BUILDINGENERGY BOSTON

The Climate Impact of Retrofits: Embodied and Operational Emissions in Weatherization

Megan Nedzinski (Vermont Integrated Architecture)
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Curated by Dave Boettcher (Abode) and Asher Greenberg (Steveworks)

Northeast Sustainable Energy Association (NESEA)
March 1, 2022

Research & Development provides Efficiency Vermont an opportunity *for staff and partners to pursue innovation and drive the evolution of the energy efficiency utility's programs and services.*

Overview

1 2020 Study:
Embodied Carbon in Residential Retrofits

2 2021 Study:
Embodied and Operational Emissions in Weatherization

3 Conclusions

Learning Objectives

1 Define and differentiate between embodied and operational carbon emissions

2 Quantify the relative scales of embodied and operational carbon emissions in residential weatherization

3 Analyze the time frame in which embodied and operational carbon emissions occur in residential weatherization, and how this applies to developing retrofit strategies

4 Identify different approaches for a variety of specific retrofit measures, and their relative impact on embodied and operational carbon emissions.

2020 Study:
Embodied Carbon in Residential Retrofits

Megan Nedzinski - Vermont Integrated Architecture, PC
Jacob Deva Racusin - New Frameworks
Chris Gordon, Brian Just, Matt Sharpe, and Mike Fink - Efficiency Vermont

https://www.efficiencyvermont.com/news-blog/whitepapers/embodied-carbon-in-vermont-residential-retrofits

Intro and Purpose

The authors sought to fill a gap in the growing body embodied carbon emissions analysis work by studying the contribution of weatherization materials, specifically in Vermont.

Quantify the embodied carbon associated with residential retrofit projects.

Understand if and how weatherization work, including material choices have changed over time.

Aid in decision-making for future weatherization scope and material selections from a climate impact perspective

Building on 2020 Research Tasks and Findings

1. Determine and illustrate the density of HPwES projects in Vermont by geographic location.

2. Determine the types of insulation materials used in specific residential building assemblies (walls, attics, band joist, foundation walls) and if/how these choices have changed over time.

3. Characterize the embodied carbon emissions by application type to understand:

   a) which types contribute most to CO_2e (carbon dioxide equivalent) emissions

   b) which applications are the most carbon intensive

4. Illustrate the evolution of HPwES installations and the associated embodied carbon emissions over time (by material and application).

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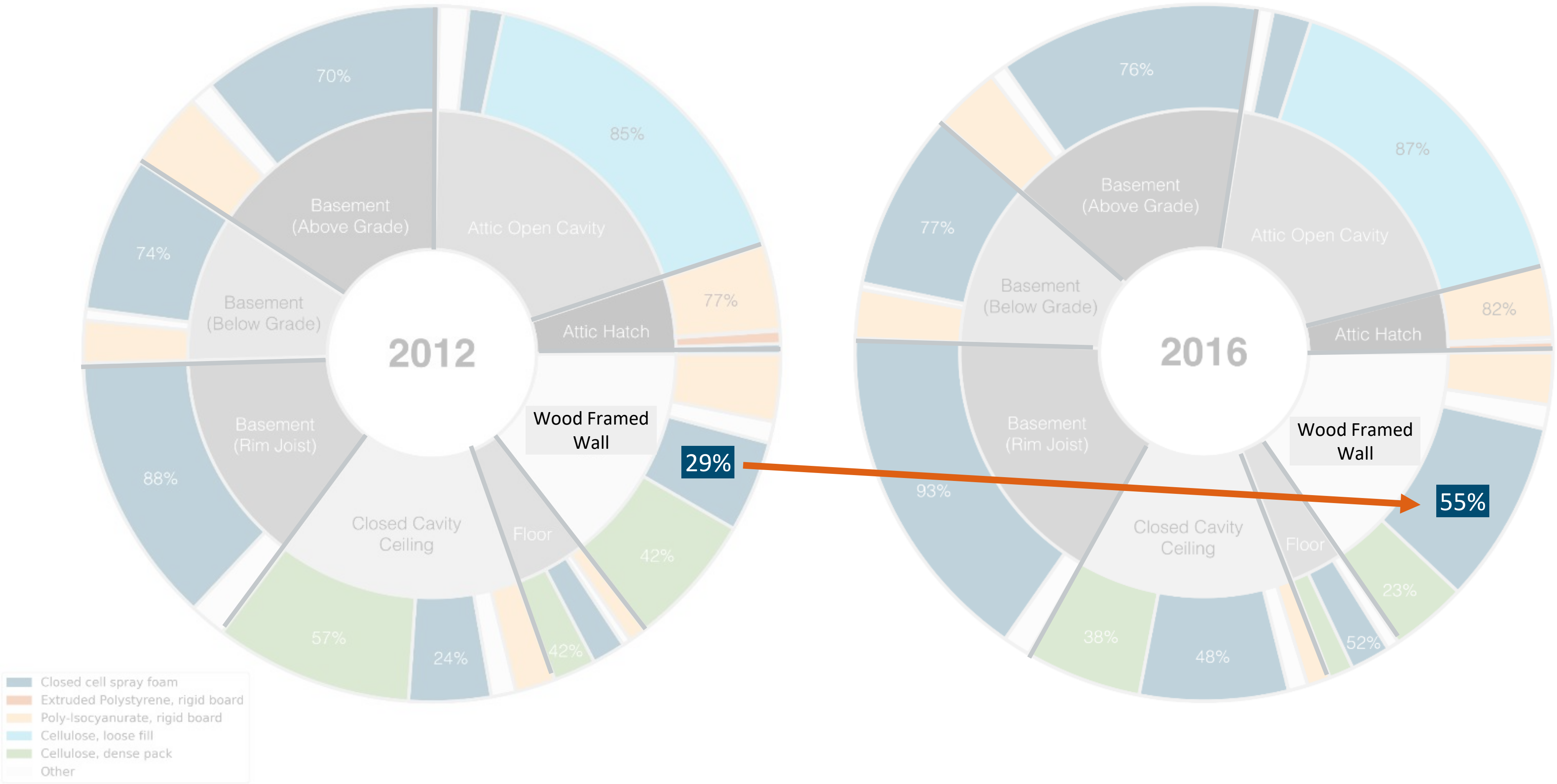
2020 Findings
#2: Types of insulation used in specific retrofit assemblies

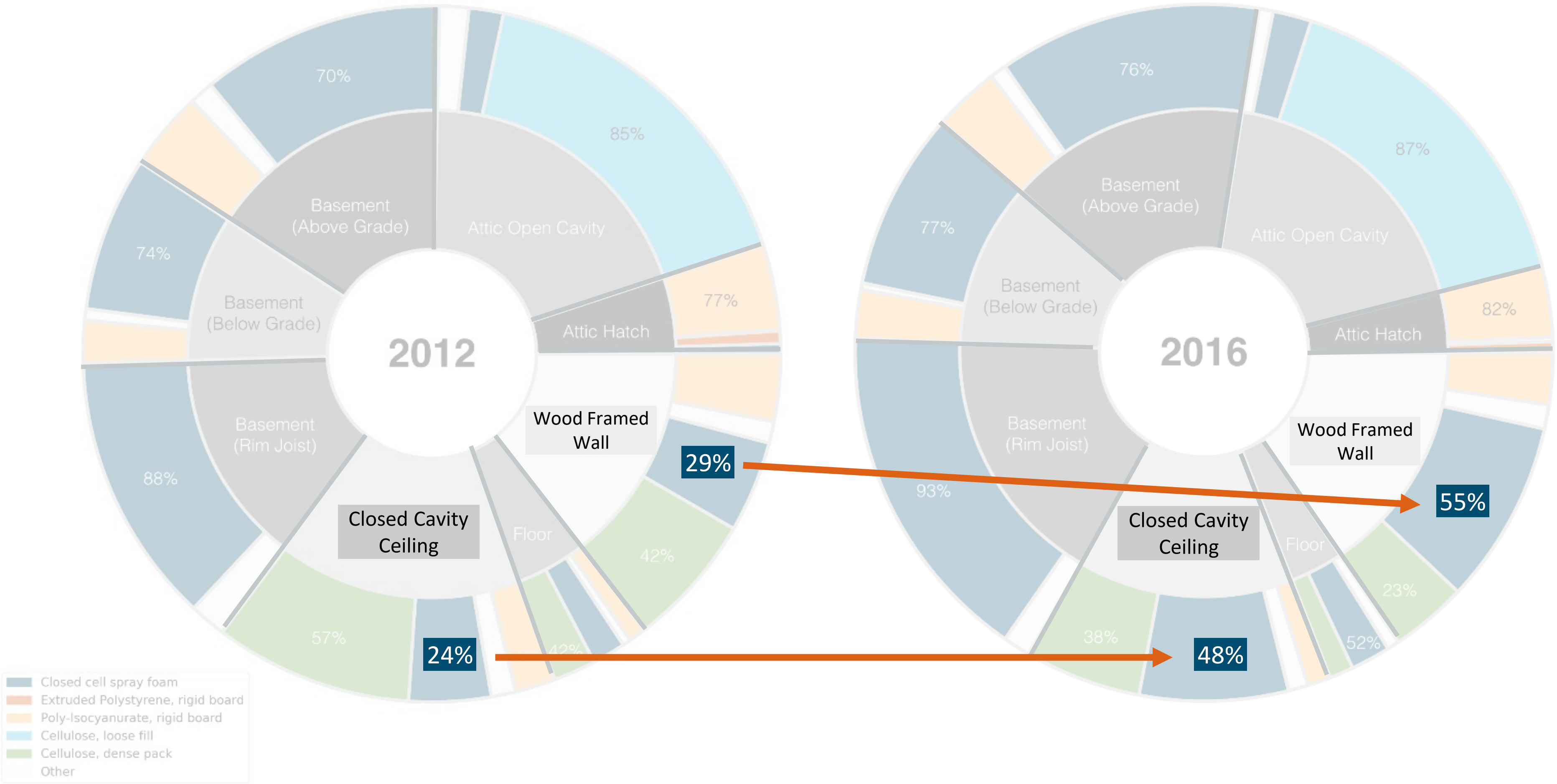


- *Assemblies receiving insulation remained fairly constant*
- *Insulation type used remained largely unchanged*
- ***Closed cavity ceilings and wood framed walls, however, showed a proportional increase in the use of closed cell spray foam.***

Closed Cavity Ceiling (2012)	Closed Cell SPF	24%	Dense Pack Cellulose	57%
Closed Cavity Ceiling (2016)	Closed Cell SPF	48%	Dense Pack Cellulose	38%
Wood Framed Walls (2012)	Closed Cell SPF	29%	Dense Pack Cellulose	42%
Wood Framed Walls (2016)	Closed Cell SPF	55%	Dense Pack Cellulose	23%

2020 Findings

#2: Types of insulation used in specific retrofit assemblies



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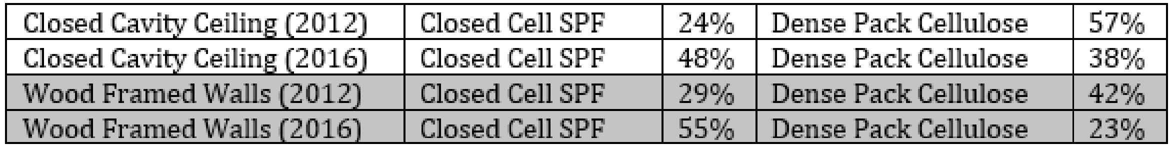

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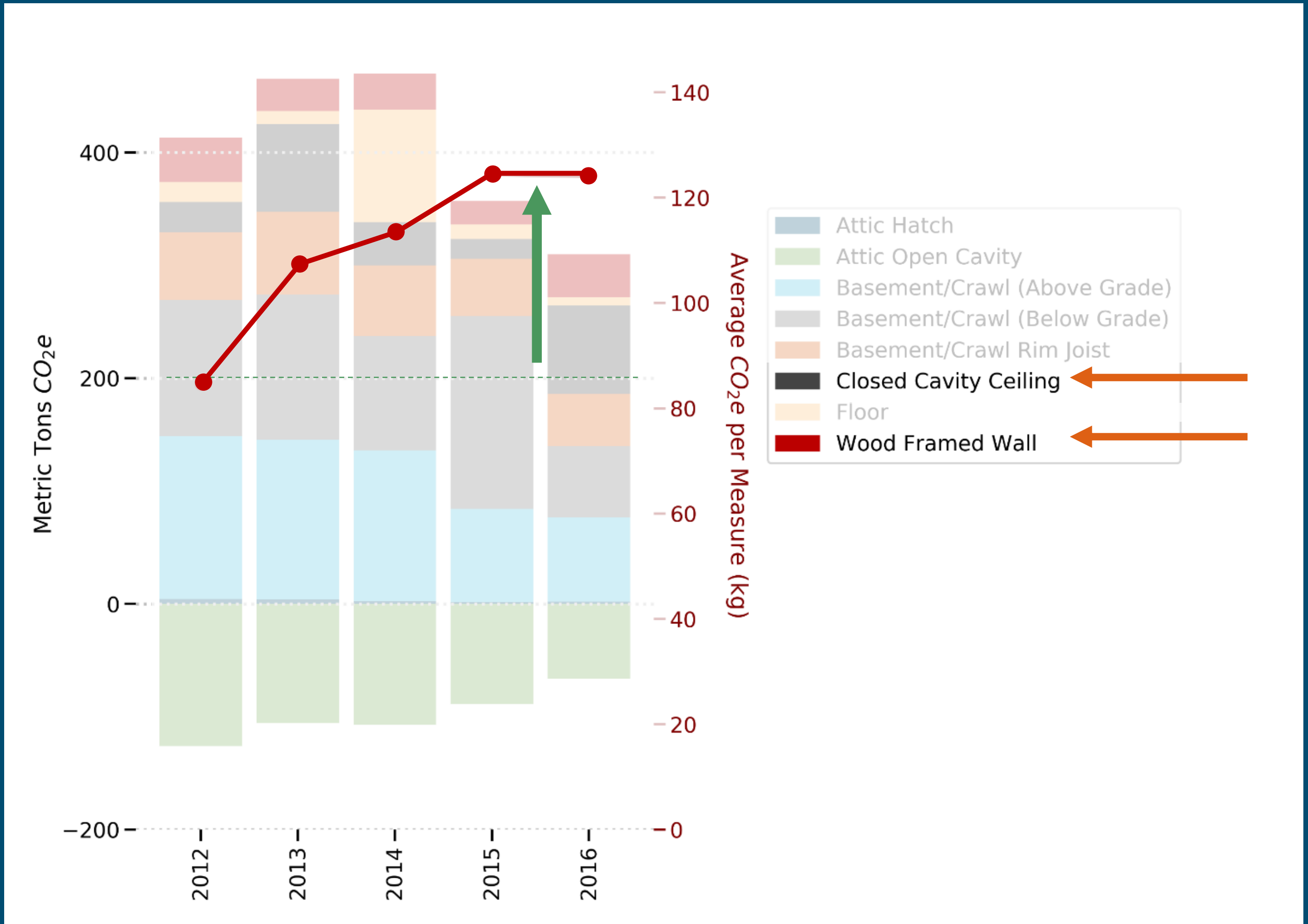
2020 Findings

#4a. Embodied carbon emissions by application type, over time:



How are total CO2e emissions changing over time?

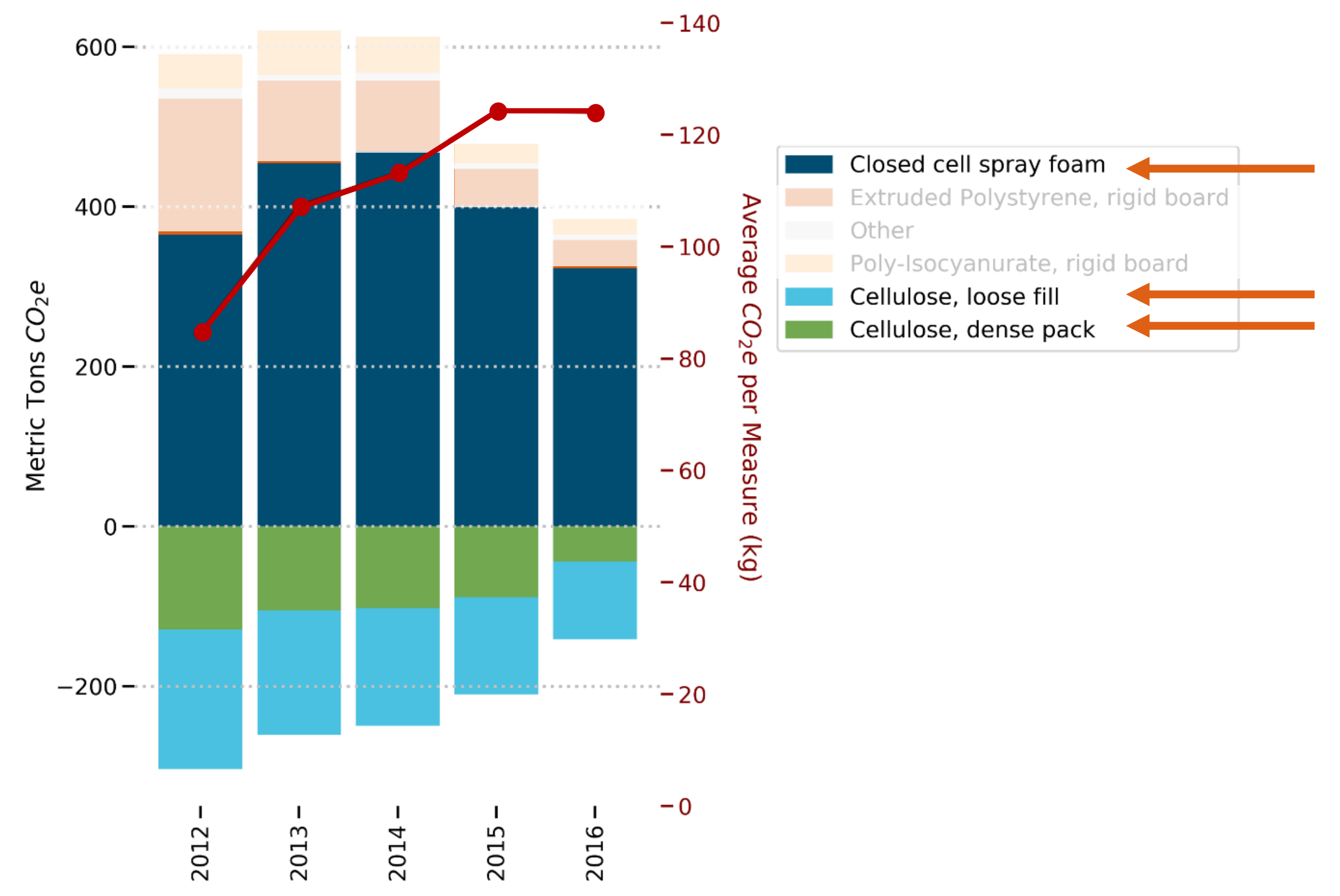
- *Emissions went down due to fewer projects*

How are CO2e emissions changing over time for different applications?

- *Becoming more carbon intensive*

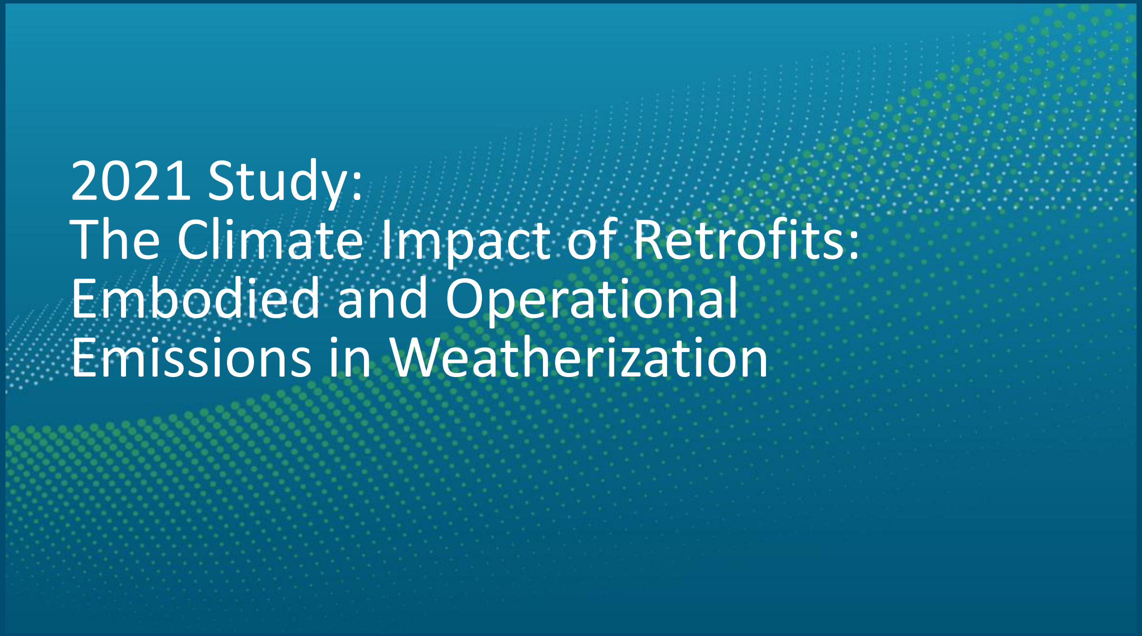
2020 Findings

4b. Embodied carbon emissions by material type, over time:



How are CO2e emissions changing over time for different materials?

What is the relationship between increasing average emissions and decreasing total emissions?



2021 Study:
The Climate Impact of Retrofits:
Embodied and Operational
Emissions in Weatherization

Megan Nedzinski - Vermont Integrated Architecture, PC
Jacob Deva Racusin - New Frameworks
Leslie Badger, Chris Gordon, Brian Just, - Efficiency Vermont

Intro and Purpose

Understand the relationship between embodied emissions and operational emissions

Identify the threshold or “tipping point” between material emissions and operational emissions of weatherized homes

Aid in decision-making for weatherization scope and material selections from a climate impact perspective

Definitions, Studied Conditions & Datasets

A “typical Vermont home”

- approximately 2,200 square feet
- two-story
- three-bedroom
- single-family residence

Datasets were used to establish baseline modeling assumptions

- HPwES was primary source of data
- Assumptions were cross-referenced with the Vermont Department of Public Service’s “Vermont Single-Family Existing Homes Overall Report” to confirm as reasonable

Definitions, Studied Conditions & Datasets

Scenarios

Baseline

- Typical VT home, unweatherized, the "do-nothing" scenario

"Common Practice"

- Derived from 2020 study
  - ccSPF (HFO)

"Carbon Smart"

- Replaced higher embodied carbon materials with lower embodied carbon materials
  - Polyiso
  - DP cellulose
- Existing Cavity restrictions / code venting

"Carbon Smart"

Equivalent-R

- "Carbon Smart" materials
  - Polyiso
  - DP cellulose
- No cavity restrictions = equivalent R

Definitions, Studied Conditions & Datasets

Materials – *“the type of insulation”*

- Cellulose
- Poly-isocyanurate- rigid board
- Spray foam- closed cell (ccSPF [HFO])
    - w/ HFO blowing agent

Applications – *“the physical space”*

- Basement, below grade
- Basement rim joist
- Wood-framed wall
- Closed-cavity ceiling

Definitions, Studied Conditions & Datasets

Datasets -

- Efficiency Vermont Home Performance with ENERGY STAR® (HPwES) program data
  - 2012-2016, installed measures
- Vermont Department of Public Service's Vermont Single-Family Existing Homes Overall Report
- State of Wisconsin 2020 study "Assessment of Energy and Cost Savings for Homes Treated under Wisconsin's Home Energy Plus Weatherization Program,"

Dataset application

- ➢ Established baseline modeling assumptions (available cavities, fenestration, areas, etc.)
- ➢ Cross-reference data source to confirm calculated cavities and assumptions as reasonable
- ➢ Energy model calibration

Definitions, Studied Conditions & Datasets

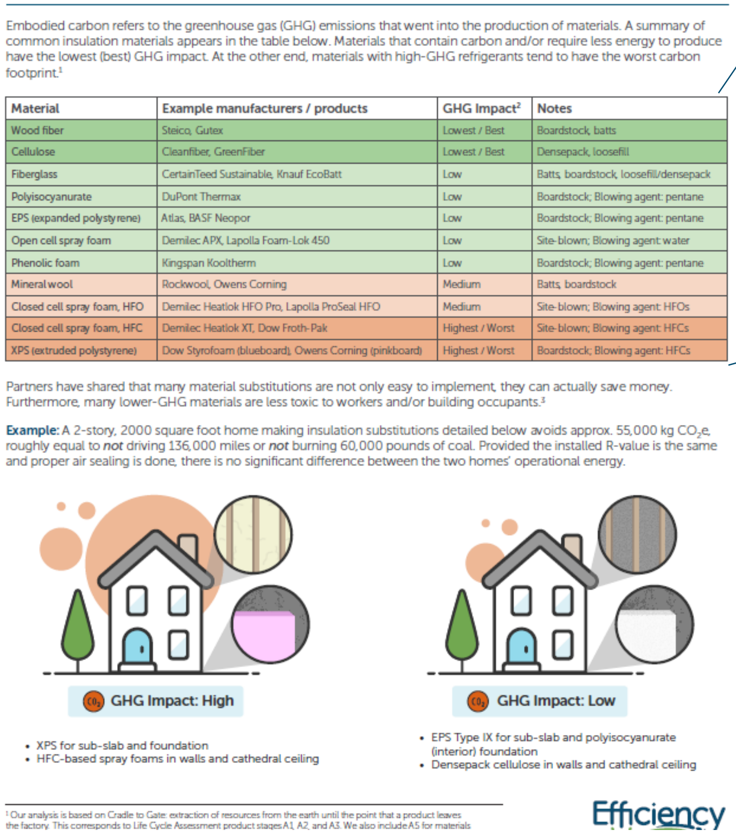
Scenarios

Condition	Baseline	Common Practice	Carbon Smart	Carbon Smart – Equivalent-R
Foundation (8” concrete)	R-3.5	R-19.8 (3” ccSPF)	R-19.6 (3” polyiso)	R-19.6 (3” polyiso)
2x10 Rim Joist	R-5.8	R-19.8 (3” ccSPF)	R-19.8 (5.5” DP cellulose w/ caulking)	R-19.8 (5.5” DP cellulose w/ caulking)
Wood framed Walls (2x4, 16” o.c.), no continuous insulation	R-6.75 nominal R-8.77 effective	R-19.8 nominal R-13.5 effective (3” ccSPF)	R-12.46 nominal R-11.49 effective (3.5” DP cellulose w/ caulking)	R-19.8 nominal R-13.5 effective (5.5” DP cellulose w/ caulking)
Attic Framing (2x8s @ 16” o.c.)	R-9.9 nominal R-10.5 effective	R-39.4 nominal R-28.57 effective (6” ccSPF)	R-18.7 nominal R-17.86 effective (5.25” DP cellulose, w/ caulking, 2” venting)	R-39.4 nominal R-28.57 effective (11” DP cellulose, w/ caulking, 2” venting)
Air-infiltration (ACH50)	12	8.4	8.4	8.4

Definitions, Studied Conditions & Datasets

Embodied Carbon – LCA stages included

2020 study by Brian Just of VEIC



Embodied carbon refers to the greenhouse gas (GHG) emissions that went into the production of materials. A summary of common insulation materials appears in the table below. Materials that contain carbon and/or require less energy to produce have the lowest (best) GHG impact. At the other end, materials with high-GHG refrigerants tend to have the worst carbon footprint.[1]

Material	Example manufacturers / products	GHG Impact[2]	Notes
Wood fiber	Steico, Gutex	Lowest / Best	Boardstock, batts
Cellulose	Cleanfiber, GreenFiber	Lowest / Best	Densepack, loosefill
Fiberglass	CertainTeed Sustainable, Knauf EcoBatt	Low	Batts, boardstock, loosefill/densepack
Polyisocyanurate	DuPont Thermax	Low	Boardstock; Blowing agent: pentane
EPS (expanded polystyrene)	Atlas, BASF Neopor	Low	Boardstock; Blowing agent: pentane
Open cell spray foam	Demilec APX, Lapolla Foam-Lok 450	Low	Site-blown; Blowing agent: water
Phenolic foam	Kingspan Kooltherm	Low	Boardstock; Blowing agent: pentane
Mineral wool	Rockwool, Owens Corning	Medium	Batts, boardstock
Closed cell spray foam, HFO	Demilec Heatlok HFO Pro, Lapolla ProSeal HFO	Medium	Site-blown; Blowing agent: HFOs
Closed cell spray foam, HFC	Demilec Heatlok XT, Dow Froth-Pak	Highest / Worst	Site-blown; Blowing agent: HFCs
XPS (extruded polystyrene)	Dow Styrofoam (blueboard), Owens Corning (pinkboard)	Highest / Worst	Boardstock; Blowing agent: HFCs

Partners have shared that many material substitutions are not only easy to implement, they can actually save money. Furthermore, many lower-GHG materials are less toxic to workers and/or building occupants.[3]

Example: A 2-story, 2000 square foot home making insulation substitutions detailed below avoids approx. 55,000 kg CO_2e, roughly equal to *not* driving 136,000 miles or *not* burning 60,000 pounds of coal. Provided the installed R-value is the same and proper air sealing is done, there is no significant difference between the two homes' operational energy.

GHG Impact: High

- XPS for sub-slab and foundation
- HFC-based spray foams in walls and cathedral ceiling

GHG Impact: Low

- EPS Type IX for sub-slab and polyisocyanurate (interior) foundation
- Densepack cellulose in walls and cathedral ceiling

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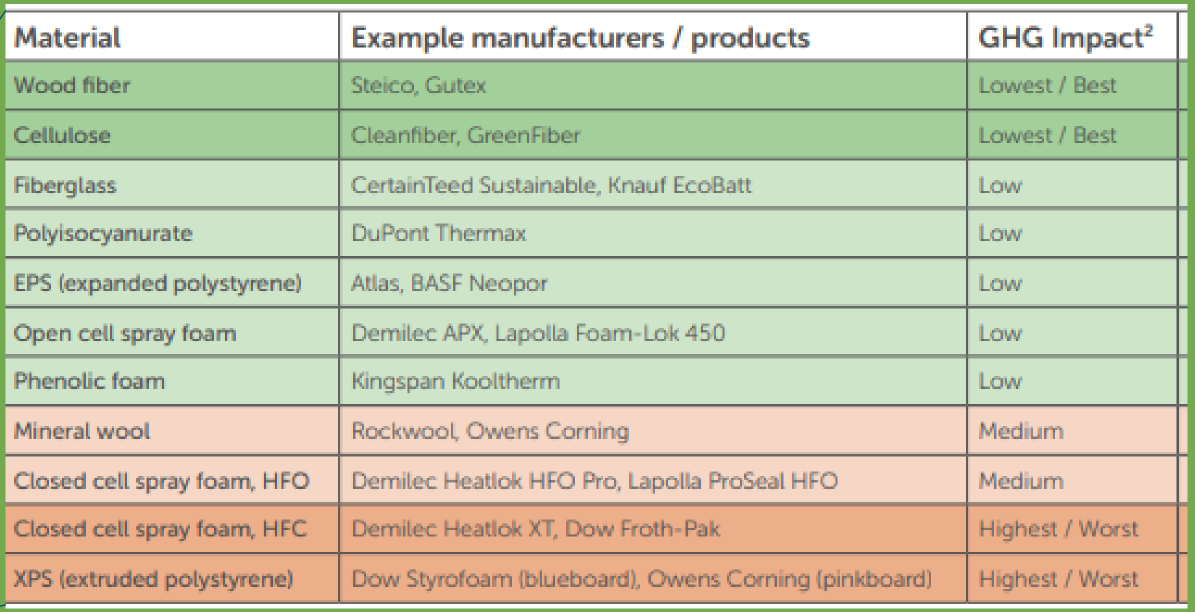
[1] Our analysis is based on Cradle to Gate: extraction of resources from the earth until the point that a product leaves the factory. This corresponds to Life Cycle Assessment product stages A1, A2, and A3. We also include A5 for materials

Source: Just, "The high greenhouse gas price tag on residential building materials: True life cycle costs (and what can be done about them)."

https://www.efficiencyvermont.com/Media/Default/docs/printable-resources/GeneralInfoForHomes/EVT-Home-Insulation-GHG-OnePager.pdf



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Cellulose	Cleanfiber, GreenFiber	Lowest / Best
Fiberglass	CertainTeed Sustainable, Knauf EcoBatt	Low
Polyisocyanurate	DuPont Thermax	Low
EPS (expanded polystyrene)	Atlas, BASF Neopor	Low
Open cell spray foam	Demilec APX, Lapolla Foam-Lok 450	Low
Phenolic foam	Kingspan Kooltherm	Low
Mineral wool	Rockwool, Owens Corning	Medium
Closed cell spray foam, HFO	Demilec Heatlok HFO Pro, Lapolla ProSeal HFO	Medium
Closed cell spray foam, HFC	Demilec Heatlok XT, Dow Froth-Pak	Highest / Worst
XPS (extruded polystyrene)	Dow Styrofoam (blueboard), Owens Corning (pinkboard)	Highest / Worst

Table 1. Global warming potential (GWP) of insulation material and R-value summary (partial list)[1]

* Averages used in this study are based on 100-year GWP value and appear in highlighted column.

Material	Form or variant	R-value/ inch	GWP average* kg CO_2e [A1-A3 w / A5+B1] per m^2 RSI-1	GWP components
Cellulose	Dense pack, 3.55 pcf	3.56	-2.16	A1-A3, A5, B1 carbon storage
Polyisocyanurate	Board, foil-faced	6.53	2.32	A1-A3; A5, B1 not given
Spray polyurethane foam (SPF)	Spray, closed-cell hydrofluorocarbons (HFC)	6.60	14.86	A1-A3, A5, B1
Spray polyurethane foam (SPF)	Spray, closed-cell hydrofluoroolefins (HFO)	6.60	4.00	A1-A3, A5, B1
Air-sealing Caulking[4]	Siliconized Acrylic Sealant	N/A	1.7	A1-A3

[1] Brian Just. "The high greenhouse gas price tag on residential building materials: True life cycle costs (and what can be done about them)." Efficiency Vermont R&D Program Report, 2020.

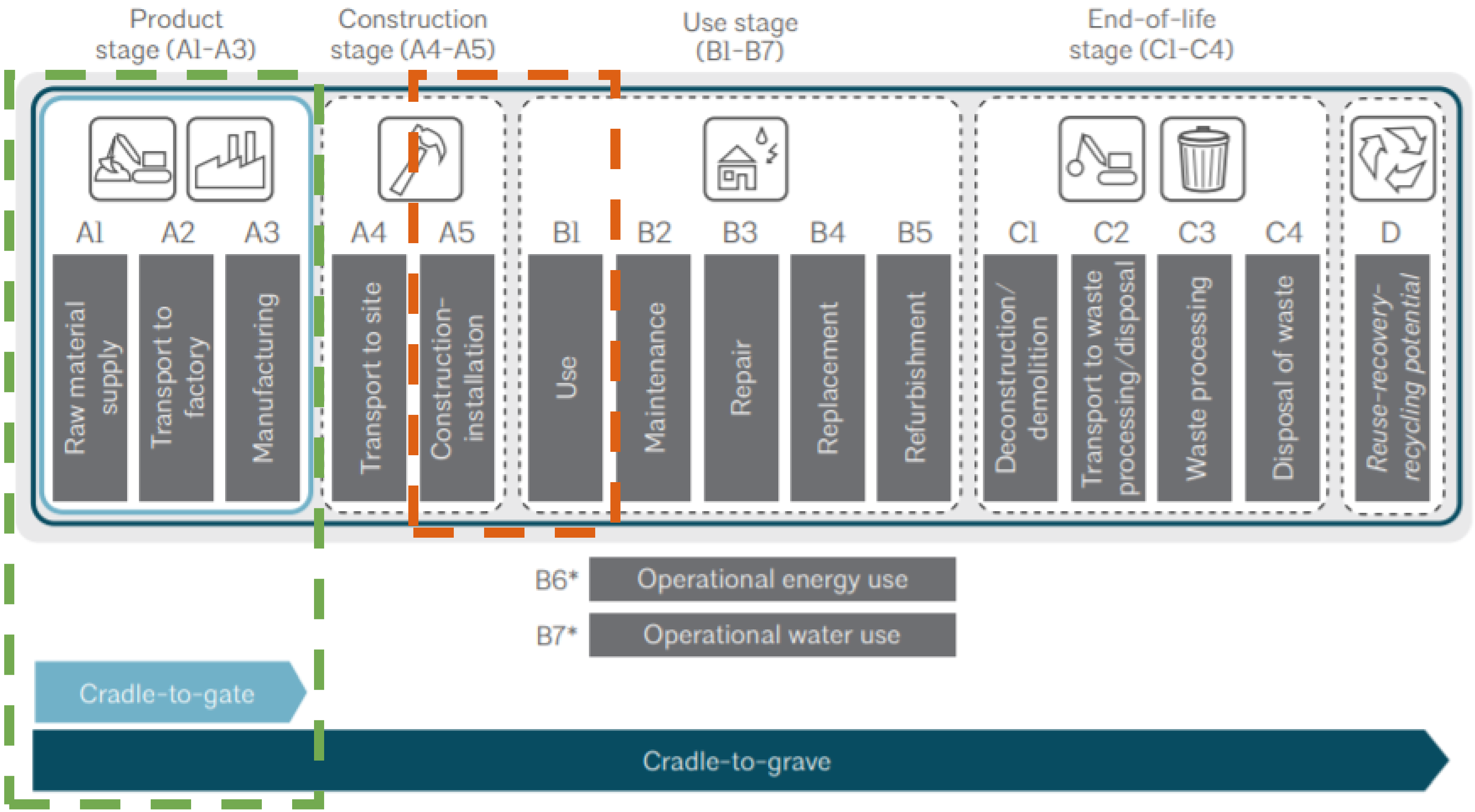
[4] This material was not included in the study referenced by footnote 6 and was calculated from Top Gun Sealants EPD

Definitions, Studied Conditions & Datasets

Embodied Carbon – LCA stages included

FIGURE 1

Life cycle stages for building products. Based on EN 15978:2011 and ISO 21930:2017.



*Operational carbon stages that are typically excluded from life cycle assessments focused on embodied carbon.

Source: Meghan Lewis, Monica Huang, Stephanie Carlisle, Kate Simonen, “AIA-CLF Embodied Carbon Toolkit for Architects, Part II: Measuring Embodied Carbon,” 2021. https://content.aia.org/sites/default/files/2021-10/21_10_STN_DesignHealth_474805_Embodied_Carbon_Guide_Part2.pdf

2021 Research Tasks

1 Calculate the approximate operational carbon savings when a typical existing Vermont home is weatherized using the most commonly adopted HPwES practices.

Approach

1 Calculate the approximate operational carbon savings when a typical existing Vermont home is weatherized using the most commonly adopted HPwES practices.

Typical VT Home
HPwES data + PSD Report

Energy Model
OpenStudio(OS)
Parametric Analysis Tool (PAT)

1st Year Operational Energy
kgCO2e

RESEARCH TASK #1: Operational Savings

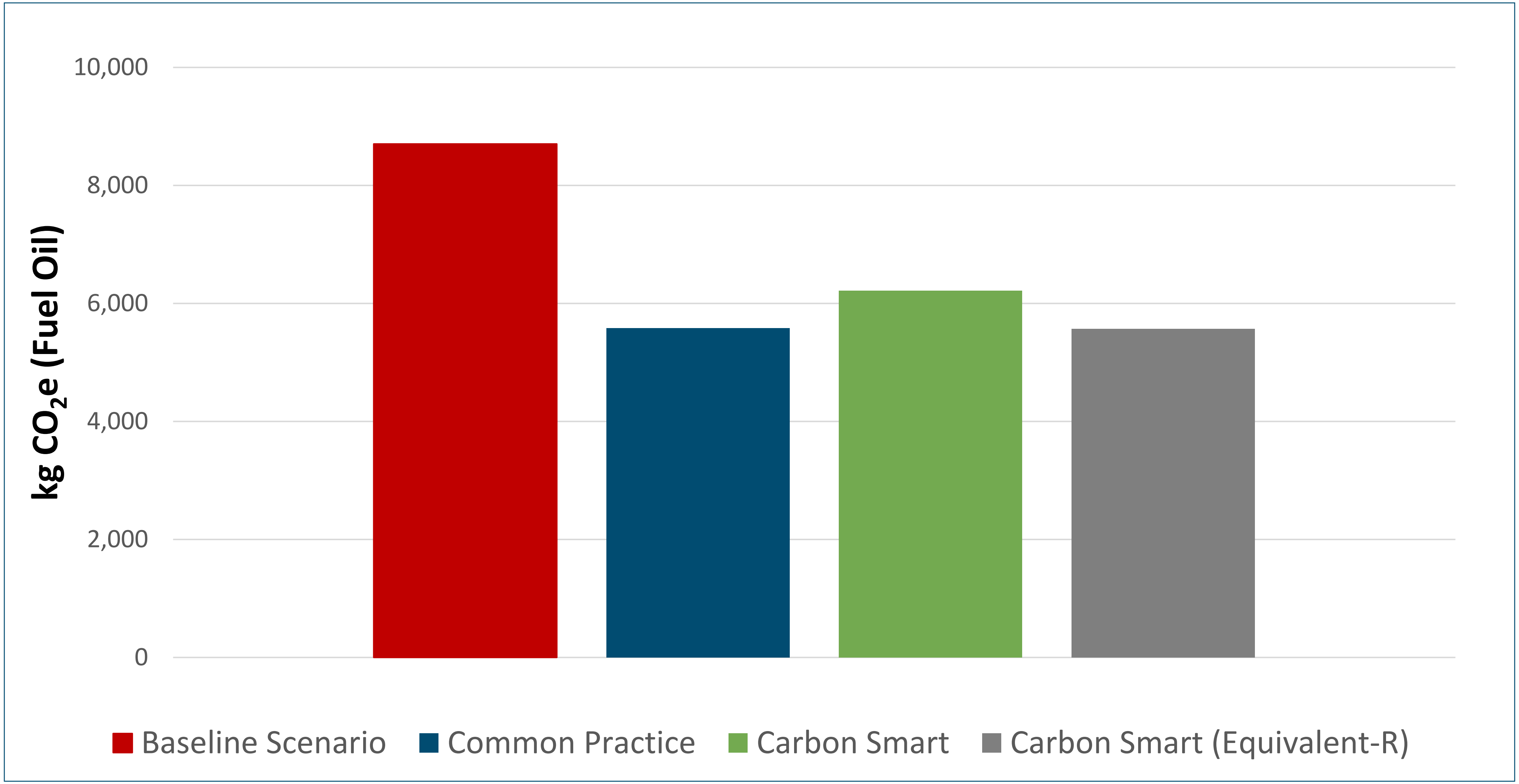


Figure 2: First-year operational kg CO2e emissions—all measures

RESEARCH TASK #1: Operational Savings

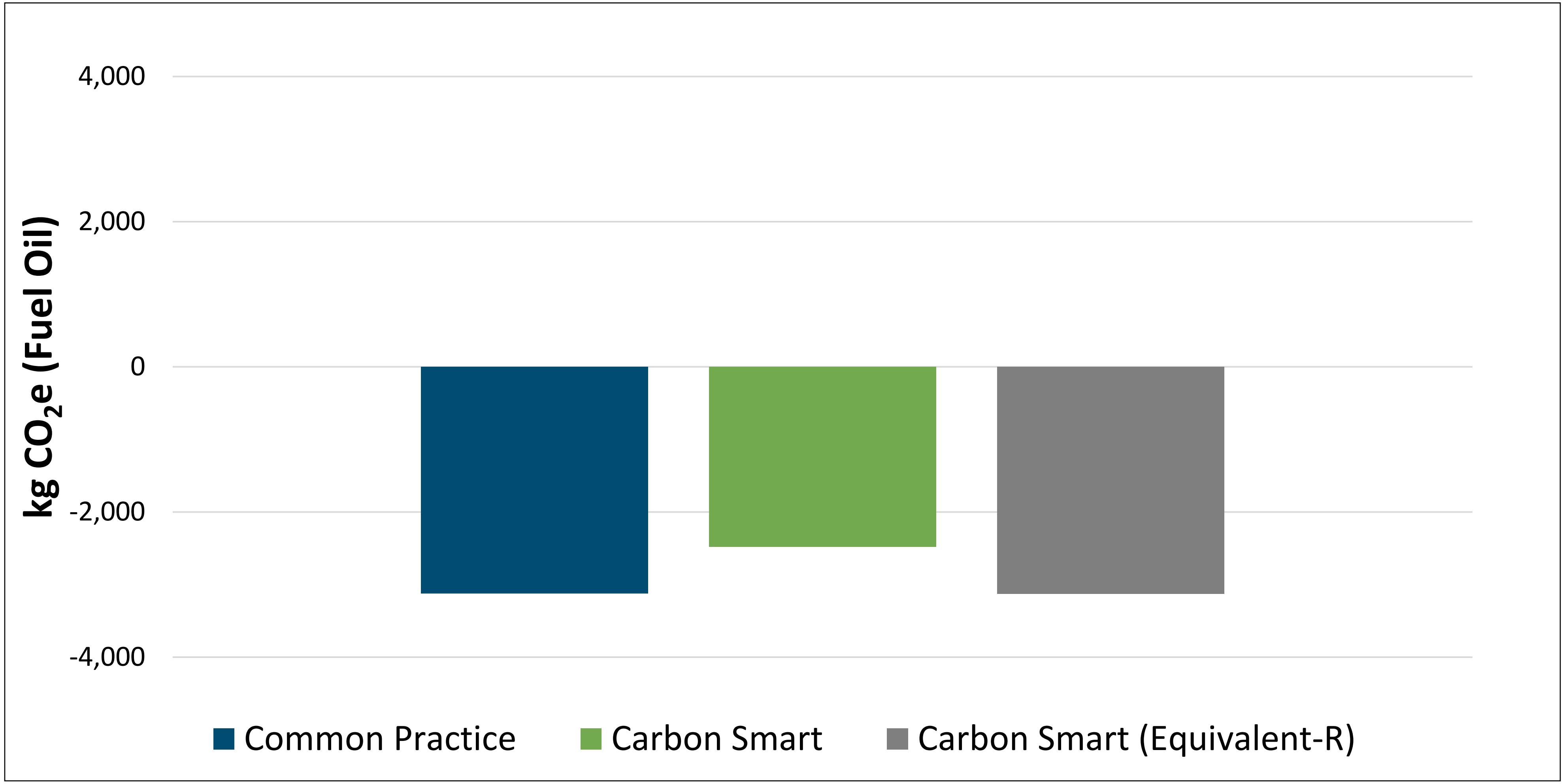


Figure 3: First-year operational kg CO_2e savings compared to baseline condition—all measures

RESEARCH TASK #1: Operational Savings – by measure

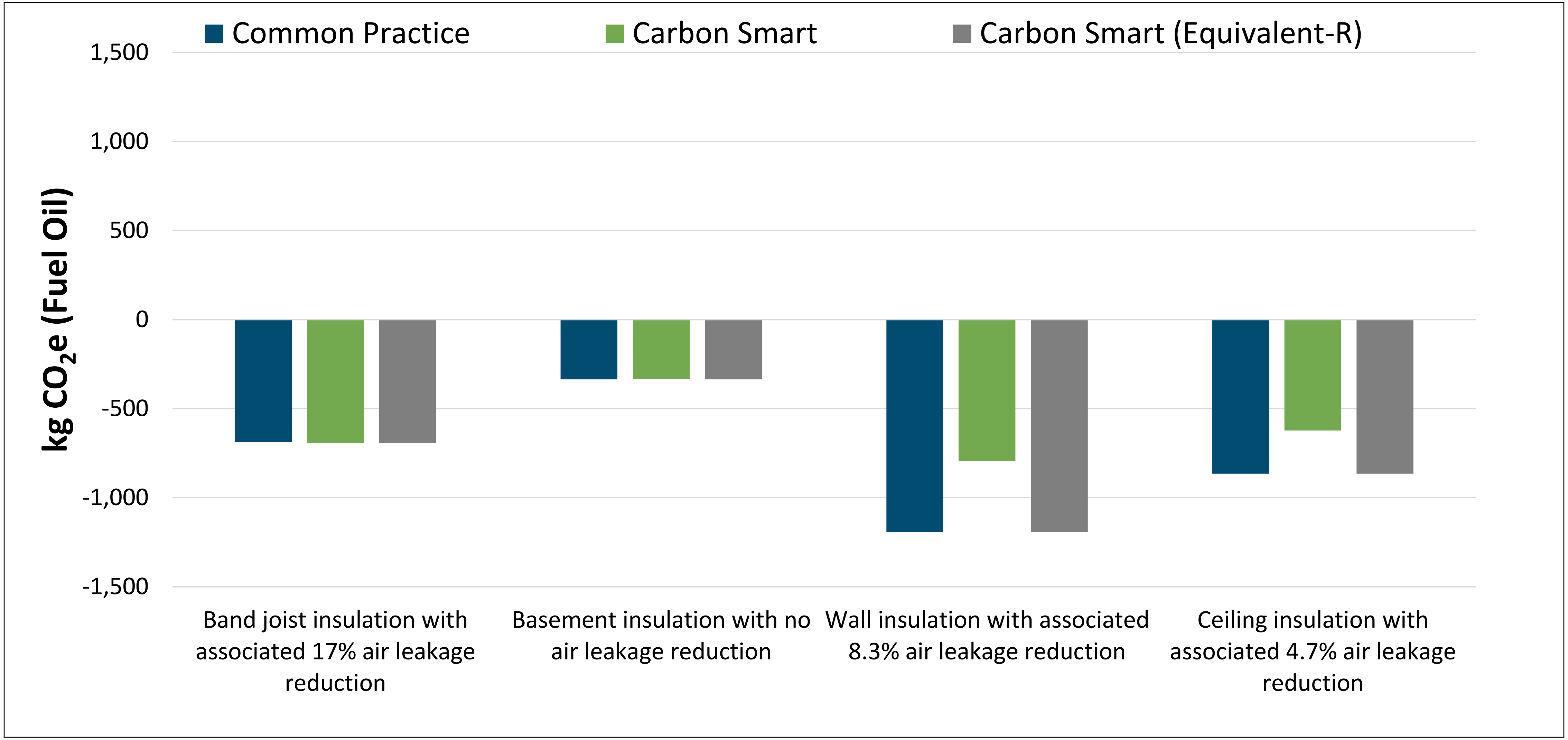


Figure 4: First-year operational kg CO_2e savings by measure compared to baseline condition

2021 Research Tasks

1 Calculate the approximate operational carbon savings when a typical existing Vermont home is weatherized using the most commonly adopted HPwES practices.

2 Calculate the carbon impact (operational and embodied emissions) for the first year of implementation when a typical Vermont home is weatherized:

- Using the most commonly adopted HPwES practices ("Common Practice").
- Using low-carbon approaches with HPwES practices ("Carbon Smart").

Approach

2

Calculate the carbon impact (operational and embodied emissions) for the first year of implementation when a typical Vermont home is weatherized:

Typical VT Home

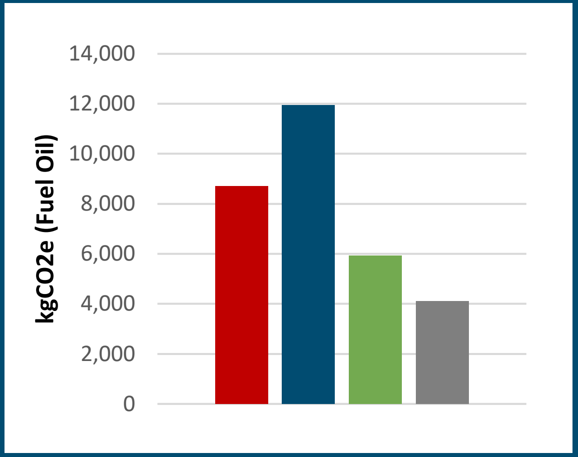
HPwES data + PSD Report

1^{st} YEAR ENERGY

+

EPD calculator

Brian Just/VEIC (2020)



1^{st} Year Carbon Impact (Embodied and Operational)

kgCO2e

RESEARCH TASK #2: First Year emissions

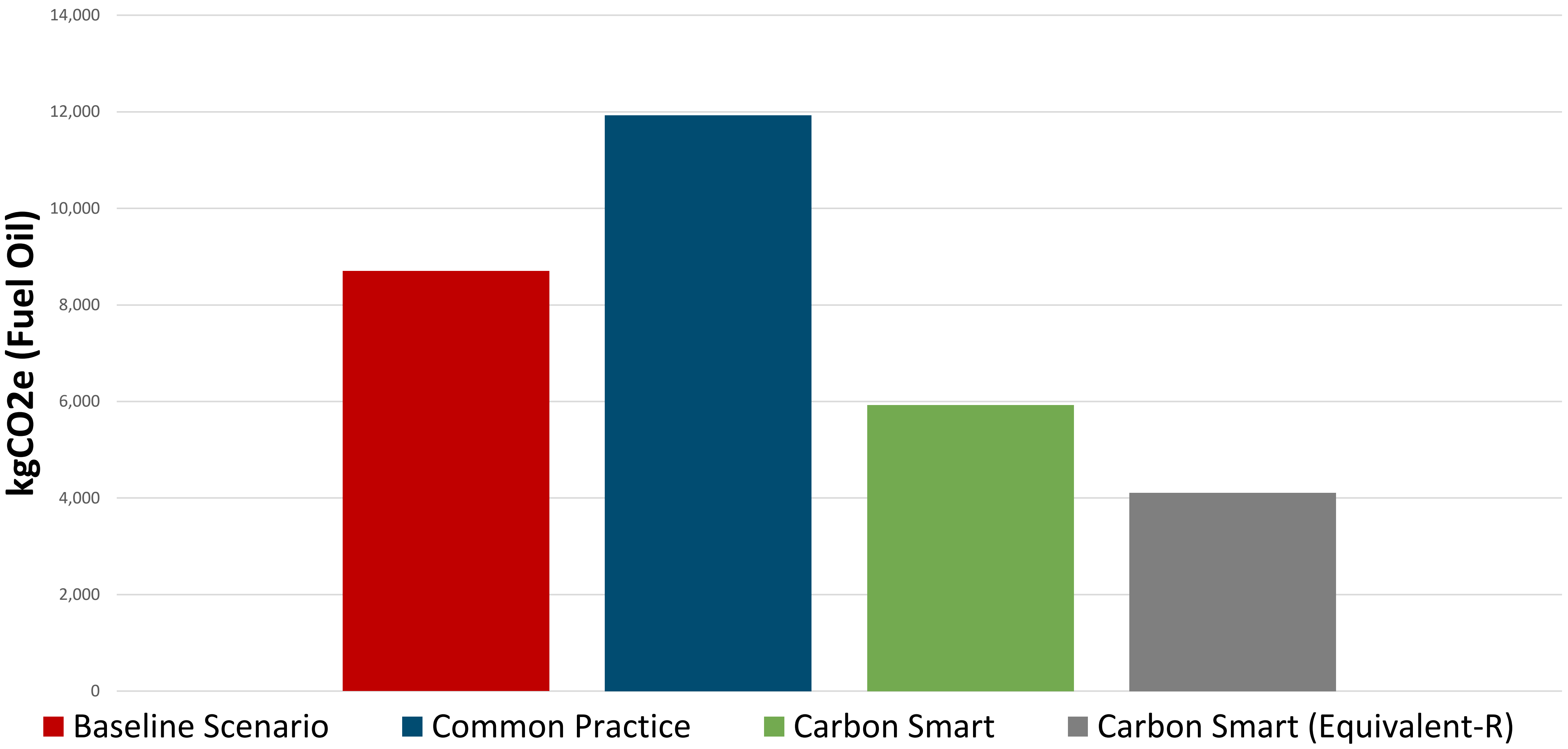


Figure 5: First-year kg CO2e emissions (operational and embodied)—all measures

RESEARCH TASK #2: First Year emissions – by measure

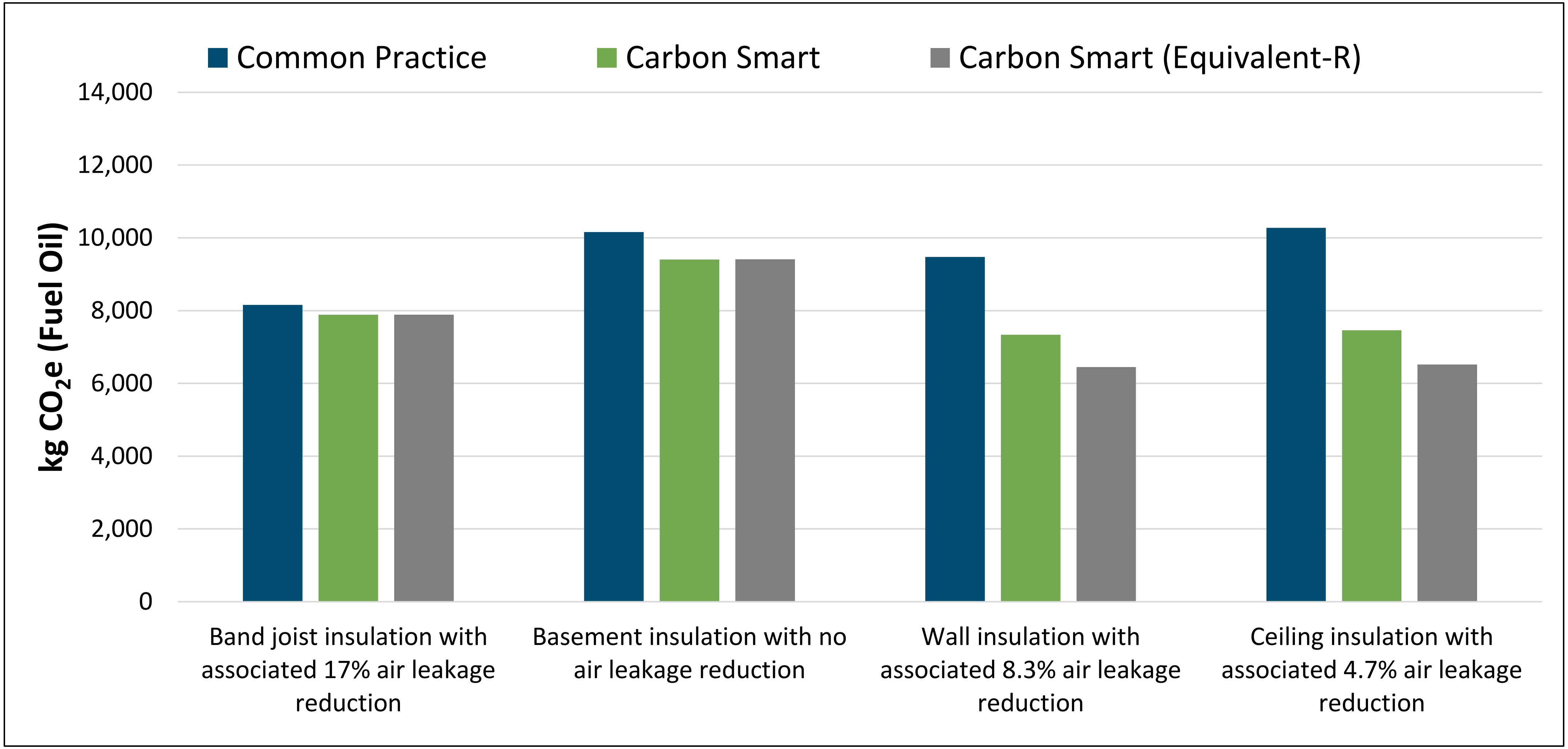


Figure 6: First-year kg CO2e emissions (operational and embodied) by measure

2021 Research Tasks

1 Calculate the approximate operational carbon savings when a typical existing Vermont home is weatherized using the most commonly adopted HPwES practices.

2 Calculate the carbon impact (operational and embodied emissions) for the first year of implementation when a typical Vermont home is weatherized:

- Using the most commonly adopted HPwES practices ("Common Practice").
- Using low-carbon approaches with HPwES practices ("Carbon Smart").

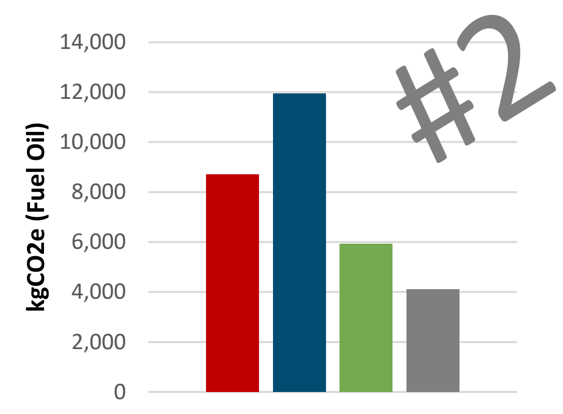
3 Calculate the time period required to equalize the up-front embodied carbon emissions for specific installed weatherization practices with the estimated operational carbon emissions avoided:

- Using the most commonly adopted HPwES practices ("Common Practice").
- Using low-carbon approaches with HPwES practices ("Carbon Smart").

Approach

3

Calculate the time period required to equalize the up-front embodied carbon emissions for specific installed weatherization practices with the estimated operational carbon emissions avoided:



1st Year Carbon Impact (Embodied and Operational)

kgCO2e

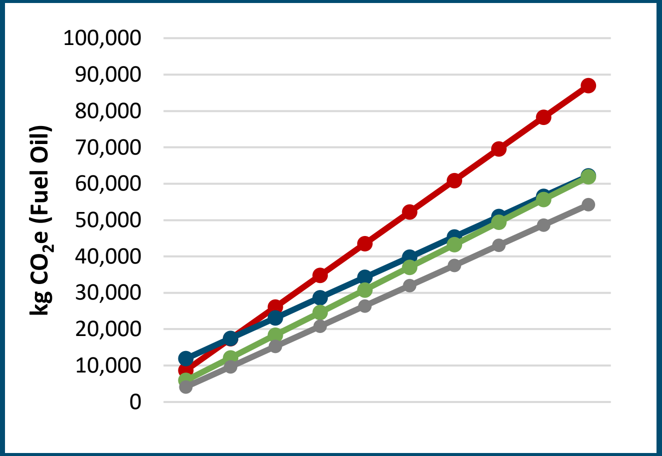
+

ANNUAL ENERGY

×

Annual Operational Energy for 10 years

kgCO2e



Time Period to equalize embodied

kgCO2e

RESEARCH TASK #3: Time period to equalize embodied CO2e emissions

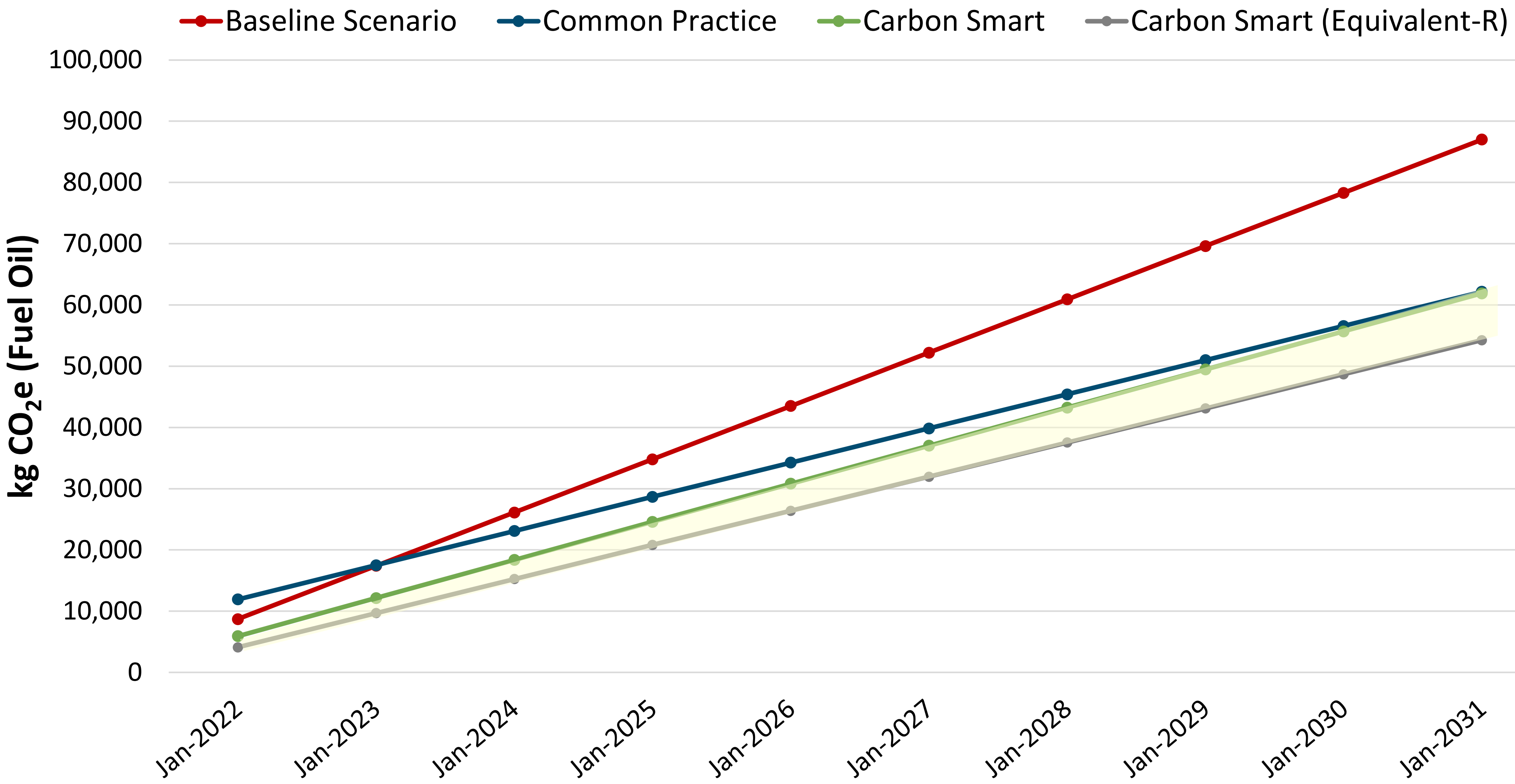
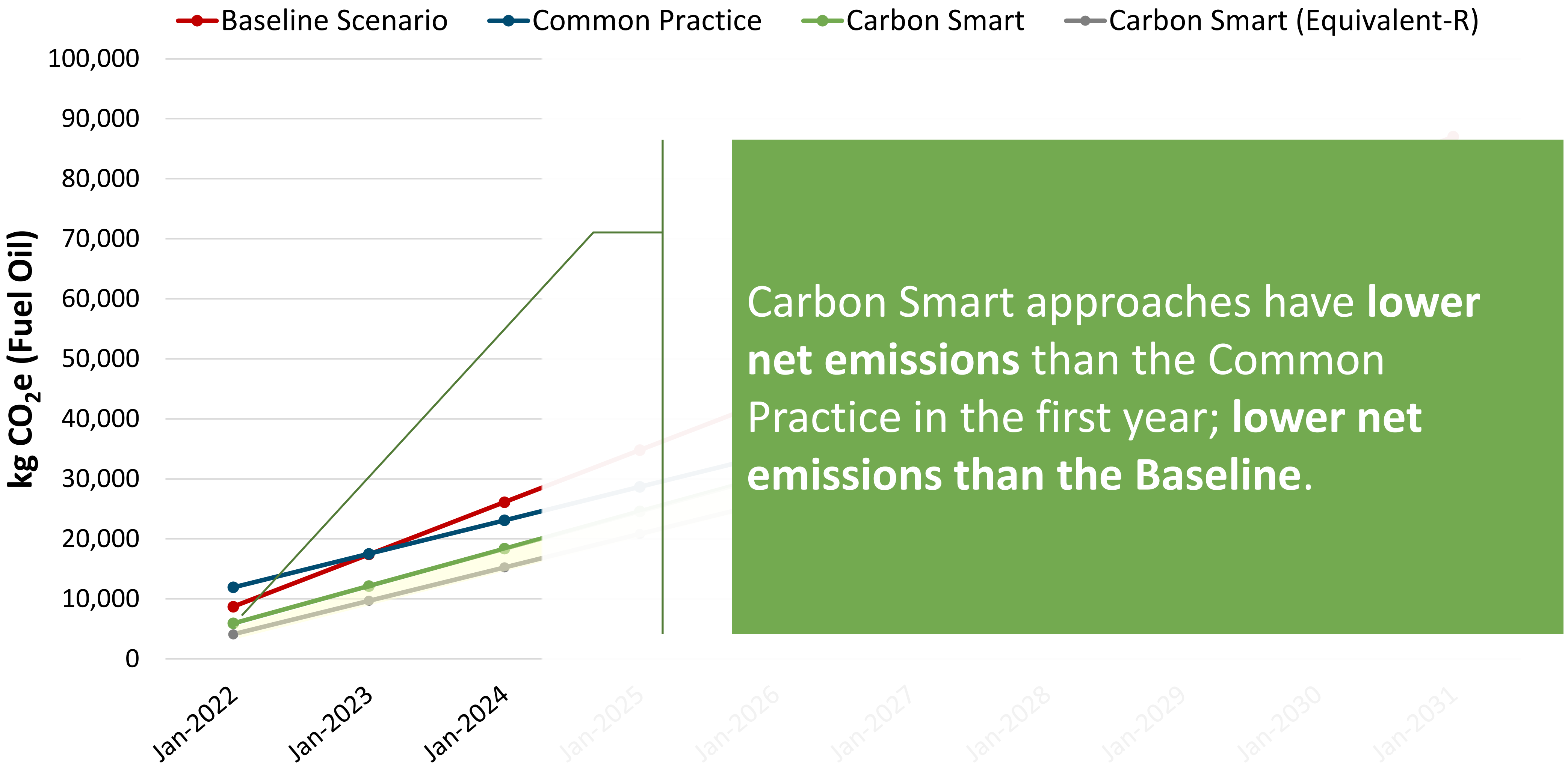


Figure 7: kg CO2e emissions (operational and embodied) over time – all measures

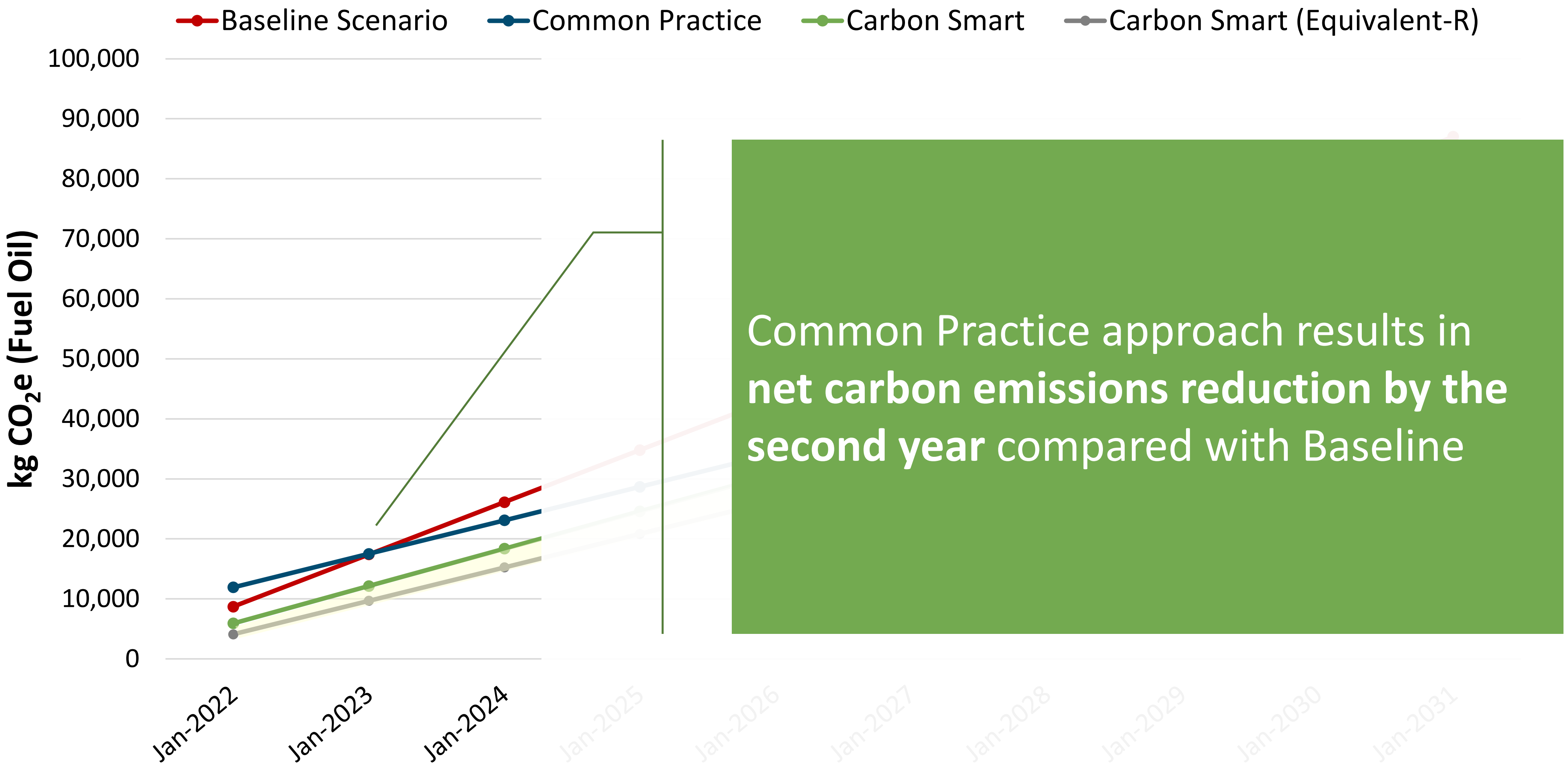
RESEARCH TASK #3: Conclusions



Carbon Smart approaches have **lower net emissions** than the Common Practice in the first year; **lower net emissions than the Baseline.**

Figure 7: kg CO2e emissions (operational and embodied) over time – all measures

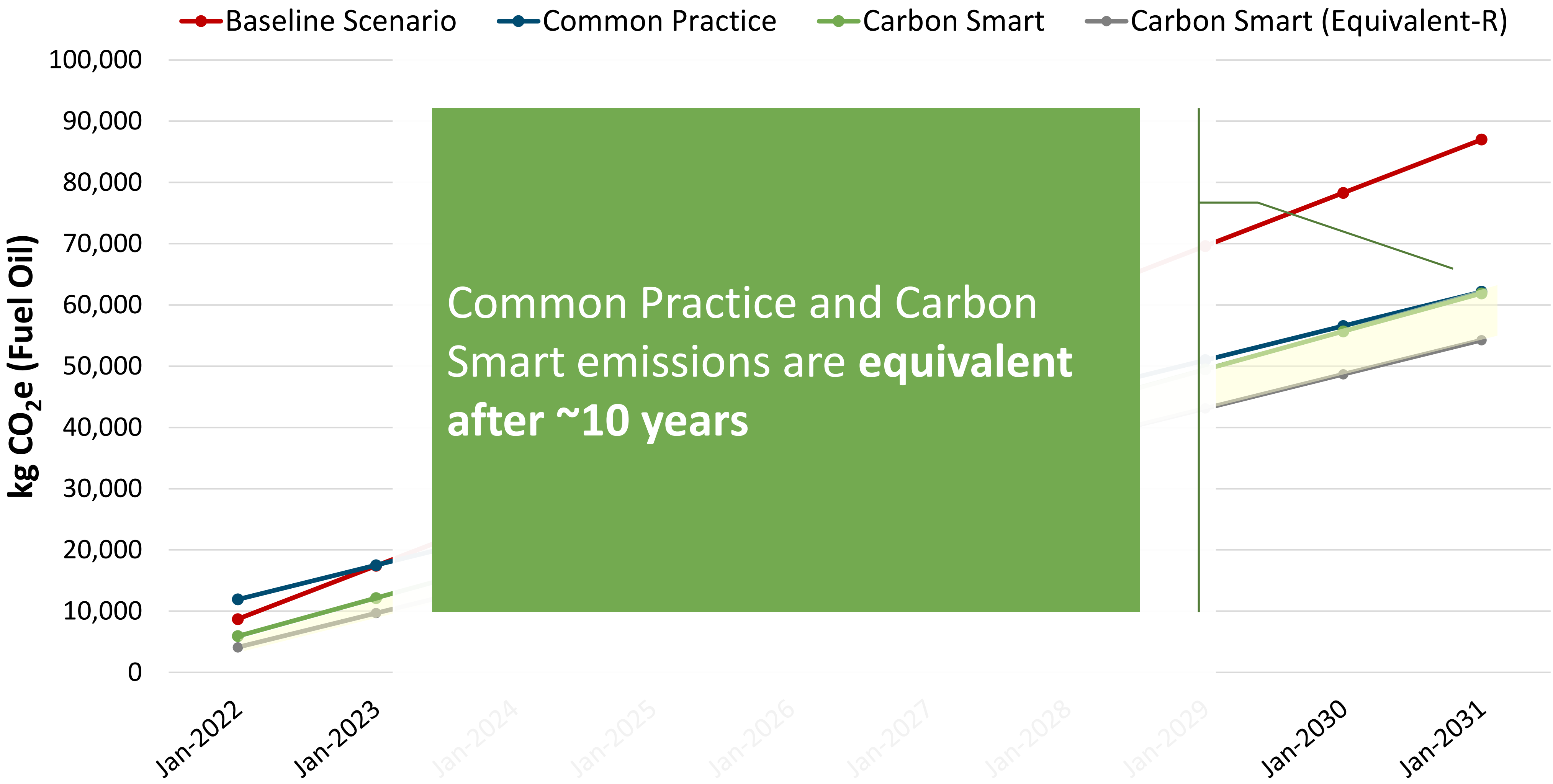
RESEARCH TASK #3: Conclusions



Common Practice approach results in **net carbon emissions reduction by the second year** compared with Baseline

Figure 7: kg CO2e emissions (operational and embodied) over time – all measures

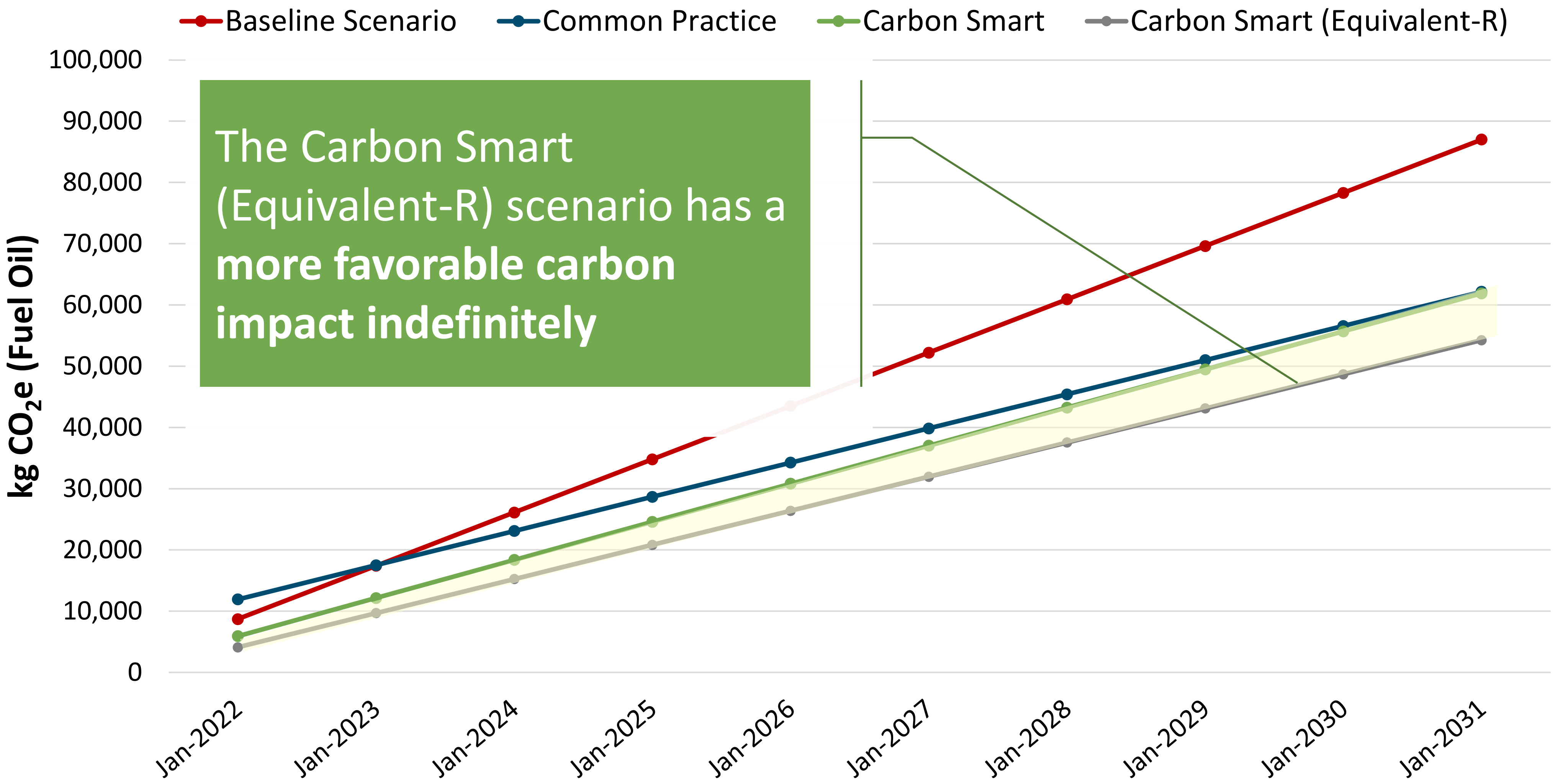
RESEARCH TASK #3: Conclusions



Common Practice and Carbon Smart emissions are **equivalent after ~10 years**

Figure 7: kg CO2e emissions (operational and embodied) over time – all measures

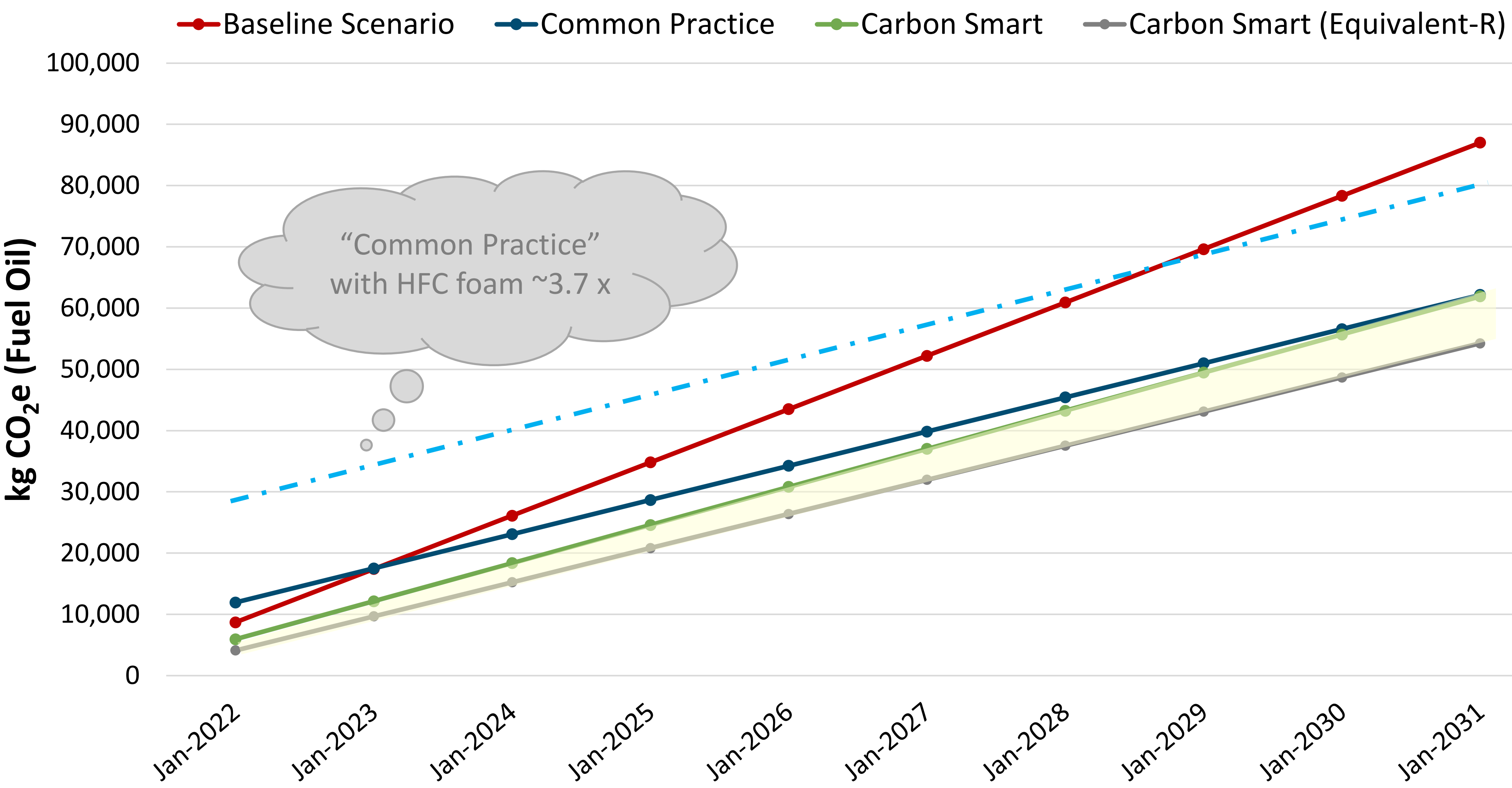
RESEARCH TASK #3: Conclusions



The Carbon Smart (Equivalent-R) scenario has a **more favorable carbon impact indefinitely**

Figure 7: kg CO2e emissions (operational and embodied) over time – all measures

RESEARCH TASK #3: Conclusions



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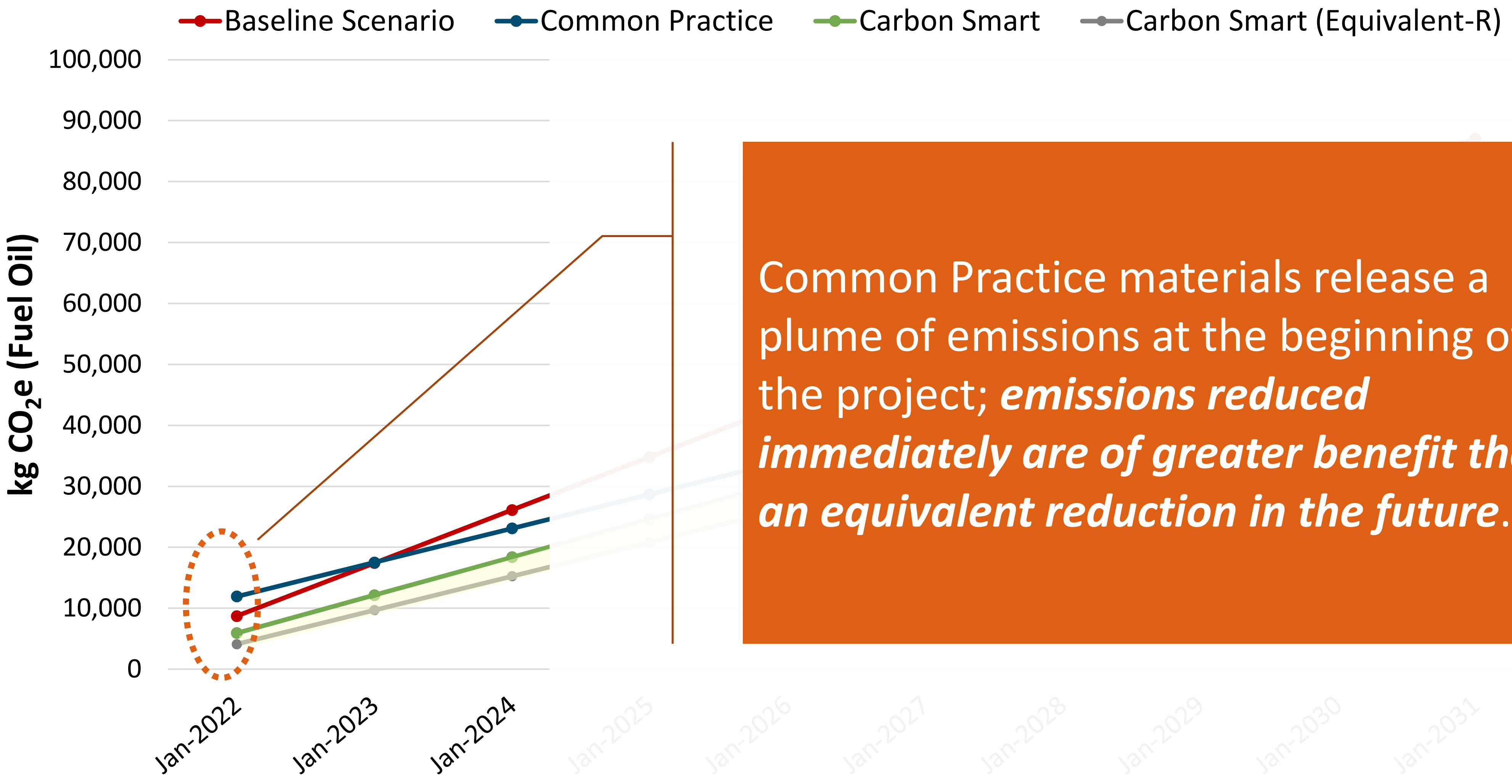
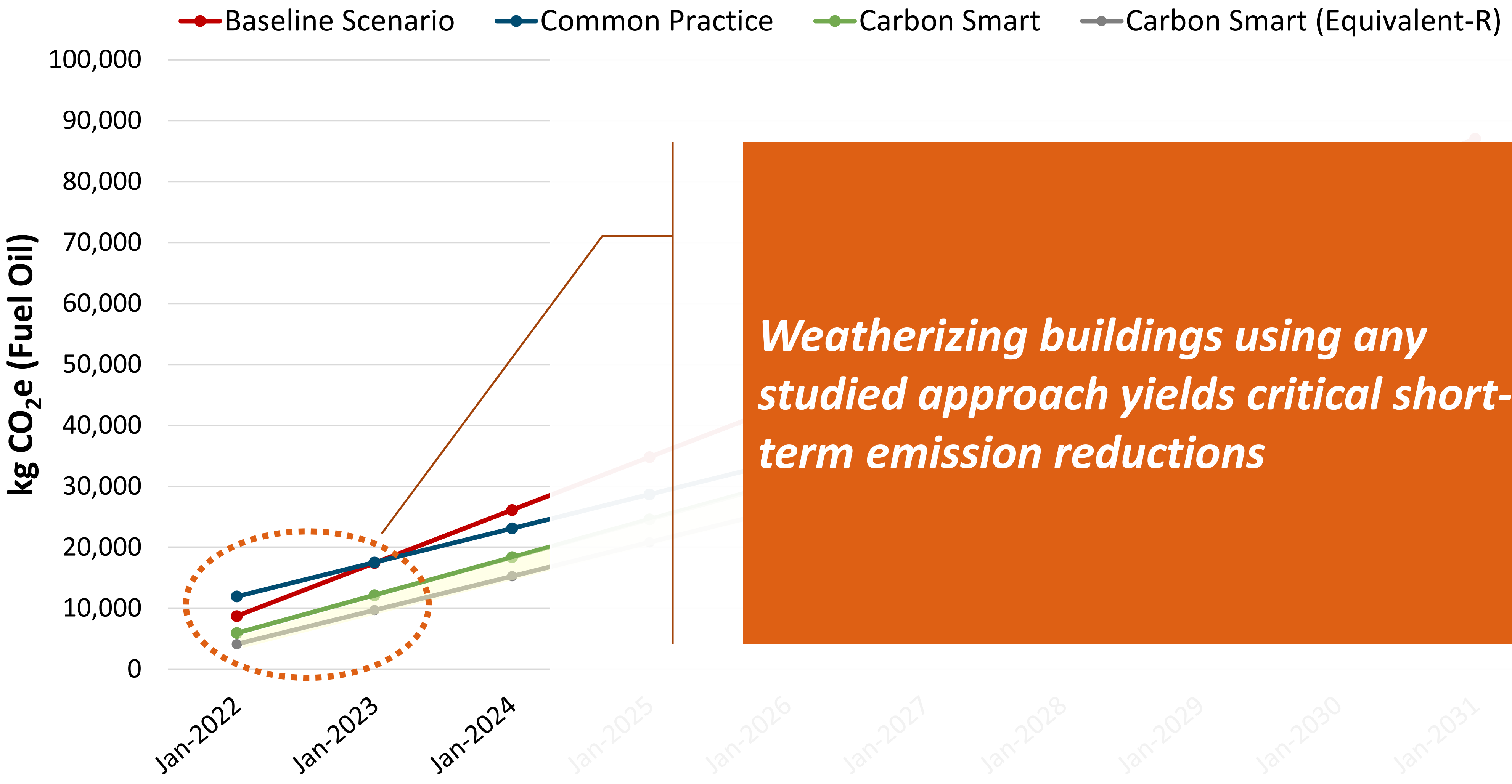
RESEARCH TASK #3: Conclusions



Common Practice materials release a plume of emissions at the beginning of the project; ***emissions reduced immediately are of greater benefit than an equivalent reduction in the future***.

Figure 7: kg CO2e emissions (operational and embodied) over time – all measures

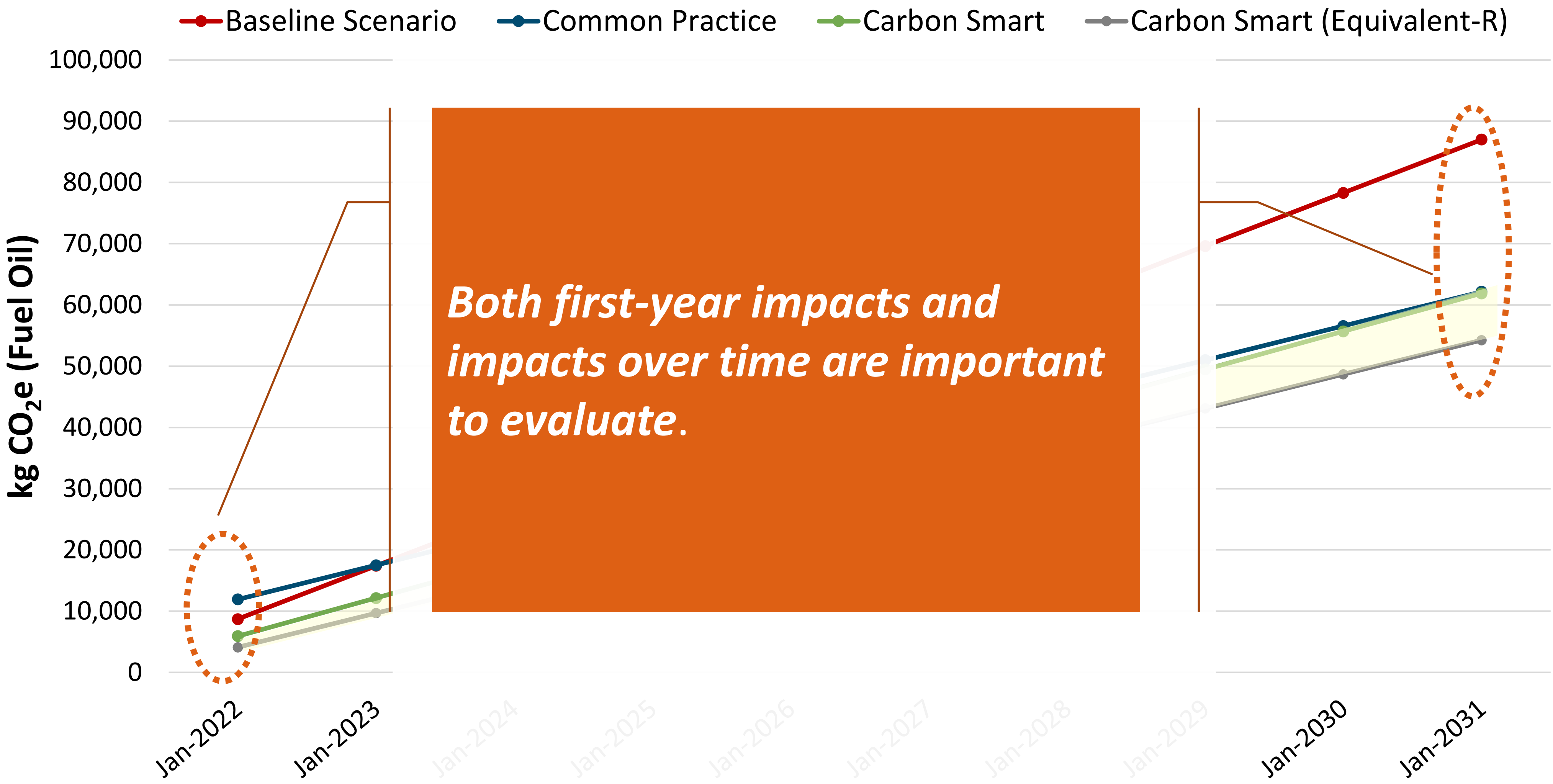
RESEARCH TASK #3: Conclusions



Weatherizing buildings using any studied approach yields critical short-term emission reductions

Figure 7: kg CO2e emissions (operational and embodied) over time – all measures

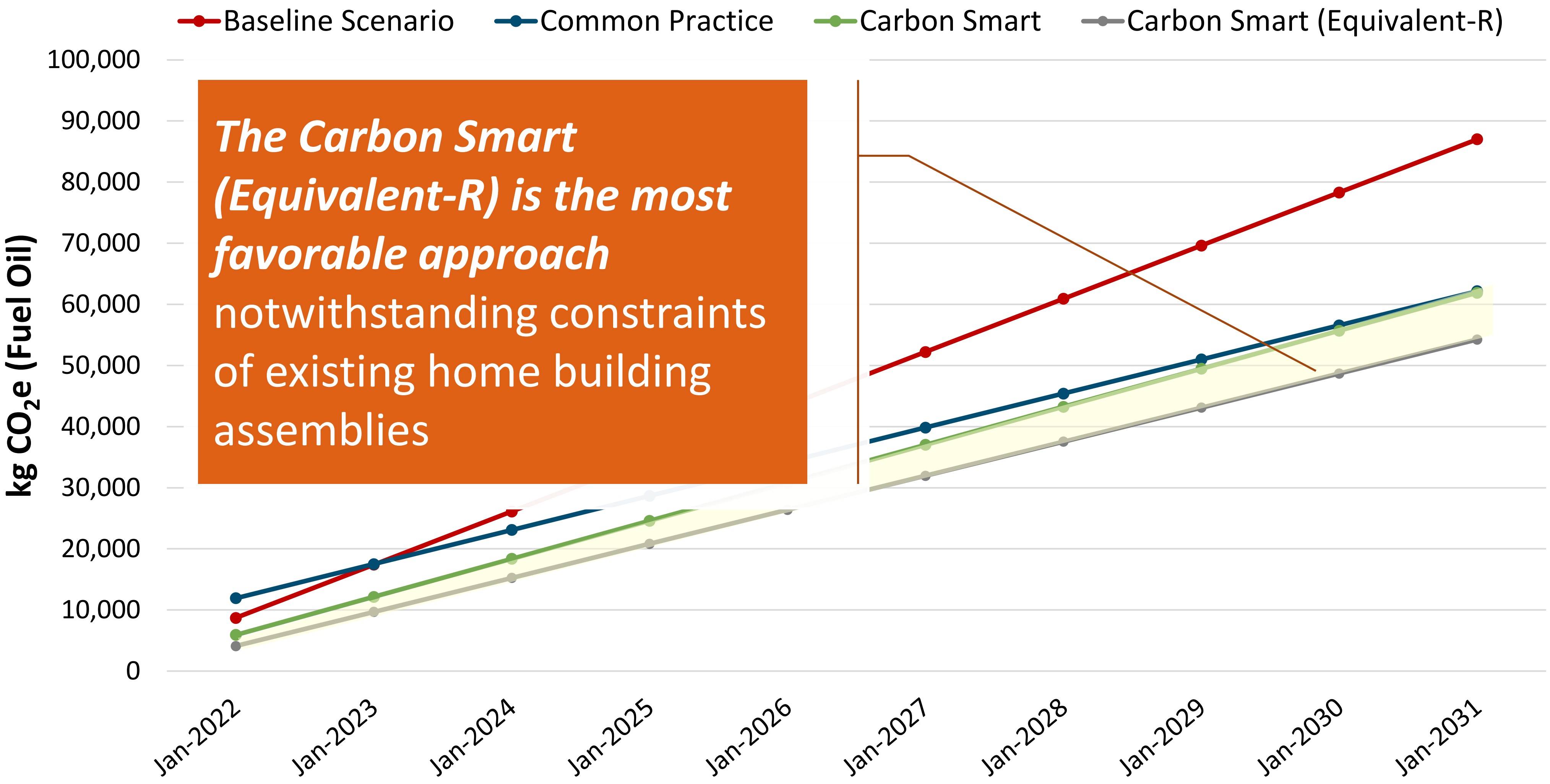
RESEARCH TASK #3: Conclusions



Both first-year impacts and impacts over time are important to evaluate.

Figure 7: kg CO2e emissions (operational and embodied) over time – all measures

RESEARCH TASK #3: Conclusions



The Carbon Smart (Equivalent-R) is the most favorable approach notwithstanding constraints of existing home building assemblies

Figure 7: kg CO2e emissions (operational and embodied) over time – all measures

Conclusions

Weatherizing **36 homes** =

saved emissions of **1 million pounds of coal**

=

Source: EPA GHG Equivalency Calculator, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

"Common Practice" and "Carbon Smart" strategies offers a pathway to significant CO2e reductions within a decade

when compared to the Baseline Scenario.

Conclusions

Weatherizing **36 homes** =

=

“Common Practice” and “Carbon Smart” strategies offers a pathway to significant CO2e reductions within a decade

when compared to the Baseline.

Nearly 8x annually

or

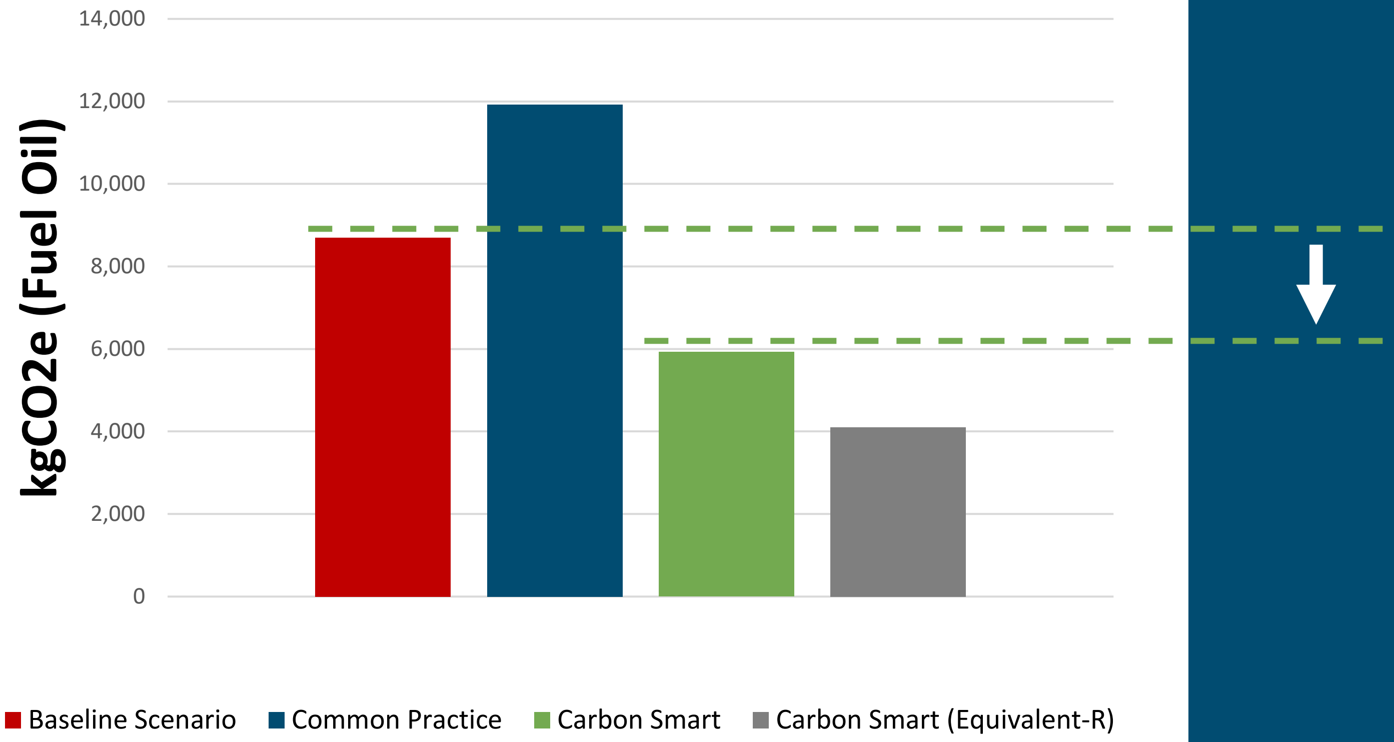
Nearly 200,000 miles annually

Source: EPA GHG Equivalency Calculator, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Conclusions

“Carbon Smart” strategy offers a pathway to significant CO2e reductions in the short-term

when compared to the Baseline.



25% REDUCTION OVER BASELINE

Figure 5: First-year kg CO2e emissions (operational and embodied)—all measures

Conclusions

Weatherizing **27 homes** =

saved emissions of **1 million pounds of coal**

Source: EPA GHG Equivalency Calculator, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

=

“Carbon Smart” (Equivalent-R) is the most favorable approach,

notwithstanding constraints of existing assemblies.

Conclusions

Weatherizing **27 homes** =

Source: EPA GHG Equivalency Calculator,
https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

=

“Carbon Smart” (Equivalent-R) is the most favorable approach,

notwithstanding constraints of existing assemblies.

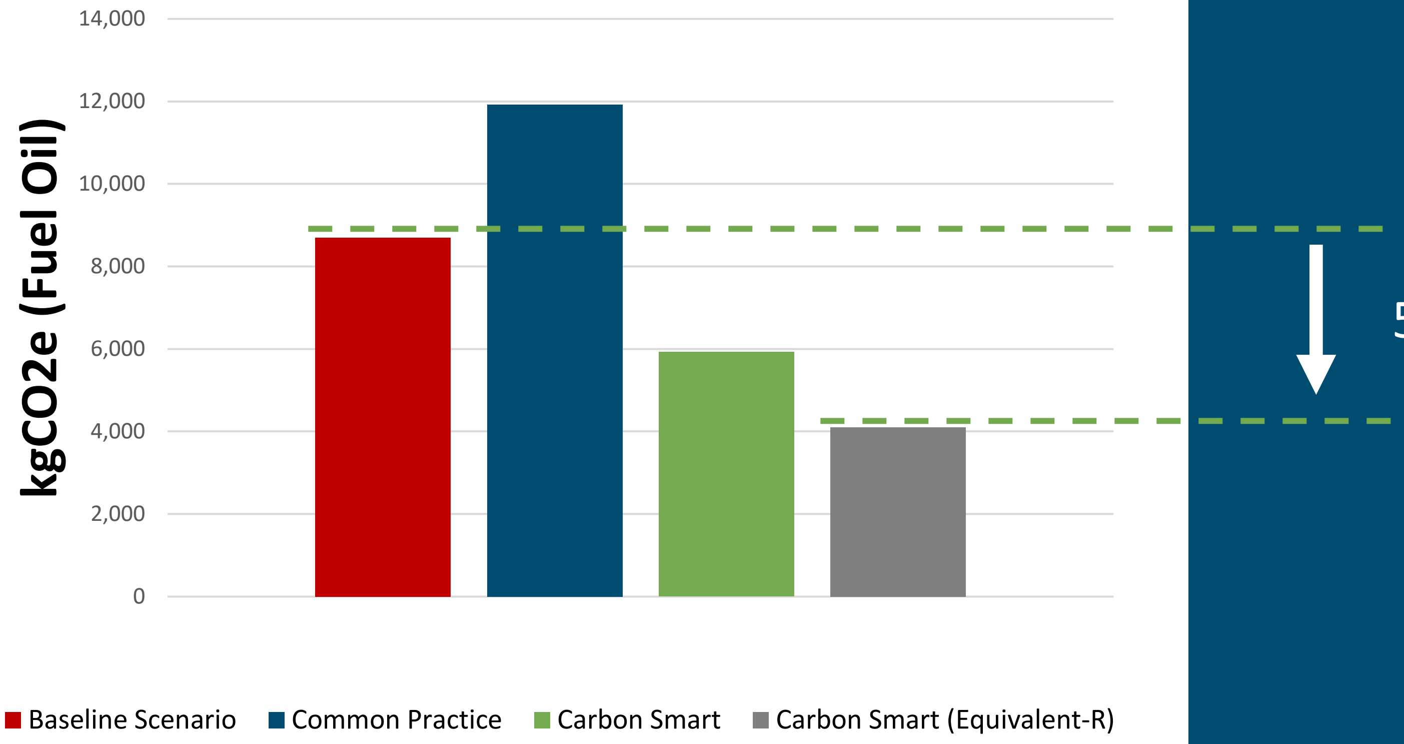
Nearly 8x annually

or

Nearly 200,000 miles annually

Conclusions

“Carbon Smart” (Equivalent-R) is the most favorable approach, notwithstanding constraints of existing assemblies.



50% REDUCTION OVER BASELINE

Figure 5: First-year kg CO2e emissions (operational and embodied)—all measures

Conclusions

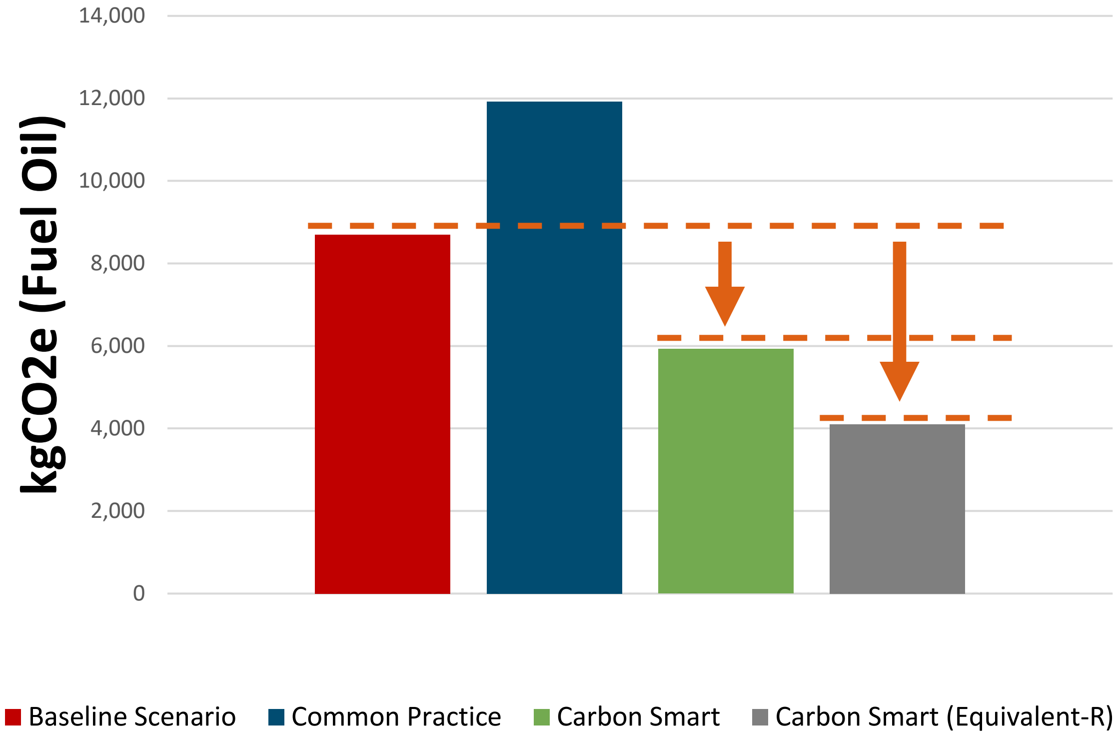


Figure 5: First-year kg CO2e emissions (operational and embodied)—all measures

First year emissions reductions are critically important when considered with the embodied carbon emissions avoided due to building reuse.

It is urgent that we weatherize existing buildings in the shortest time possible to avoid irreversible climate change.

< +2°C

TICK-TOCK

THANK YOU!

Questions / Discussion?

Efficiency Vermont

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