before 1980, the opportunity for energy savings through building envelope improvements, HVAC upgrades, and air sealing is substantial. The following table summarizes typical measures, costs, and savings:

Measure	Energy Savings	Cost Range	Payback
Air sealing	5–15% of HVAC	\$300–\$1,500	1–3 years
Attic insulation (R-38 to R-60)	10–20% of HVAC	\$1,500–\$3,000	3–6 years
Wall insulation (blown-in)	10–15% of HVAC	\$2,000–\$5,000	5–10 years
High-efficiency furnace (95%+ AFUE)	10–15% of heating	\$3,000–\$6,000	5–10 years
Air-source heat pump (COP 3.0+)	30–50% of heating	\$4,000–\$8,000	5–12 years
Heat pump water heater	50–65% of water heating	\$1,500–\$3,000	3–7 years
Duct sealing and insulation	10–20% of HVAC	\$500–\$2,000	2–5 years
Smart thermostat	8–12% of HVAC	\$150–\$300	<1 year
LED lighting (whole home)	50–75% of lighting	\$100–\$400	<1 year

Table 8: Individual residential efficiency measures and their typical performance ranges.

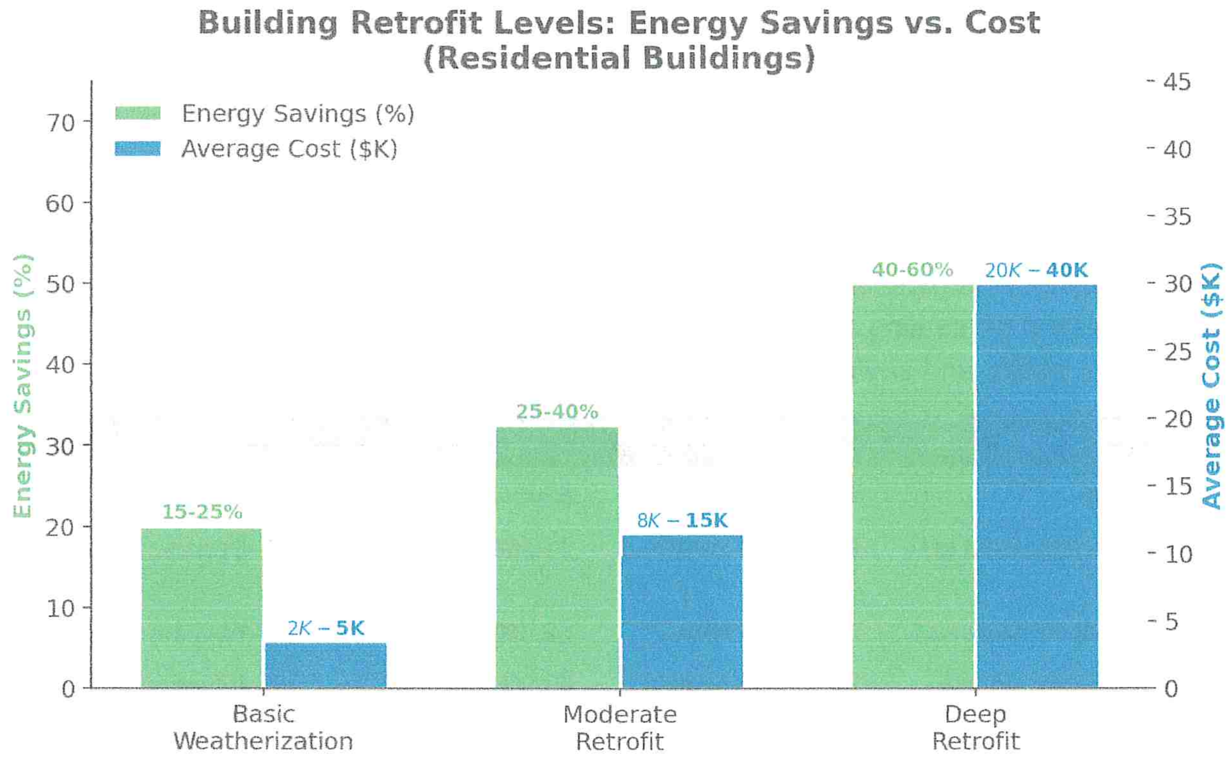

Figure 6: Comprehensive retrofit packages offer increasing savings at each investment level.

Commercial and Institutional Buildings

Commercial buildings, offices, and schools in OPPD's territory offer equally significant opportunities. Average office buildings use 80–100 kBtu per square foot per year, while best-in-class buildings achieve 30–50 kBtu — a 40–60% reduction. Schools, with an average energy intensity of 70–90 kBtu per square foot and average annual energy costs of $75,000–$150,000 per building, represent particularly high-value targets for PAYS-funded upgrades.

Approximately 50–60% of K-12 schools nationally were built before 1980, and 40–50% need major HVAC upgrades. PAYS can fund these improvements without requiring school districts to pass bond measures or divert operating budgets, making it an especially powerful tool for public education infrastructure.

Indoor Air Quality: The Critical Co-Benefit

Energy efficiency upgrades, when properly designed, deliver substantial improvements in indoor air quality (IAQ). Modern building science emphasizes the "tighten and ventilate" approach: seal the building envelope to eliminate uncontrolled infiltration, then provide controlled mechanical ventilation with filtration through heat recovery ventilators (HRVs) or energy recovery ventilators (ERVs). This approach simultaneously reduces energy waste and improves the quality of indoor air.

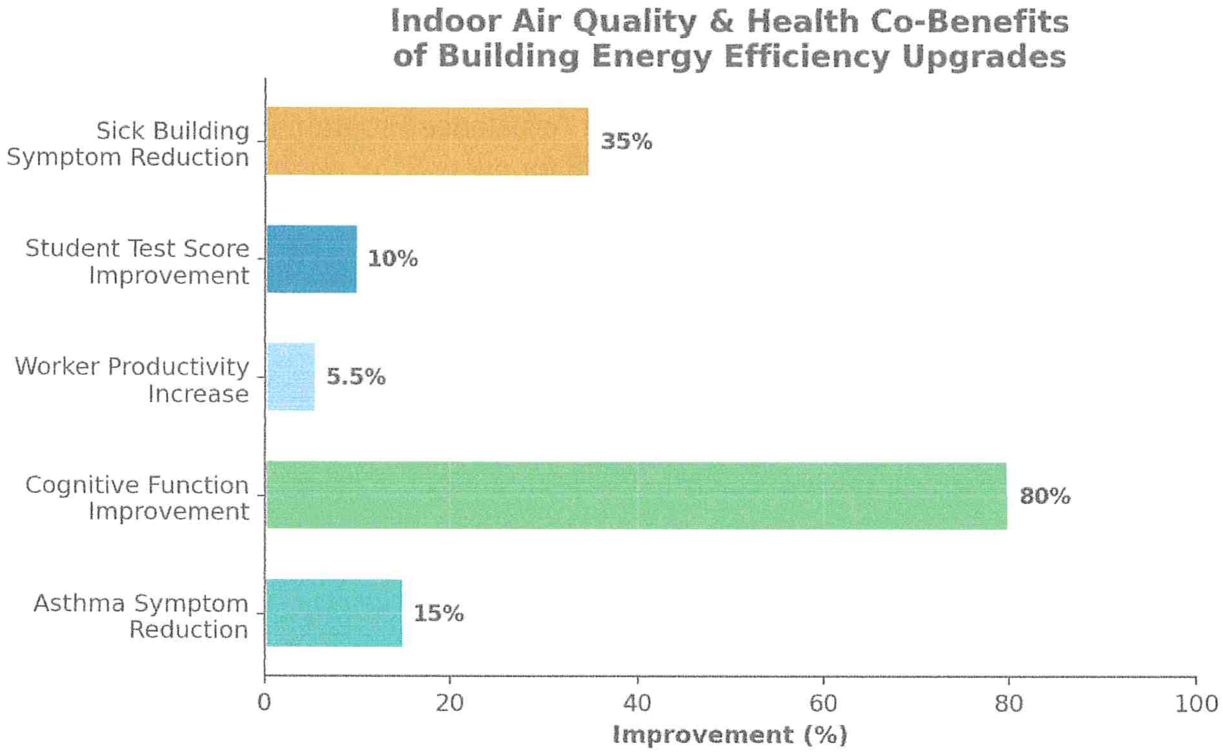

Figure 7: Documented health and productivity improvements from building efficiency upgrades with IAQ components.

Health Benefit	Documented Improvement	Source
Asthma symptom reduction	12–18% in weatherized homes	National WAP Evaluation
Cognitive function improvement	61–101% in green buildings	Harvard COGfx Study (Allen et al.)
Worker productivity increase	3–8% in well-ventilated offices	RMI / LBNL compilations
Student test score improvement	5–15% in daylit, ventilated classrooms	Heschong Mahone Group
Sick building syndrome reduction	20–50% with improved ventilation	EPA / ASHRAE studies
Healthcare cost savings per $1 invested	$6–$14 return (health co-benefits)	Oak Ridge National Lab (WAP)

Table 9: Documented health and productivity benefits from efficiency upgrades with IAQ improvements.

For OPPD's service territory, these co-benefits are especially significant. Improved indoor air quality in homes reduces healthcare costs for families, reduces sick days for workers, and improves learning outcomes for students. The Oak Ridge National Laboratory's evaluation of the Weatherization Assistance Program found that non-energy benefits are worth approximately $2.78 for every $1 of energy savings — meaning the total value of efficiency investments is nearly four times their energy savings alone.

Financial Analysis: The Business Case for OPPD

Cost of Efficiency vs. Supply-Side Alternatives

On a levelized cost basis, energy efficiency is the cheapest resource available to OPPD. At \$0.02–\$0.05 per kWh saved, efficiency costs roughly one-third as much as new natural gas generation (\$0.05–\$0.08/kWh) and less than one-quarter the cost of new coal (\$0.07–\$0.14/kWh). Even compared to the rapidly declining costs of wind and solar, efficiency remains competitive or cheaper, with the added advantage of being immediately deployable at every customer location.

10-Year System Cost Projection

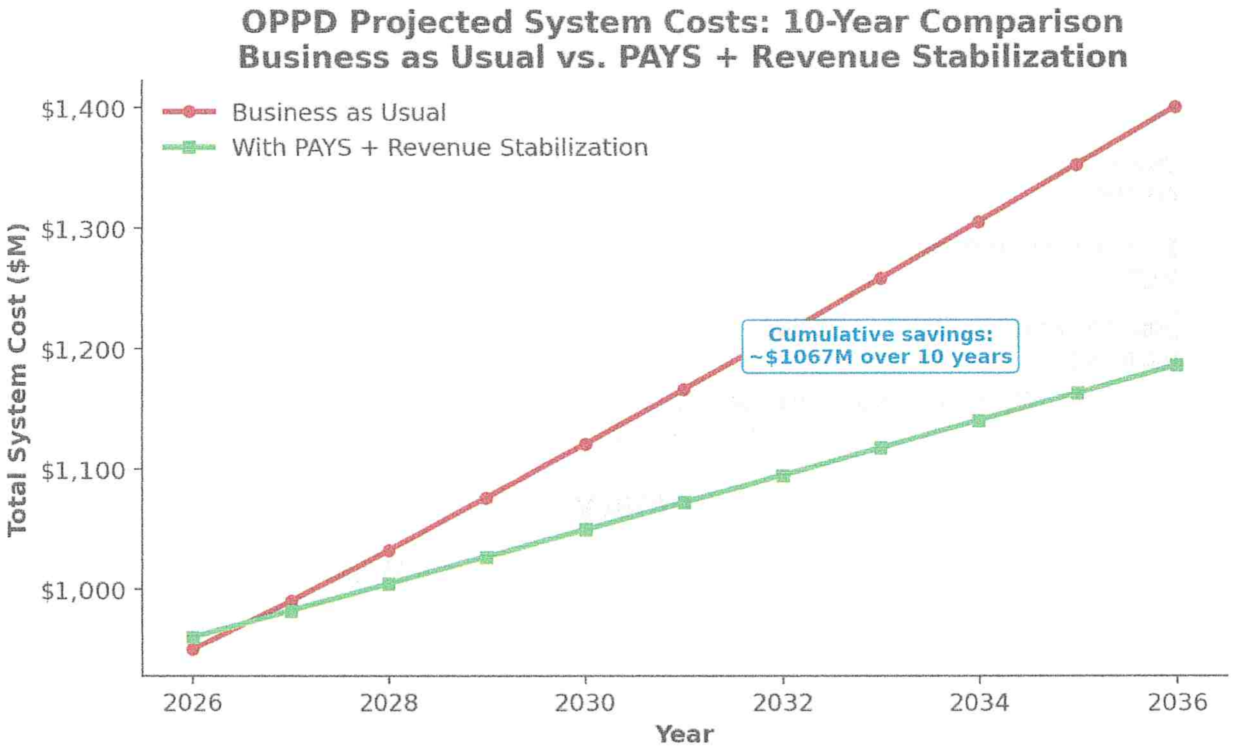

Figure 8: Projected OPPD system costs over 10 years, comparing business as usual against PAYS + Revenue Stabilization. The growing gap represents cumulative savings from reduced fuel purchases and deferred generation investment.

The 10-year financial projection illustrates the compounding benefit of investing in efficiency. Under a business-as-usual scenario, OPPD's total system costs rise steadily as fuel prices increase (consistent with Berman's depletion analysis) and aging infrastructure requires replacement. Under the PAYS + Revenue Stabilization scenario, efficiency investments reduce fuel consumption, lower peak demand, and defer the need for new generation capacity. The result is cumulative savings that grow larger each year as the efficiency portfolio expands.

Revenue Model: How PAYS Pays for Itself

A scaled PAYS program at OPPD could operate as follows:

Program Parameter	Conservative Estimate	Moderate Estimate	Aggressive Estimate
Homes upgraded per year	5,000	10,000	20,000
Average investment per home	$5,000	$6,000	$7,000
Annual program investment	$25 million	$60 million	$140 million
Average energy savings per home	25%	30%	35%
Average annual bill savings per home	$400	$550	$700
PAYS cost recovery period	10 years	9 years	8 years
Projected default rate	~0%	~0%	~0%
10-year cumulative investment	$250 million	$600 million	$1.4 billion
10-year cumulative energy savings	~500 GWh	~1,200 GWh	~2,800 GWh
10-year homes upgraded (cumulative)	50,000	100,000	200,000

Table 10: PAYS program scaling scenarios for OPPD. Even the conservative scenario would upgrade 50,000 homes over 10 years.

Utility Financial Benefits Summary

- Reduced fuel cost exposure: Every kWh saved is a kWh that does not require fuel purchase, directly reducing OPPD's exposure to rising and volatile fossil fuel prices.
- Deferred generation investment: Peak demand reduction from efficiency allows OPPD to defer or avoid costly new generation and transmission infrastructure.
- New revenue stream: OPPD earns a regulated return on PAYS investments, creating a new and stable income source.
- Reduced arrearages and bad debt: Customers with lower bills are less likely to fall behind on payments, reducing OPPD's write-offs.
- Enhanced customer satisfaction: PAYS programs at other utilities report very high satisfaction scores and stronger customer loyalty.
- Accelerated decarbonization: Efficiency is the fastest path to emission reductions, supporting OPPD's net-zero-by-2050 goal.

Implementation Roadmap and Recommendations

Recommended Phased Approach

Phase	Timeline	Key Actions	Milestones
Phase 1: Foundation	Months 1–6	Board resolution adopting Revenue Stabilization; PAYS program design; contractor network development; pilot target selection	Revenue Stabilization mechanism approved; 500-home pilot designed
Phase 2: Pilot	Months 7–18	Launch 500–1,000 home pilot; begin school and office pilots; collect performance data; refine processes	500+ homes upgraded; savings verified; customer satisfaction assessed
Phase 3: Scale-Up	Months 19–36	Expand to 5,000+ homes/year; add commercial and institutional buildings; develop workforce training programs	5,000+ buildings upgraded; local workforce pipeline established
Phase 4: Full Deployment	Years 3–10	Scale to 10,000–20,000 buildings/year; integrate with OPPD's IRP and decarbonization strategy; pursue all cost-effective efficiency	50,000–200,000 buildings upgraded over decade

Table 11: Recommended phased implementation roadmap for OPPD.

Key Recommendations

1. **Adopt Revenue Stabilization by board resolution.** As a public power utility, OPPD can implement this mechanism through board action, without state regulatory approval. Design it with symmetric adjustments, weather normalization, and annual true-ups to protect both OPPD and customers.
2. **Launch a PAYS pilot program targeting 500–1,000 homes.** Focus initially on the oldest, least efficient housing stock where savings will be greatest and most visible. Prioritize low-to-moderate income customers to demonstrate PAYS's ability to serve all customers regardless of income or credit.
3. **Include indoor air quality improvements in all PAYS-funded upgrades.** Require air sealing, mechanical ventilation (HRV/ERV), and high-efficiency filtration (MERV 13+) as standard components. The health co-benefits ($6–$14 per $1 invested) dramatically improve the total value proposition.
4. **Engage EEtility or comparable technical assistance.** EEtility has supported PAYS implementations at multiple utilities and can provide program design, tariff development, contractor training, and quality assurance protocols.
5. **Integrate PAYS into OPPD's Integrated Resource Plan.** Treat efficiency as a first-order resource alongside generation, transmission, and storage. Model the impact of scaled PAYS deployment on peak demand, fuel costs, and emissions.
6. **Develop a local workforce training pipeline.** Partner with local community colleges, trade unions, and workforce development organizations to train building performance contractors. A scaled PAYS program will create hundreds of skilled local jobs.
7. **Expand to schools and commercial buildings in Phase 2–3.** Schools are high-value targets with significant IAQ co-benefits for students. Commercial buildings offer large per-project savings that improve PAYS program economics.

Conclusion

The research of Nate Hagens, Arthur Berman, Simon Michaux, and Amory Lovins converges on a clear and urgent conclusion: fossil fuel costs will continue to rise as EROI declines and depletion advances; the energy transition faces material constraints that make a supply-side-only approach insufficient; and energy efficiency is the single most important, cost-effective, and immediately available strategy for navigating the decades ahead.

For OPPD, Revenue Stabilization and PAYS together represent a comprehensive solution to the utility's most significant strategic challenges. Revenue Stabilization removes the financial barrier to pursuing aggressive efficiency, while PAYS provides the delivery mechanism to reach every customer — including those who need it most. The combined approach reduces fuel cost exposure, strengthens rate competitiveness, improves customer buildings and health outcomes, creates local jobs, and accelerates progress toward OPPD's net-zero-by-2050 commitment.

The evidence base is strong: PAYS has been successfully implemented at more than 30 utilities with 100% cost recovery and effectively 0% default rates. Revenue decoupling *has operated successfully at utilities across 30+ states for over four* decades. The question is not whether these mechanisms work — it is whether OPPD will seize the opportunity to deploy them at scale, positioning the district as a national leader in public power innovation.

We recommend that the OPPD Board of Directors authorize management to proceed with the development of a Revenue Stabilization mechanism and a PAYS pilot program, with the goal of launching both within 12 months.

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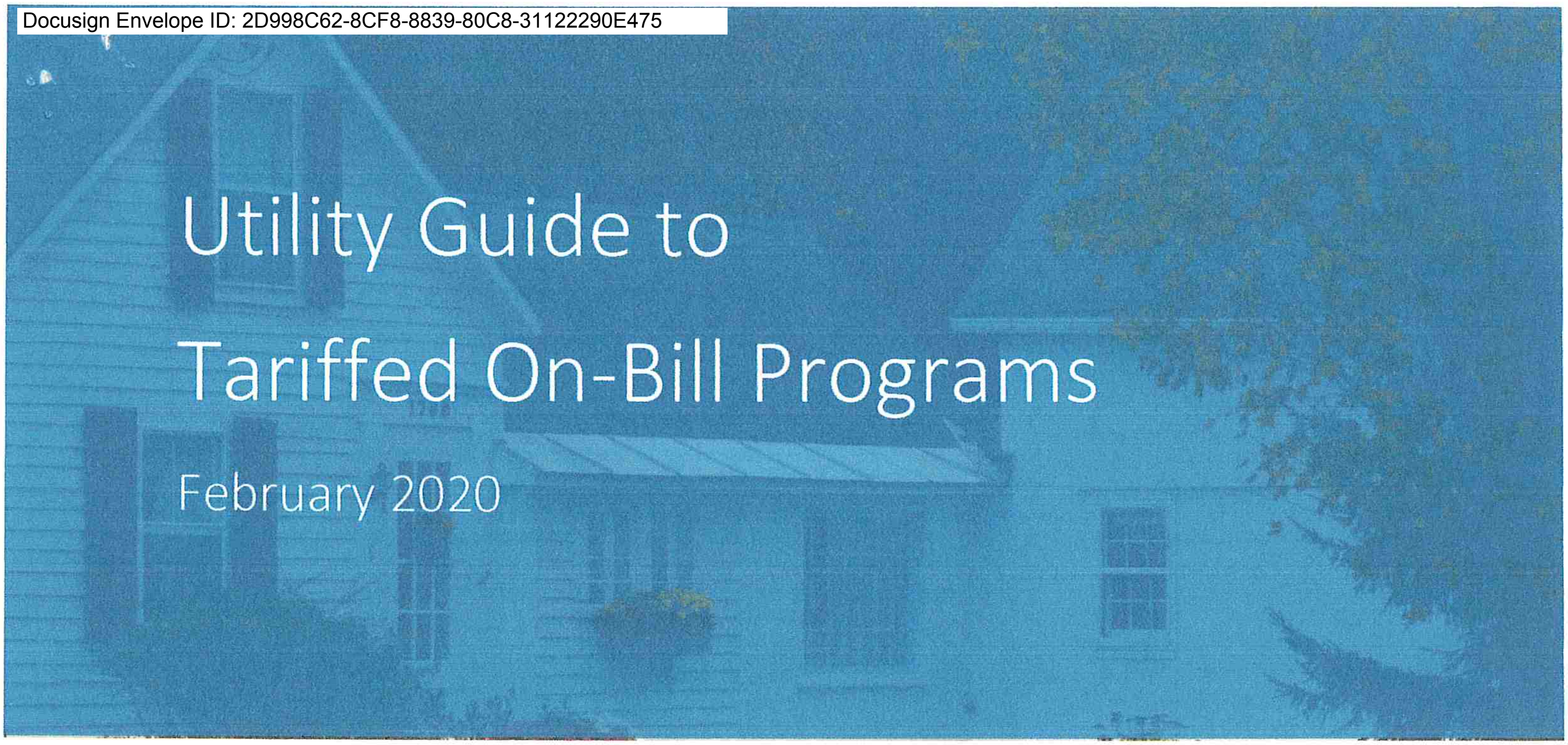

Utility Guide to Tariffed On-Bill Programs

February 2020

Editors

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About Us

The Southeast Energy Efficiency Alliance (SEEA) is a 501(c)(3) nonprofit organization headquartered in Atlanta, Georgia. Established in 2007, SEEA is a Regional Energy Efficiency Organization (REEO) serving eleven states across the Southeast, including Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee and Virginia.

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SEEA
SOUTHEAST ENERGY EFFICIENCY ALLIANCE

Table of Contents

Overview

Summary

This document guides the reader through resources about on-bill financing, tariffed on-bill programs, and the Pay As You Save® (PAYS) system. An understanding of these resources is necessary for the design and implementation of a successful tariffed on-bill program. This guide follows steps outlined in the EEI Decision Tool to facilitate navigation of this process, available under **Introductory Resources**.

On-bill financing is a means of paying for energy efficiency upgrades through payments on customer electric bills over time. It has been most commonly implemented using a loan model where a utility loans capital to a customer to pay for the upfront cost of energy upgrades, or alternatively, a third-party lender makes consumer loans to eligible customers and collects the debt payments with a charge on the utility monthly bill.

Over the past decade, many utilities have seen greater program participation and energy savings by implementing a tariffed on-bill program (TOB). A TOB program differs from typical utility rebate and loan programs in several important ways, in particular, the customer eligibility criteria are much broader and barriers to participation are much lower. For example, TOB programs can be implemented to serve any type of customer, including renters and low-to-moderate income (LMI) customers, whereas rebate and loan programs are effectively limited to building owners with available capital or a willingness to take on debt. This guide is intended to describe key attributes of TOB programs and the resulting benefits reported in the field. For utilities interested in adopting a TOB program model, it also provides information on best practices and lessons learned as well as answers to frequently asked questions.

On-Bill Program Model

Tariffed on-bill programs treat improvements to the energy performance of homes and buildings as an investment in system reliability and as a development of lower cost distributed energy resources, such as energy efficiency. The utility employs its established authority to make investments and seek cost recovery through tariffs using existing mechanisms for issuing bills and collecting revenue. The investment in energy savings is tied not to an individual customer but to the location until the value of the utility's investment is recovered. A tariffed investment does not add to the debt profile of the location owner the way a bank loan would. A notable benefit of this model is that it can be utilized by renters and LMI customers, especially those with limited credit or low credit scores, because the utility's investment is based on the cost effectiveness of the upgrades and not the socio-economic status of the billpayer at that location.

Pay As You Save® (PAYS®) is a market-based system developed by the Energy Efficiency Institute (EEI) that provides a platform for TOB investment programs. Pay As You Save® and its acronym, PAYS®, are EEI trademarks for a resource efficiency system defined by specific essential elements and minimum program requirements. EEI has never charged a utility implementing a program consistent with that definition for use of the trademark, providing the program has all of these elements and program requirements. The trademarks ensure that "Pay As You Save" and "PAYS" may only be used to refer to programs with the essential elements and program requirements that have produced successful programs reaching all customers, including hard-to-reach customers. Customers, vendors, and capital providers using the PAYS system have produced an unprecedented rate of resource efficiency investment while also improving options for low cost, local, clean energy resources. PAYS is the most widely used form of tariffed on-bill programs for energy efficiency.

Introductory Resources

- On-Bill Finance (SEEA website)
- Inclusive Financing for Energy Efficiency Webinar Series
- Low-income Energy Efficiency Financing through On-Bill Tariff Programs
- Tariffed On-Bill Financing Programs Presentation
- ACEEE Summer Study on Buildings, 2018
- EEI Tariffed On-Bill Decision Tool for Utilities

Preliminary Assessment and Program Design

There are several steps to conducting an effective preliminary analysis and many program design elements to consider in launching a TOB program. The utility must establish a tariff to recover its costs on customer bills and secure or allocate sufficient funds to pay for installations and to operate the TOB program. Program design considerations include the role of a program operator, the duration and estimated size of the program, outreach to customers with a high likelihood of cost-effective savings, and potential software system upgrades. Other considerations include legal and regulatory requirements, licensing or developing program forms, and agreements and protocols.

From preliminary analysis to program approval, timelines have ranged from six to eighteen months. Once a tariff is approved, utilities have been able to launch programs in as little as three to four months. The overall process is shorter if the utility's regulatory oversight body is its own board.

Financial Analysis

Cost Recovery

Of the utilities who have implemented TOB programs, and who have reported on cost recovery, TOB program collection rates exceed those for electricity sales. One utility reported cost recovery for their TOB program at 99.8%, the others 99.9%. Because the utility must meet its capital obligations regardless of collections from upgraded locations, it must recover missed payments charged off from its accounts receivables (i.e. expected payments). For charge offs of this scale (0.1% and 0.2%), utilities routinely recover the missed revenue from all customers as part of their normal rate setting mechanisms.

Resources

- Financial Analysis of a Pay As You Save® Investment Program

To maintain high levels of customer engagement, utilities must ensure that no more than 80% of the estimated annual savings are used to cover annual TOB cost recovery charges. The onsite cost effectiveness analysis for targeted upgrades must include the utility's current retail rates, actual upgrade price, estimated savings at that location, the value of rebates or incentives that can be applied to lower project expenses, and the utility's upfront investment. The maximum cost recovery period must be equal or less than 80% of the estimated life of the upgrades.

To recover its investments, the utility must have a billing and collection system capable of processing TOB charges throughout the duration of cost recovery. Once the monthly charge is established for a participating location, the fixed payment amount remains constant. However, the time span for cost recovery may be increased due to missed payments, extended vacancy, or repair expense at that location to keep the upgrade functioning.

Feasibility

Utilities must consider the aggregate effect of energy efficiency investments on its overall business. Prior to implementation of a PAYS program, utilities are urged to perform a financial analysis of the impacts of operating the program. This analysis should include the inputs to the cost effectiveness analysis, the utility's cost of power supply, the value of all utility benefit streams generated by the upgrades (e.g. peak demand reduction), and the estimated number of participating customers.

Legal and Regulatory Approval

Generally, TOB programs are subject to the same oversight and approval process as other tariffs. The specifics vary by utility type and the utility's relationship with its oversight or regulatory body (public service commission, cooperative board, city council, etc.). While evaluating the feasibility of implementing a TOB program, utilities should also complete a legal review of tariff, contracts, and other forms to ensure compliance with state and local requirements. The utility should also have a clear understanding of the agreements involved in a tariffed on-bill program. Most current TOB programs purchased licensed Intellectual Property (IP) from EEI or hired a licensed IP operator. Alternatively, a utility can develop its own agreements, worksheets, and forms. The choice includes consideration of staff time and cost to develop documents that are untested in the field. Utilities using licensed IP to develop their TOB program may adapt the materials, recognizing that changes in the PAYS system may impact performance.

Resources

- Authority for Rural Electric Membership Corporations to adopt the PAYS® System of Tariffed On-Bill Financing for Energy Efficiency in North Carolina

Many electric cooperatives and municipal utilities can establish tariffs under the authority of their oversight boards without being subject to state regulatory approval. Regulated utilities seeking public service commission (PSC) approval of TOB programs can benefit from precedents set by commissions in other states. Dockets for proposed TOB program tariffs are currently open in Arkansas, Hawaii, Kansas, Kentucky, and New Hampshire. The orders linked below show commission approval; see full dockets for more details.

TOB Docket Orders

- Arkansas PSC Docket 15-106-TF Order No. 2
- Hawaii PSC Docket No. 2006-0425 Order No. 23531
- Kansas Corporation Commission Docket No. 09-MDWG-777-TAR
- Kentucky PSC Docket Order No. 20101-00089
- New Hampshire PSC Docket DE 01-080 Order No. 23,758

Sourcing Capital

There are multiple options for sourcing capital for a TOB program. The cost of capital varies depending on whether it is sourced as debt, equity, or a weighted average of both. Investor Owned Utilities (IOUs) in New Hampshire and Hawaii have used ratepayer funds budgeted for efficiency programs to start their TOB programs, and in both cases, the funds proved to be insufficient compared to demand for the programs. As a result, ratepayer funds are not considered to be a long-term capital source solution.

Resources

- Sourcing Capital for Inclusive Financing Webinar
- Deliberative Approach to Developing a Reserve Fund for a TOB Investment Program for Efficiency Upgrades
- NCSEA Energy Solutions Reserve Fund

Licensing (PAYS® vs. TOB)

PAYS start-up expenses can include the cost for licensing Intellectual Property (IP), which includes a standardized Implementation Plan and consulting support. A utility may license IP directly itself or work with a program operator that has licensed IP.

A utility can design and implement a TOB program without the PAYS IP, however, there is currently not a successful TOB program that has been tested and measured that did not use directly use PAYS IP or an operator with licensed IP.

Whether or not a TOB program is designed with licensed IP, the utility is required to arrange for a legal review of all program documentation in the context of the state legal and regulatory environment.

PAYS® Intellectual Property

EEI licenses its IP to individual utilities and states for fees based on the size of the utility. EEI includes the PAYS Tariff Model as a part of its IP but offers it free of charge to any utility that requests it and can provide a list of PAYS-certified program operators who can use its IP without a utility fee.

Program Design Considerations

Eligibility: While a customer may be eligible to opt into a TOB program, the building that they seek to upgrade may not qualify. Most utilities prohibit installations at buildings not likely to be habitable or suitable for the building's purpose for the duration of TOB charges. If a building needs major structural repairs, it is likely not a good site for investing in a long-term energy efficiency upgrade.

Program Size: Custom TOB programs can be of any size, providing they are cost-effective. Programs often vary based on the size of the utility and the class of customers served. Pilot programs should target enough customers to provide useful program data for evaluation. The most effective programs reach approximately 4% of their customers in approximately three years and can spend approximately four dollars on customer improvements for every one dollar of program administration.

Program Operator Models: A utility can implement its own TOB program or it can hire a third-party operator to oversee the program. This decision may depend on the amount of available staff, the staff's experience with and knowledge of the targeted technologies, the accurate estimation of their savings, and the size and complexity of the program.

Standard or Custom Implementation: The PAYS system is designed so that a utility can invest in any upgrades that produce sufficient net savings for any class of customers while allowing the utility to recover its costs. The utility can follow a standardized implementation plan for residential customers or create a customized plan to reach more customers. Whole house energy upgrades are likely to qualify for a tariffed charge at any utility but will vary with weather, residential energy rates, labor rates, negotiated upgrade prices, and housing types and conditions. Utilities can also offer single-measure upgrades such as heat pumps for a standardized residential program.

Resources

- PAYS® Model Tariff
- PAYS® Essential Elements & Minimum Program Requirements
- Options for Program Operator Services in an Inclusive Financing Program Webinar

Software and Billing

Integration of a TOB program with the utility's billing and information system is an essential component of planning for implementation. Utilities may consider adjusting billing and management systems for TOB programs. Of the 18 utilities that have implemented TOB, only one paid for enhancements to support program implementation. This utility's cost for enhancements was under $40,000. Utilities already considering enhancements to their billing and information systems can easily integrate requirements for a TOB program as part of the improvement project.

Resources

- Program Billing Systems and Administrative Functions Checklist
- Billing and Information System Enhancement Advice

Program Evaluation

Cost effectiveness analysis software and training support program implementation and facilitate evaluation, measurement, and verification (EM&V) processes. Utilizing deemed savings is too generalized to accurately estimate individual project savings. Utilities, or their program operators, implementing whole-house energy upgrades must purchase building energy efficiency analysis tools such as blower doors, pressure pans or duct blasters, and in some jurisdictions infrared cameras. For quality assurance and oversight, it is important that utilities implementing TOB programs have staff knowledgeable about the proper use of this equipment and capable of verifying third party staff performance and test results.

Resources

- HELP PAYS® Residential Energy Efficiency Program Evaluation
- DOE Uniform Method for Whole Building Energy Retrofits

Success Stories

Utilities exploring their options can gain insight from the experience of existing TOB programs in the region. The following resources provide information on TOB programs for energy efficiency.

Arkansas

Ouachita Electric Cooperative – HELP PAYS®
Ouachita Electric Cooperative started its HELP PAYS® program in 2016 after recognizing its previous on-bill loan program, called HELP, posed higher financial risks, limited eligibility, and limited project size.

Learn More

- Ouachita's HELP PAYS® Program
- HELP PAYS® Program Report, June 2017

Ouachita Electric worked with its program operator, EEtility, to make the transition from making consumer loans to making TOB investments. The tariff was approved by the state's utility commission in approximately four months, accounting for half of the time in the transition from due diligence to field implementation, which was eight months. Ouachita EMC upgraded 198 homes during eight months of 2016, reaching 2% of the market in the utility's service area. The utility prioritized attention to renters in multifamily homes, making an offer to capitalize upgrades in every rental unit assessed. Of eligible units, 100% opted to proceed with the upgrades. In addition, more than 80% of the residents in single-family homes who received an offer through the HELP PAYS® program accepted it. Comparing the best four months of the previous on-bill loan program to the first four months of the HELP PAYS® program, the project size and number of participants doubled. The average cost of an upgrade project was $5,634, and the average estimated energy savings was 22%.

Kentucky

MACED – How$mart®KY

The Mountain Association for Community Economic Development (MACED) has administered the How$mart®KY TOB program since 2011. At the time of publication, it is offered by six electric co-ops, all of which partner with MACED as the program operator. MACED worked with the co-ops to adapt its program design from intellectual property licensed from the Energy Efficiency Institute, as well as on precedents developed by Midwest Energy's How$mart® program in Kansas. Residential and small commercial customer classes are eligible, and most of the projects are residential. As of June 2019, the program had assessed 607 buildings, offered upgrades to 405 member-owners, and facilitated 320 energy efficiency retrofits. The average job cost is $7,743, and the cost recovery rate is over 99.6%, with zero disconnections for non-payment. The average monthly projected savings is $51.98, or 5492 kWh, while the average monthly charge is $39.98.

Learn More

- How$mart®KY
- How the Program Works

North Carolina

Roanoke Electric Cooperative – Upgrade to $ave

Roanoke Electric Cooperative began Upgrade to $ave in July 2015 after finding the vast majority of customers with the highest bills in its service area would not qualify for or be willing to apply for a loan through its debt-based program. As of September 2017, the average Upgrade to $ave job cost was $7,200, and the average monthly tariffed charge for cost recovery was about $60, with cost recovery ranging from 4-12 years, while the estimated monthly savings averaged over $80 per month. Participants are estimated to keep an average of 25% of savings during the cost recovery period. As of June 30, 2019, the co-op has invested approximately $3.4 million into energy efficient upgrades for

Learn More

- Upgrade to $ave
- Open letter on the TOB program from the president and CEO of Roanoke Electric Cooperative, February 21, 2017
- Upgrade to $ave video
- Update on Inclusive Financing Programs in the South Webinar

member-owners through Upgrade to $ave and still has nearly $3.1 million left in federal financing to invest in the program with a capital cost less than 3%. 638 member-owners have already benefited from this high-impact program.

Tennessee

Appalachian Electric Cooperative – U-$ave Advantage

Appalachian Electric Cooperative was the third cooperative in the Southeast to implement a PAYS program and the first Tennessee Valley Authority local power company to do so. As of September 2019, the average job cost was $6,414, while the estimated monthly savings averaged more than $68 and 640 kWh per month. 37 member-owners have already benefited from this high-impact program, the result of an 82% conversion rate of eligible homeowners.

Learn More

- U-$Save Advantage

TOB Program Comparison

	AR	KY	NC	TN
Enrollees	850	N/A	1,093	103
Enrollees Assessed	630	607	632	80
PAYS Upgraded Buildings	518	405	511	57
Lite Upgrades	N/A	320	376	N/A
Average Dollars Financed	$6,041	$7,743	$7,096	$6,730
Average Monthly Energy Savings	$71.50	$51.98	$74.33	$63.08
Average Monthly Tariff	$54.45	$39.98	$56.97	$48.95
Charge Offs	0	0	0	0

Frequently Asked Questions

What is the average scale of investment in cost-effective energy efficiency upgrades through a tariffed, on-bill program?

- The average scale of investment in cost-effective energy efficiency upgrades at a site depends on the type of site, weather zone, the energy use equipment in the building, the utility's cost of capital, and the useful life of the upgrades being undertaken.
- For residential energy efficiency upgrades undertaken through on-bill programs in Kansas, Kentucky, and South Carolina, the average cost of all cost-effective energy efficiency upgrades at a location are in the range of $7,000-8,000.

If the utility capitalizes efficiency upgrades at a site, what happens to the obligation for cost recovery when a new customer signs up for service at that meter?

- In a tariffed on-bill program, the utility's cost recovery for a site-specific investment is tied to the location at the site until cost recovery is complete. The successor customer (whether renter or owner) will enjoy the net savings from the investment and will likewise be obligated to pay the fixed, on-bill charge, which is significantly less than the estimated annual savings.
- Due to the on-bill payments made by the prior customer(s) served by that meter, a successor customer will have fewer billing cycles remaining until cost recovery is complete, at which point they will keep 100% of the savings.

In the case of a renter, does the opt-in tariff require landlord approval? Does it require new renter approval?

- Before a utility can capitalize an upgrade to a property, the owner must consent by signing an agreement. In the same agreement, the owner commits to not removing the upgrade and to maintain it. The owner also agrees to provide notice to successor renters or prospective buyers that the utility has made improvements that result in savings for the account holder at that site. The agreement provides the owner with language that can be added to a lease agreement, for example.
- Because the terms of the tariff are binding on successor customers at that site, the utility need not seek approval from a landlord or renter thereafter. When each new successor customer opens an account at an upgraded site, the utility must provide information about the program and its benefits in order to explain the cost recovery charge that will appear on the bill until cost recovery is complete. This communication also ensures that notice has taken place.

Will an investor-owned utility require legislation to gain the authority to disconnect for non-payment of cost recovery for cost-effective energy efficiency upgrades?

- In states that do not allow customers to choose and change energy service providers: For a tariffed on-bill program, an investor-owned utility will need approval from the state utility commission for the terms of its investments that deliver essential utility services, as it does for other tariffed terms of service. Once approved, the tariff is a regulated charge, and subject to the same rules governing disconnection as any other regulated service.

Has any utility using the PAYS system reported a program participant being disconnected for non-payment?

- No, each utility with experience has affirmed no disconnections for non-payment of tariffed charges.

Does the opt-in tariff generate benefits that flow to all ratepayers?

- Yes, there are cross-subsidies from the opt-in tariff participants to non-participants. Examples of such benefits include avoided wholesale demand charges, avoided Transmission and Distribution costs, and deferred capital requirements to accommodate higher peak demand.
    - Utility systems with weather-driven peak demand can reduce peak demand by investing in energy efficiency upgrades to weather-driven loads. The scale of this potential savings stream depends on the climate zone of the service area.
    - Utility systems with distribution circuits or substations that are reaching load capacity can defer investment in expansion with deliberate focus on energy efficiency.

Acknowledgements

Support for this report is provided by the Weatherization and Intergovernmental Programs Office of the Department of Energy as well as the JPB Foundation. SEEA would like to thank the many organizations and individuals who provided input and expertise to help create this report.

Clean Energy
WORKS

EEtility
EFFICIENCY IS POWER

Energy Efficiency Institute

EESI
Environmental and Energy
Study Institute

NC SUSTAINABLE
ENERGY ASSOCIATION

MACED
Mountain Association for Community Economic Development

Liberty
Homes
LH

Southface

We, the undersigned, urge OPPD to set a firm date to close the North Omaha Coal Station on or before 2028.

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We, the undersigned, urge OPPD to set a firm date to close the North Omaha Coal Station on or before 2028.

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	Nils Ericksen	O	68132	
4/26	Hunter Saunders	Papillion	68133	
4/26	Adam Peterson	Omaha	68114	
4/26	Clara Wallace	Omaha	68157	
4/26	kayla Wycoff	Omaha	68122	
4/26	Sharon Clawson	Omaha	68122	
4/26	Tay Vickrey	Omaha	68131	
4/26	Andrew Kirchner	Omaha	68106	
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We, the undersigned, urge OPPD to set a firm date to close the North Omaha Coal Station on or before 2028.

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NO AGE REQUIREMENTS — ANYONE CAN SIGN!

12

We, the undersigned, urge OPPD to set a firm date to close the North Omaha Coal Station on or before 2028.

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6

We, the undersigned, urge OPPD to set a firm date to close the North Omaha Coal Station on or before 2028.

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We, the undersigned, urge OPPD to set a firm date to close the North Omaha Coal Station on or before 2028.

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Home Energy Reports and Beyond: Meeting the Moment with Behavior-Based Energy Efficiency

Reuven Sussman, Anna Johnson, and Forest Bradley-Wright

May 2026
Research Report

ACEEE

previous reports and analyses from multiple large datasets and data sources to provide a broad overview of the current landscape of behavior programs, which were also used to inform our recommendations.

Our review finds that HERs are an effective tool for driving residential energy savings. Analyses from 2016 and 2022 (as well as our review of 13 additional evaluations between 2023 and 2025) found that HERs continued to change behavior at roughly the same rate as when they were first introduced (Sussman and Chikumbo 2016; Galport 2022). As utilities, regulators, and program implementers consider the next generation of HERs, the emphasis should be on both sustaining traditional HER programs and pilot testing innovative enhancements that can expand their impact.

Key recommendations for utility regulators

Encourage customer participation in complementary programs by revising evaluation criteria and requiring channeling to low-income programs. Incentivize HER implementers to channel customers to structural efficiency programs to drive higher overall efficiency savings, support electrification, and connect low-income customers to energy support services. Revise evaluation criteria for HER programs to better assign savings attribution (to both HERs and other programs) and avoid penalizing HER programs for increased electricity consumption from home electrification or low-income energy assistance programs. These changes can be piloted (alongside traditional evaluation) before full implementation.

Encourage balanced efficiency portfolios. To meet evolving utility priorities, regulators can encourage utilities to maintain balanced portfolios that combine behavior-based "quick win" programs with deeper energy upgrade initiatives. While HERs deliver immediate savings, long-term strategies are also essential.[1] High-performing utilities invest between 3% and 53% of their residential efficiency budgets in HER programs. Performance incentives for utilities should be appropriate (not too high, not too low) for running HER programs. More research is needed to determine the optimal mix of short- and long-term programs that would best suit utilities with varying priorities and budgets.

Allow programs to continue as long as they remain cost effective. HER programs thrive when reports are consistently delivered over multiple years. Savings increase over the first two years, as customers develop energy-saving habits and behaviors, and those savings continue as long as reports are still received. We do not recommend terminating programs that deliver consistent and reliable savings as long as the cumulative lifetime savings are cost effective, but we recognize that some utilities' incentives and goals encourage short-duration programs.

Measure peak savings too. Encourage utilities to invest in behavior-based energy efficiency programs that reduce peak load by requiring the evaluation of peak savings alongside overall savings.

Pilot programs that use emerging behavior-based approaches. Regulators can encourage new behavior-based efficiency programs, both as standalone initiatives and as add-ons to HERs, by supporting pilot testing of HER 2.0-type programs and more innovative programs that go beyond HERs.

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[1] The optimal balance of long- and short-term programs required to achieve utilities' varied priorities has not yet been established. We recommend a gradual and measured approach to shifting the balance of program types within a portfolio to allow observation of how savings impacts are affected and ensure that both long and short-term savings are maintained at desired levels.

Potential HER 2.0 programs

Several new programs are currently offered by program implementers that save energy through similar behavior mechanisms to HERs. These might be considered "HER 2.0" options and are ready to be deployed at scale.

- **Peak energy savings**: Using behavioral science-informed messaging with customers during peak heat events to reduce energy consumption
- **High-bill alerts**: Sending customers notifications that their bill is likely to be higher than expected at the end of the month
- **Rate coaches, weekly energy updates, and HERs focused on load shaping**: Providing customers timely information on how to save money with special rates (e.g., electric vehicle (EV) rates and time-of-use rates) and coaching them to shift their energy use to specific times of the day when the grid is "cleanest"
- **Virtual energy assessments and infrared home visualizations**: Noninvasive virtual home energy assessments and/or overhead images of homes showing heat retention relative to other homes
- **Disaggregated real-time feedback**: Phone and web apps that provide real-time granular feedback on current home energy use by every device, appliance, and system

Recommendations for program implementers to augment traditional HERs

New research in psychology and behavioral science suggests that traditional HER programs could potentially increase their impact with some minor tweaks. Program implementers may want to consider pilot testing one or more of these if they are not already doing so:

- **Describe health and environmental benefits in targeted messaging.** Test messages with some audiences that highlight the health and environmental benefits of energy savings.
- **Highlight rising trends with dynamic norm messaging.** Incorporate dynamic norms (behaviors that are not yet conducted by most others but are on the rise) to encourage adoption of less common energy-saving actions, such as heat pump installation.
- **Augment neighbor comparisons to increase their relevance.** Compare peers who share both demographic and structural characteristics (similar people, not just similar buildings), which may increase the relevance and impact of HERs.[2]

Beyond HERs: new potential behavior-based energy efficiency ideas

Regulators and utilities that want to be on the forefront of behavior-based energy efficiency innovations could consider pilot testing strategies with demonstrated potential in peer-reviewed literature. These could include:

- **School-based programs**: Educating students on energy efficiency and encouraging them to save energy at home
- **Online tools facilitating energy conservation goal setting and commitment**: Providing a platform for customers to pick their goals and choose from a menu of energy efficiency actions to achieve them

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[2] Advanced analytics of customer data may be able to help create these comparisons, but data privacy regulations and customer perceptions are important to consider when using this strategy.

- **Gamification and "serious games":** Create and promote electronic games that teach energy efficiency and can be connected to actual home energy use

The role of HER programs and behavior-based efficiency

HERs have established themselves as a significant contributor to residential energy efficiency, delivering reliable savings at scale. The recommendations highlight the importance of sustaining traditional HER programs while evolving them into more sophisticated tools that leverage advanced data, behavioral science, and targeted messaging. Regulators play a critical role in enabling program longevity, portfolio balance, and innovation through flexible evaluation criteria and pilot support. Program implementers, meanwhile, are encouraged to experiment with HER 2.0 features that deepen customer engagement and align energy-saving behaviors with broader climate and equity goals.

By combining proven HER strategies with emerging approaches, utilities can maximize cost-effective savings, expand participation, and contribute meaningfully to decarbonization and energy equity. The path forward requires both continuity and innovation—maintaining the strengths of HERs while embracing new opportunities to enhance their impact in a rapidly evolving energy landscape.