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Fluorocarbon Technologies: Environmental Considerations and Contributions to Building Energy Efficiency

Solstice Advanced Materials Inc.

August 3, 2026

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AGENDA

- Introductions- Mary

- Who is Solstice Advanced Materials- Mary

- Fluorocarbons:- Mary
  - The history of fluorocarbons
  - The application of fluorocarbons
  - Fluorocarbon properties
  - Global perspective on fluorocarbons regulations
  - US perspective on fluorocarbons regulations
  - The Lists

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AGENDA

- Refrigerants- Bruno
  - Background/context on refrigerants
  - Refrigerant selection criteria
  - Refrigerant performance overview
  - System design requirements for next-gen refrigerants

- Insulation & Fluorocarbons: Mary
  - Comparison of insulation materials
  - What is a blowing agent
  - Where are fluorocarbons used and why
  - How is performance measured and why
  - How does fluorocarbon insulation perform long term and why

- Application Embodied Carbon- Rocky

- Questions

Presenting:

Mary Bogdan
Sr Research Fellow
Solstice Advanced Materials

Bruno Yuji Kimura De Carvalho
Sr. Advanced R&D Scientist
Solstice Advanced Materials

ROCKY BOYER, B. ARCH. SC., MBSC, BSS-ELASTOCHEM

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Solstice Advanced Materials Overview

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Where we started

- March 2, 1899 - The General Chemical Company commenced business
- 1920 - Allied Chemical and Dye Corporation combined from (Barrett Chemical Company (est. 1858), The General Chemical Company (est. 1899), National Aniline & Chemical Company (est. 1917), Semet-Solvay Company (est. 1895), and the Solvay Process Company (est. 1881)
- 1958- Renamed Allied Chemical Corporation
- 1981 – Allied Chemical became Allied Corporation
- 1985 – Allied Chemical merged with signal Corporation to AlliedSIgnal
- 1999 - AlliedSignal Merged with Honeywell- took Corporate name of Honeywell
- *October 30, 2025 – Honeywell completed Spinoff of Solstice Advanced Materials*

130- Year Legacy of Innovation- Fluorocarbons from CFC's to HFO's

The History

Solstice Advanced Materials is a specialty chemicals and materials business with leading positions across fluorine products, electronic materials, industrial grade fibers and healthcare packaging solutions.

Snapshot

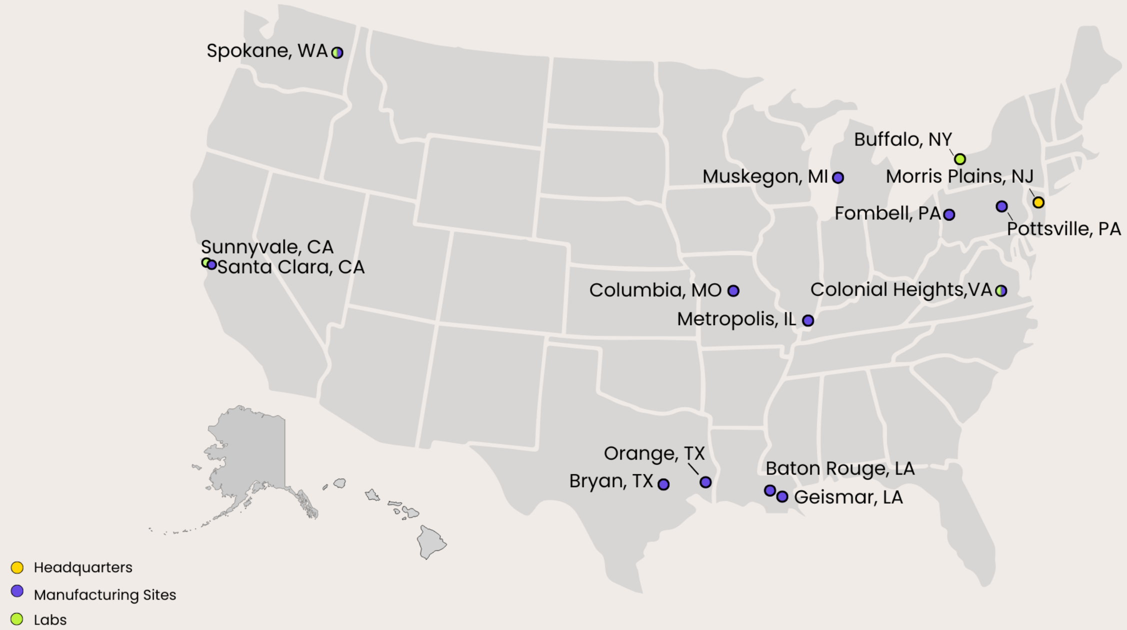
~$4B	Sales
>5K	Active patents and applications
~120	Countries and territories where we sell our products
>400	Technologists and engineers

Overview

- Solstice Advanced Materials, the Advanced Materials business of Honeywell, **completed their spin-off in October 30,2025.**
- **Solstice Advanced Materials serves a wide range of end markets**, including leading brands such as Solstice®, Spectra®, Hydranal® and Aclar®.

All sales figures represent 2024 information.

Solstice U.S. Footprint



3,200+
Employees in the U.S.
Including Contract Service Workers

5,700
Patents & Pending Applications

400+
Technologists & Engineers

3,000+
Customers Across 120+ Countries

12
Manufacturing Sites

4
R&D Centers

Our leading products:
Refrigerants and Applied solutions

REFRIGERANTS

Why Solstice Advanced Materials Wins

A leading position in U.S. HFO production, driving transition from HFC.

Macro Drivers

Increasing demand for LGWP refrigerants bolstered by regulatory requirements, stationary and automotive HVAC/R applications

Products / Brands Solstice® | Genetron® | Refrigerants | Foam Blowing Agents

HEALTHCARE PACKAGING

Why Solstice Advanced Materials Wins

A leading position in pharmaceutical packaging, highest moisture barrier of any clear thermoplastic film.

Macro Drivers

Increasing need for highly-engineered solutions for healthcare applications.

Products / Brands Aclar® | Aclar Accel™

BUILDING SOLUTIONS & INTERMEDIARIES

Why Solstice Advanced Materials Wins

Strong U.S. commercial footprint and tailored formulations. Technology leader in LGWP blowing agents and cleaning solvents

Macro Drivers

Demand for energy-efficient building materials, Sustainability-driven solvent conversions

Products / Brands Solstice® | Blowing Agents | Cleaning Solvents

ALTERNATIVE ENERGY SERVICES

Why Solstice Advanced Materials Wins

Only U.S.-based provider of uranium hexafluoride (UF_6) conversion

Macro Drivers

Energy security and nuclear renaissance, long-term backlog from regulated utility customers

Products / Brands Uranium Hexafluoride Conversion Services

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Our Leading Products:
Electronic and Specialty Materials

RESEARCH & PERFORMANCE CHEMICALS

Why Solstice Advanced Materials Wins

A global industry leader in high purity lab chemicals.

Macro Drivers

Heightened demand and increasing investment in pharmaceutical and biotechnology.

Products / Brands Fluka™ | Hydranal™ | Burdick & Jackson™ BioSyn™ | Chromasolv™

ELECTRONIC MATERIALS

Why Solstice Advanced Materials Wins

Leveraging U.S. manufacturing base and unique technologies to create differentiated solutions.

Macro Drivers

Growing demand in electronic materials driven by high-end computing, AI and 5G.

Products / Brands Thermal Interface Materials | Polymers | Sputtering Targets

SAFETY & DEFENSE SOLUTIONS

Why Solstice Advanced Materials Wins

A leading position globally for high-end armor technology and a variety of other high-performance fibers.

Macro Drivers

Strong demand for latest generation technology that protects military and law enforcement.

Products / Brands Spectra® | Spectra Shield® | Spectra® MG

SYNTHETIC WAXES & BLENDS

Why Solstice Advanced Materials Wins

Delivering high quality products and superior technical support for formulation development.

Macro Drivers

Growing demand of construction materials driven by urbanization and coating reformulations to provide better performance.

Products / Brands A-C® | NduroMatt™ | Acumist® | Rheochem™

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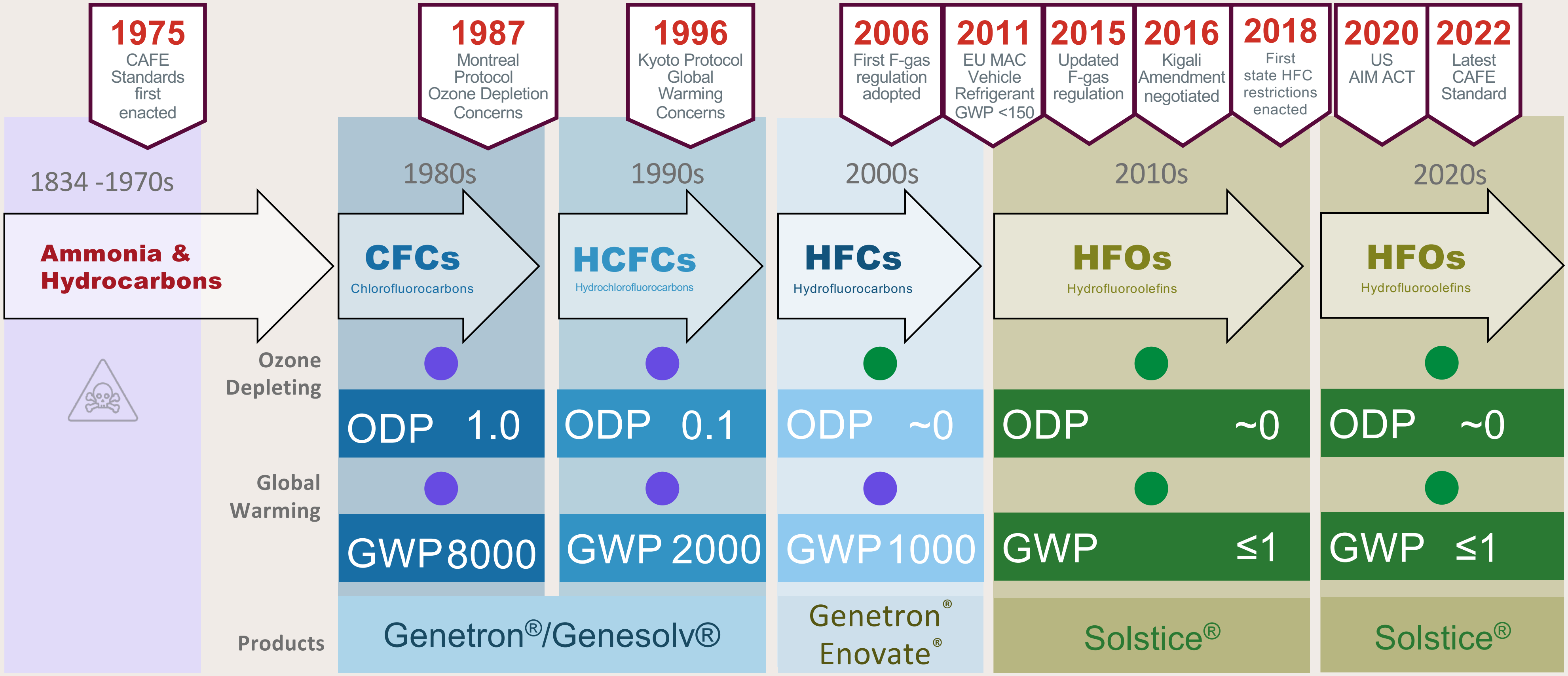
Fluorocarbons:

- The history of fluorocarbons
- The application of fluorocarbons
- Fluorocarbon properties
- Global perspective on fluorocarbons regulations
- US perspective on fluorocarbons regulations
- The Lists

Solstice Advanced Materials: A History of Innovation



1975 CAFE Standards first enacted

1987 Montreal Protocol Ozone Depletion Concerns

1996 Kyoto Protocol Global Warming Concerns

2006 First F-gas regulation adopted

2011 EU MAC Vehicle Refrigerant GWP <150

2015 Updated F-gas regulation

2016 Kigali Amendment negotiated

2018 First state HFC restrictions enacted

2020 US AIM ACT

2022 Latest CAFE Standard

	1834 -1970s	1980s	1990s	2000s	2010s	2020s
	Ammonia & Hydrocarbons	**CFCs** Chlorofluorocarbons	**HCFCs** Hydrochlorofluorocarbons	**HFCs** Hydrofluorocarbons	**HFOs** Hydrofluoroolefins	**HFOs** Hydrofluoroolefins
Ozone Depleting		● ODP 1.0	● ODP 0.1	● ODP ~0	● ODP ~0	● ODP ~0
Global Warming		● GWP 8000	● GWP 2000	● GWP 1000	● GWP ≤1	● GWP ≤1
Products		Genetron®/Genesolv®		Genetron® Enovate®	Solstice®	Solstice®

Technology Leadership

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Based IPCC AR5

Low Global Warming Solutions from Solstice Advanced Materials

APPLICATION		**SOLSTICE OPTIONS**	
	Low Global Warming Products	**Molecule**	***GWP$_{100}$**
Foams	Solstice® GBA	HFO-1234zeE	<1
	Solstice® LBA	HFO-1233zdE	1
Refrigerants	Solstice® MAC	HFO-1234yf	<1
	Solstice® ZE	HFO-1233zdE	<1
	Solstice® HFO Blends	Blend	200-500
Solvents	Solstice® Performance Fluid	HFO-1234zeE	1
Aerosols	Solstice® Propellant	HFO-1234zeE	<1
Meter Dose Inhalers (MDI)	Solstice® Air	HFO-1234zeE	<1

*Based IPCC AR5

Solstice Advanced Materials
Commercialization of low GWP products

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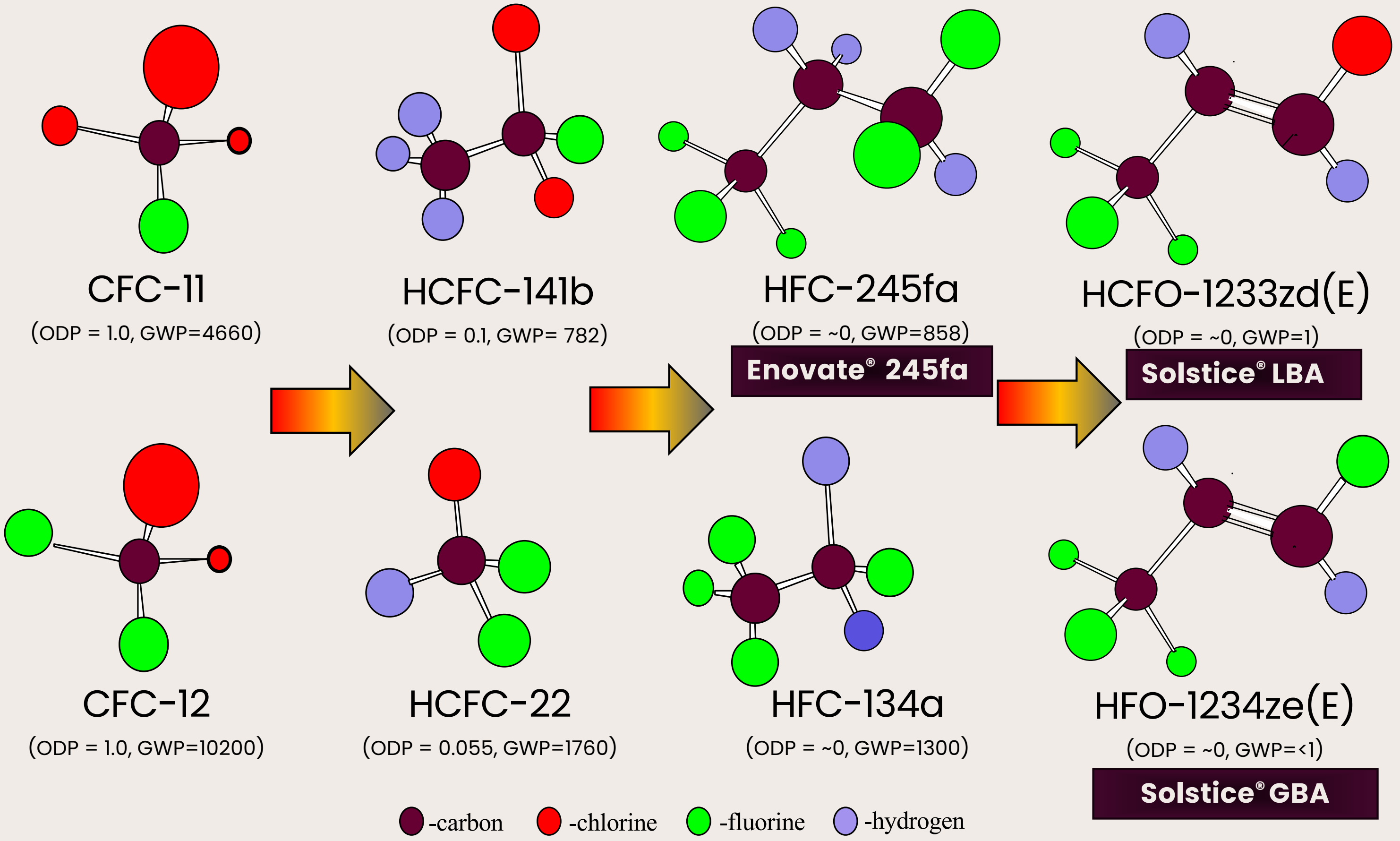
Evolution of Solstice Advanced Materials Blowing Agents



Liquid

CFC-11
(ODP = 1.0, GWP=4660)

HCFC-141b
(ODP = 0.1, GWP= 782)

HFC-245fa
(ODP = ~0, GWP=858)
Enovate® 245fa

HCFO-1233zd(E)
(ODP = ~0, GWP=1)
Solstice® LBA

Gas

CFC-12
(ODP = 1.0, GWP=10200)

HCFC-22
(ODP = 0.055, GWP=1760)

HFC-134a
(ODP = ~0, GWP=1300)

HFO-1234ze(E)
(ODP = ~0, GWP=<1)
Solstice® GBA

● -carbon ● -chlorine ● -fluorine ● -hydrogen

GWP – IPCC AR-5

Blowing agents developed to address Montreal and Kyoto protocol issues

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Recent Regulatory Activity

HFC Phasedown

Triggered by Kigali Requirements to Montreal Protocol

Global Legislative and Regulatory Activity

PFAS*

Concerns about PFAS impacts to the environment

Global Legislative and Regulatory Activity

**Definitions of PFAS differ by jurisdiction and may change over time.*

Goal: Monitor, Analyze and Respond

HFC Phasedown

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2024 Montreal protocol TEAP Report : Major Issues Influencing the Global Foams Market

Regulatory Drivers

- Regulations are driving transitions from high-GWP HFCs in non-A5 parties and HCFCs in A5 parties.
- Emphasis on avoiding high-GWP HFCs where possible.

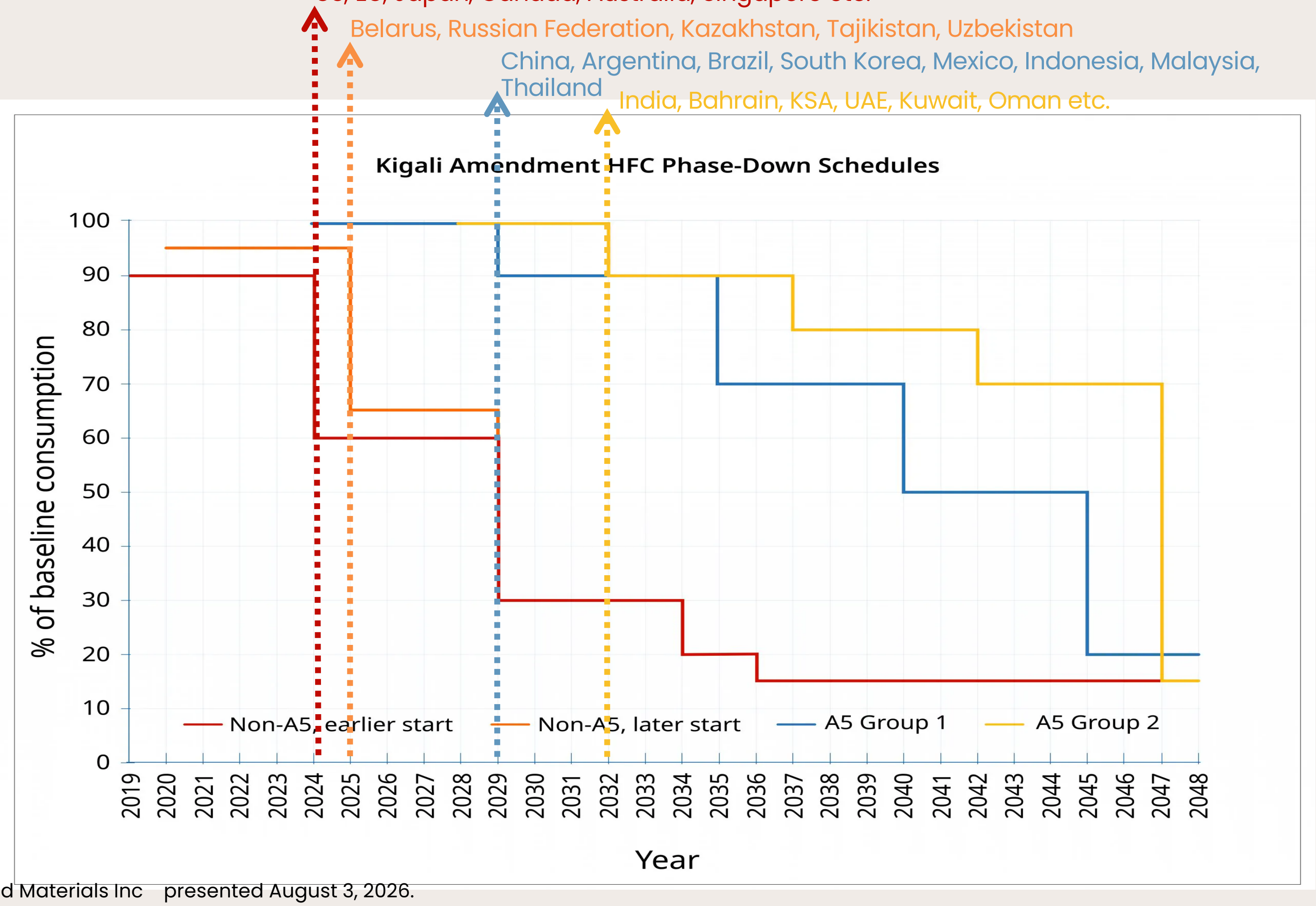
Supply Chain and Market Impact

- Pandemic related shortages of lower GWP fluorinated and non-fluorinated FBAs have improved.
- Pandemic related shortages led to increased use of higher GWP HFCs blends in some A5 parties and a reversion to HFCs in some non-A5 parties.

Transition Delays

- Cost concerns of FBAs and additional safety requirements have delayed the transition away from ozone-depleting and high-GWP FBAs in some regions.

Global Kigali Adoption



US, EU, Japan, Canada, Australia, Singapore etc.

Belarus, Russian Federation, Kazakhstan, Tajikistan, Uzbekistan

China, Argentina, Brazil, South Korea, Mexico, Indonesia, Malaysia, Thailand

India, Bahrain, KSA, UAE, Kuwait, Oman etc.

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US HFC Phasedown

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US – HFC PHASEDOWN UPDATES

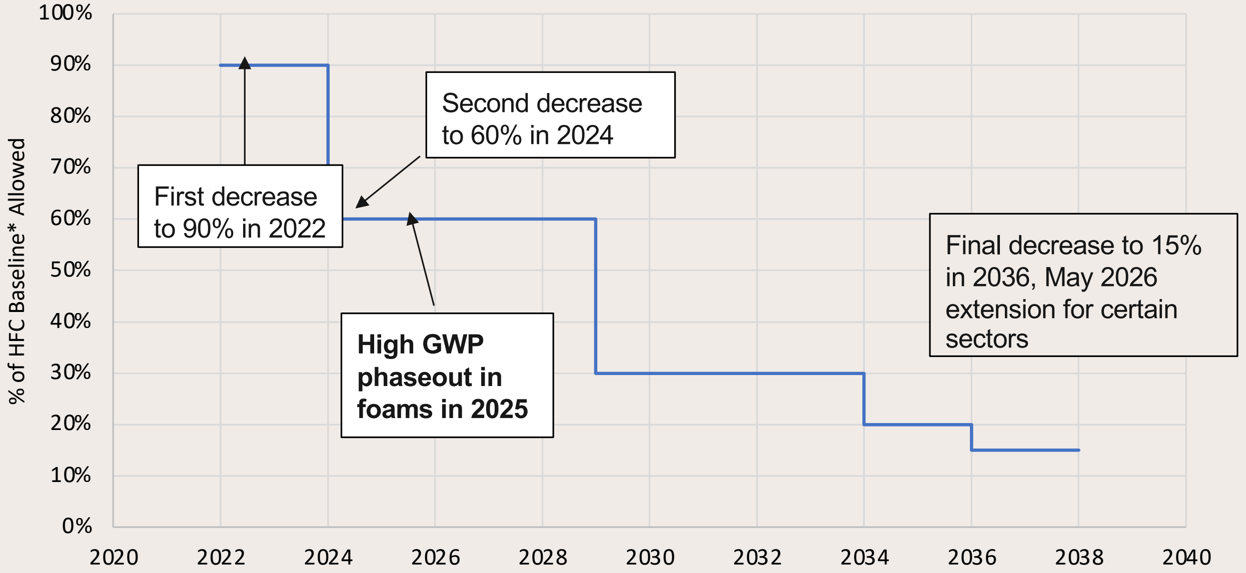
US HFC Phasedown in Progress

EPA Finalizes Allowance Allocation System 2024-2028

EPA Finalizes Sector-Specific Prohibitions (October 2023)

EPA Proposes End-of-life Management Rules/Reclaim Rule (October 2023)

US AIM HFC Phase-down Schedule



First decrease to 90% in 2022

Second decrease to 60% in 2024

High GWP phaseout in foams in 2025

Final decrease to 15% in 2036, May 2026 extension for certain sectors

**The average annual US HFC production/sales in 2011 – 2013 is used to establish a baseline for the phase-down (100%)*

EPA Continues to implement the AIM ACT through regulatory activity

US HFC Phasedown Updates

1. **Context:** Under the AIM Act, EPA can "partially, fully, or on a graduated schedule" restrict HFC use in specific sectors and subsectors.
2. **Finalized Rule:** Restricts HFCs used in refrigeration, aerosols, **foams**, AC, and heat pump products and equipment by setting GWP thresholds for most sectors. Based largely on ~12 petitions EPA granted. Protected 6 sectors in Kigali are excluded.
3. **Scope:** Applies to **new** products, systems, and components only.
4. **Transition Dates:**
   - In most cases, manufacture/import/install prohibition begins on **Jan. 1, 2025**,
   - prohibition of sale, distribution, and export of products begins **three years** after manufacture/import prohibition.

- **Technology rule update occurred May 2026**

In October of 2023, EPA finalized a rule to restrict certain HFCs in certain applications using its authority under the AIM Act. Prohibitions largely align or build upon those in SNAP 20/21, adopted by States and CARB.

Example Prohibitions Included in Final Rule

End-Use	GWP Limit*	Production/ Import Prohibition	Sales Prohibition
Propellants**	150	Jan. 1, 2025	Jan 1, 2026
Retail food ref. – Standalone units	150	Jan. 1, 2025	Jan 1, 2026
Polystyrene – extruded boardstock and billet	150	Jan. 1, 2025	Jan 1, 2026
Residential and light commercial air conditioning and heat pump systems	700	Jan. 1, 2025	Jan 1, 2026
Motor vehicle air conditioning – light-duty passenger vehicles	150	Model Year 2025	Jan 1, 2026
High Pressure Two Component Spray Foam	150	Jan. 1, 2025	Jan 1, 2028
Low-Pressure Two Component Spray Foam	150	Jan. 1, 2025	Jan 1, 2028
One Component Foam Sealant	150	Jan. 1, 2025	Jan 1, 2028

**Using AR-4 GWPs, if product isn't listed, use WMO*
***Some exclusions apply, including for spray foam used in space vehicles*

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Technology Transitions Rules Update: EPA Finalizes Revisions

On May 21st, 2026, EPA announced revisions to the 2023 Technology Transitions Rule that delay compliance timelines and increase near-term flexibility use of HFC use across refrigeration and HVAC sectors.

- **Supermarkets and Remote Condensing Units** EPA extended the compliance date to 2032 for supermarkets (originally 2027) and remote condensing units (originally 2026) and established a short-term GWP prohibition threshold of 1,400.
- **Cold Storage Warehouses** EPA extended the compliance date to 2032 for cold storage warehouses (originally 2026) and established a GWP threshold of 700 in the short term.
- **R-410A Condensing Units** Units manufactured or imported before January 1, 2025, may be sold until existing inventory is depleted.

EPA maintained the exemption for new 410A condensing units manufactured or imported for service or repair.

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EU F-Gas

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F-gas overview – state of play

March 2024 **Entry into force**	**2025**	**2026**	**2027** **MAC Review**	**2028** **MDI Review**	**2029**	**2030** **Annex IV Review**	**2040** **HFC quota review**

Timeline of F-gas Regulation implementation takes us through several rounds of review clauses, application by application – based on efficiency, cost, availability and safety.

In addition, the Regulation includes options for exemptions based on safety requirements and general derogations on applying the Regulation – triggered at Member State competent authority level.

- **These include a built-in review by 2030 to evaluate the availability, technical feasibility, energy efficiency, cost effectiveness, safety, and reliability of potential alternatives. This review will include an assessment as to whether bans can be applied to certain applications. Most of the bans also include the language 'except when required to meet safety requirements, enabling exemptions where they do not.'**

FOAMS Proposed Ban (2033)

Chillers
≤12kw Proposed Full Ban (2032)

Self Contained AC and HP
≤12kw Proposed Full Ban (2032)

Split AC and HP
≤12kw Proposed Full Ban (2035)

Subject to safety requirements exemptions and a full review in 2030

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Risk Considerations

The potential risk from exposure is dependent on several factors

- Dose
- Concentration
- the route of exposure
- the frequency & duration of exposure
- bioaccumulation and persistence
- metabolism and elimination
- the *individual’s factors

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WHAT
IS PFAS ?

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PFAS The Science

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WHAT IS “PFAS”

Per- and polyfluoroalkyl substances (PFASs) are a large group of chemicals (24 Million chemical structures) widely used in industrial and consumer applications, most usually where extremely low surface energy or surface tension and/or durable water- and oil-repellency is needed.

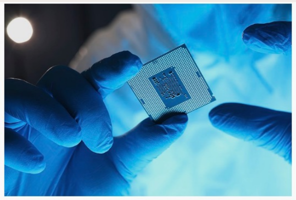
Examples of uses range from chromium metal plating, to surface treatment of textiles, carpets and papers, to semiconductor chip manufacturing, to medicines and pesticides.


Automotive Safety & Reliability


Military Readiness


Advanced Refrigerants


Life-Saving Medical Care


Semiconductor-Powered Technologies


Clean Energy

“PFAS” is a broad, general, non-specific term, and does not inform whether a compound is harmful nor is a basis for regulation

SOURCE: About PFASs - OECD Portal on Per and Poly Fluorinated Chemicals

Quick primer: PFAS is a class, not a single chemical

➢ Definition Matters

EU OECD PFAS DEFINITION (2021)

PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e. with a few noted exceptions**, any chemical with at least a perfluorinated methyl group (–CF3) or a perfluorinated methylene group (–CF2–)** is a PFAS.

US EPA PFAS DEFINITION (2023) - FEDERAL

“PFAS” is defined as a chemical substance that contains at least one of the following three structures:

1. R-(CF2)-CF(R′)R″, where **both the CF2 and CF moieties are saturated carbons**.
2. R-CF2OCF2-R′, where **R and R′ can either be F, O, or saturated carbons**.
3. CF3C(CF3)R′R″, where R′ and R″ can **either be F or saturated carbons**.

US states and other countries have different definitions

Reference:

1. OECD, HT. "Reconciling Terminology of the Universe of Per-and Polyfluoroalkyl Substances: Recommendations and Practical Guidance." (2021).
2. US.EPA, 40 CFR Part 705, Reporting and recordkeeping requirements for certain per- and polyfluoroalkyl substances. (2023)
3. CAS, PFAS regulation and research: Impact, landscape, and outlook. https://www.cas.org/report/pfas-regulation

PFAS CONCERNS

Some of the unique properties of PFAS (such as water-, oil- and grease-repellence and high thermal stability) that originally popularized their widespread use are associated with potential environmental and human health concerns.

For over a decade, particular PFAS compounds like PFOS and PFOA and their precursors have attracted the most attention among PFAS as emerging contaminants of global concern.

PFOA and PFOS are **persistent** and distributed ubiquitously in the global environment, and are **bioaccumulative**, meaning they collect in the human body, and **toxic**, meaning they can cause various adverse effects in wildlife and humans.

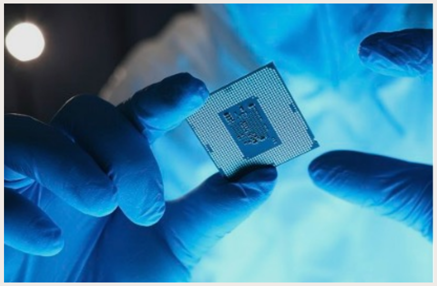
Because of the concerns raised by the known PFAS compounds of concern, some jurisdictions are exploring **various forms of PFAS regulation, including broad-based bans and phaseout in certain products and particular uses.**

The Issue

No universally recognized definition of PFAS

High variability in regulations

Regulations for consumer and commercial products



Major industry impacts

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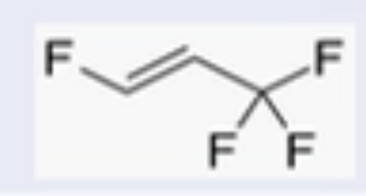

Definitional alignment and clarity needed across the U.S. and globally

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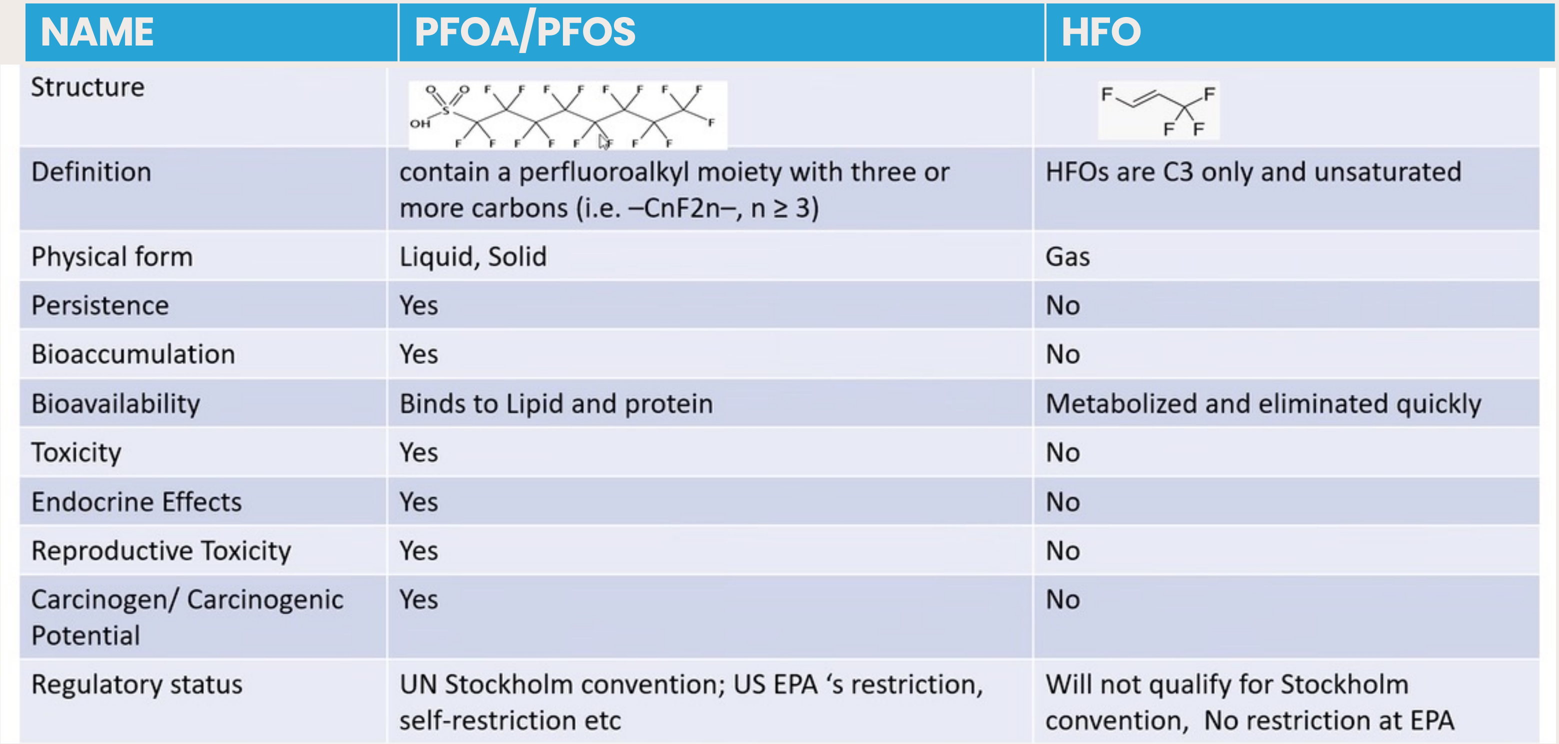
Fundamental Differences Between PFOAS/PFOS and HFOs



NAME	PFOA/PFOS	HFO
Structure		
Definition	contain a perfluoroalkyl moiety with three or more carbons (i.e. –CnF2n–, n ≥ 3)	HFOs are C3 only and unsaturated
Physical form	Liquid, Solid	Gas
Persistence	Yes	No
Bioaccumulation	Yes	No
Bioavailability	Binds to Lipid and protein	Metabolized and eliminated quickly
Toxicity	Yes	No
Endocrine Effects	Yes	No
Reproductive Toxicity	Yes	No
Carcinogen/ Carcinogenic Potential	Yes	No
Regulatory status	UN Stockholm convention; US EPA 's restriction, self-restriction etc	Will not qualify for Stockholm convention, No restriction at EPA

HFOs: SCIENCE, FACTS AND EVIDENCE

HFOs SHOULD BE EXCLUDED FROM SCOPE OF PFAS RESTRICTIONS

- HFOs are not **PERSISTENT**. HFOs break down in the atmosphere relatively quickly and do not persist in the environment. Lifespans are much shorter than CO_2, methane, or nitrous oxide (N_2O).

- HFOs are not **BIOACCUMULATIVE**. They are not retained for long periods in the human body or other biological systems.

- HFOs are not **TOXIC**. They are not considered toxic according to The European Chemicals Agency (ECHA) guidelines.

- HFOs have **LOW GLOBAL WARMING POTENTIALS** (<1) and are an important technology in keeping **energy costs low**

- HFOs are **SAFER IN USE** than alternative solutions such as hydrocarbons due to their low flammability and low toxicity

HFOs are not persistent, bioaccumulative, or toxic

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PFAS Regulatory Action

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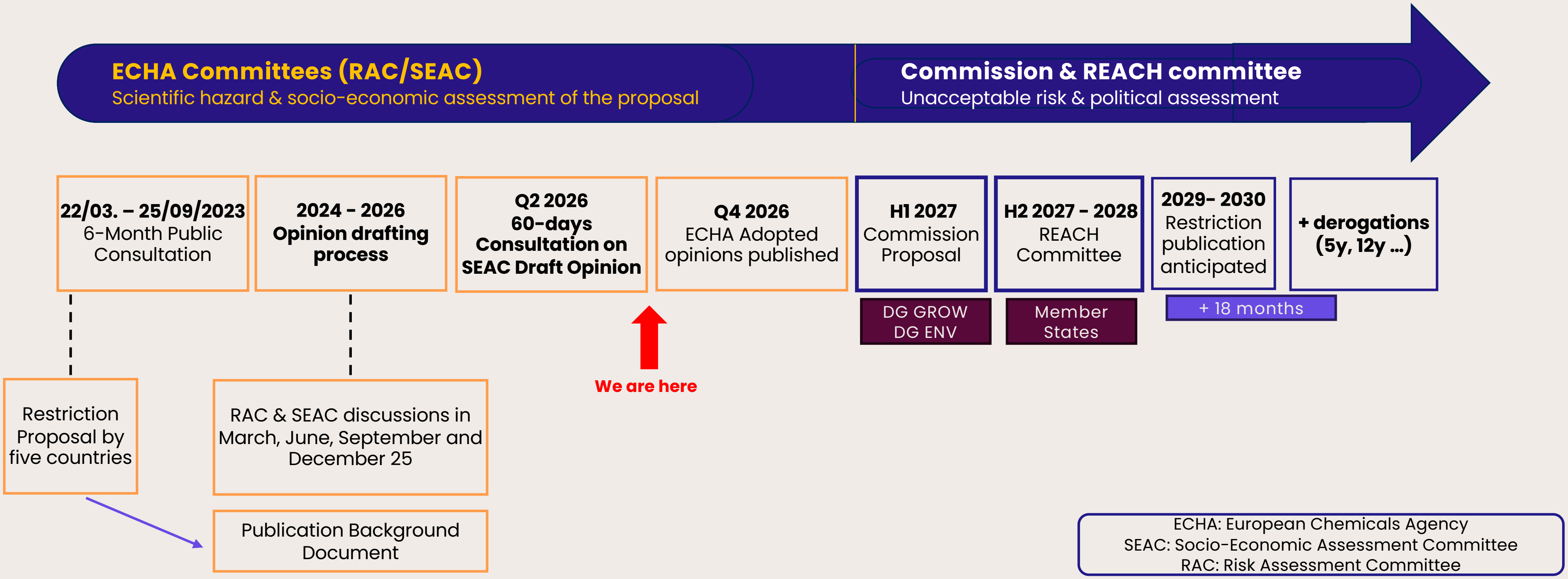
EU PROCESS OF THE PFAS RESTRICTION PROPOSAL



ECHA Committees (RAC/SEAC)
Scientific hazard & socio-economic assessment of the proposal

Commission & REACH committee
Unacceptable risk & political assessment

22/03. – 25/09/2023
6-Month Public Consultation

2024 - 2026
Opinion drafting process

Q2 2026
60-days Consultation on SEAC Draft Opinion

Q4 2026
ECHA Adopted opinions published

H1 2027
Commission Proposal

H2 2027 - 2028
REACH Committee

2029- 2030
Restriction publication anticipated

+ derogations (5y, 12y …)

DG GROW
DG ENV

Member States

+ 18 months

We are here

Restriction Proposal by five countries

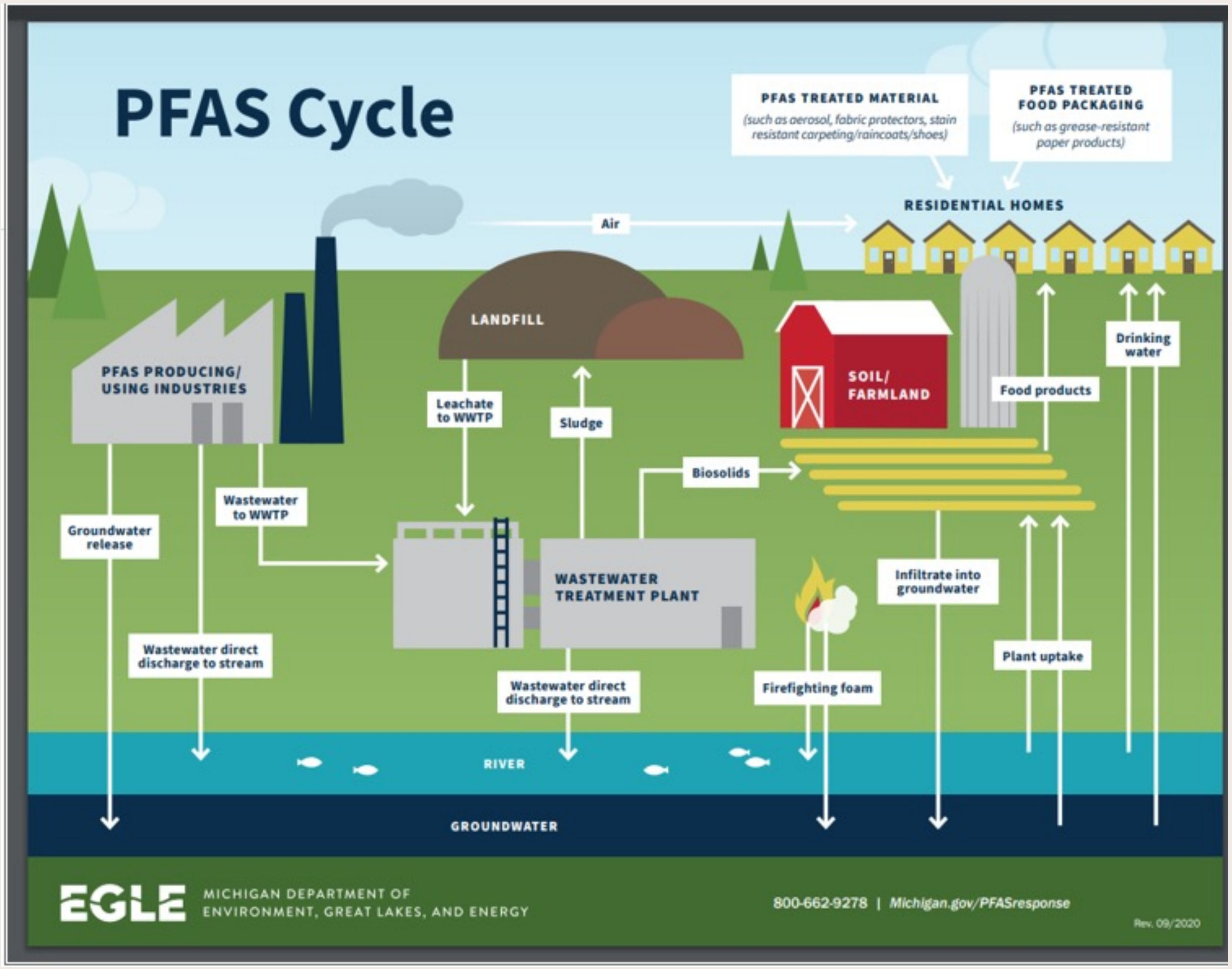
RAC & SEAC discussions in March, June, September and December 25

Publication Background Document

ECHA: European Chemicals Agency
SEAC: Socio-Economic Assessment Committee
RAC: Risk Assessment Committee

Two-phased process: Commission holds the pen. ECHA opinion non-binding

MANY SOURCES OF PFAS IN ENVIRONMENT



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PFAS- The Market

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“PFAS-Free” claims appear across many product categories and industries and have different meanings

Floor Care

First Certification for Floor Care Products Formulated Without PFAS

https://www.cleanlink.com/news/article/First-Certification-for-Floor-Care-Products-Formulated-Without-PFAS--32347

Textile

The Push Towards PFAS-Free Uniforms: A New Era in Workwear Sustainability

Sep 2, 2024 | Sustainability

https://naumd.com/the-push-towards-pfas-free-uniforms-a-new-era-in-workwear-sustainability/

Firefighting

PFAS-Free Fire Extinguishers: What Are ‘Forever Chemicals’ - And Should Your Business Make the Switch Now?

https://www.safetybuyer.com/safety-hub/resource/pfas-free-fire-extinguishers-what-are-forever-chemicals---and-should-your-business-make-the-switch-now?srsltid=AfmBOookJLZHWQoOc8F1mY-Yqa6C9fZhliva8q3eqkwEnjL91YvUec3W

Mattresses

Cottonsafe® Explains PFAS Guide

https://www.cottonsafenaturalmattress.co.uk/blog/cottonsafe-explains-pfas-guide

Gearbox

APEX DYNAMICS PRODUCTS GUARANTEED PFAS FREE

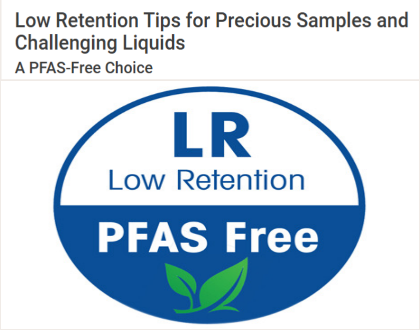
https://www.apexdyna.nl/en/news/pfas-gearbox-lubricants

Building materials

Quadrant Announces PFAS-Free Certification Across EnviroSeal Open-Cell Insulation Products

https://www.sprayfoammagazine.com/foam-news/quadrant-announces-pfas-free-certification-across-enviroseal-open-cell-insulation-products/4644

Biotechnology



Low Retention Tips for Precious Samples and Challenging Liquids

A PFAS-Free Choice

https://www.shoprainin.com/pfas-free-pipette-tips?srsltid=AfmBOoqoBqH8hrbRIks8Rahmh3O9CyAAzTc6MYzSeydHsIPbplw0su3K

Food packaging

https://sundanceusa.com/blog/flexible-packaging-making-the-transition-pfas-free-packaging/

presented August 3, 2026.

Comparison of PFAS Certifications

Program	Typical Scope	PFAS-Free Criteria
GreenScreen Certified	Industrial and consumer products	Product-category-specific limits, e.g. • Medical supplies & devices: total fluorine < 0.01% by mass (100 ppm) • Firefighting foam: total organic fluorine < 0.0001 % by mass (1 ppm)
NSF 537	Nonfood Compounds & Food Equipment Mat	• No intentionally added PFAS, no post-consumer recycled material, and no deliberately used PFAS additives • Total organic fluorine < 50 ppm
OEKO-TEX Standard 100	Textiles, leather, footwear	• Textile articles are classified into 4 product classes. Limit values are different for each class. • Specific restricted PFAS testing • Total fluorine limit as an indicator for PFAS presence
UL Solutions 746G	Engineering materials	• Non-fluorine materials – Plastic materials recognized as non-fluorine contain ≤50 parts ppm of fluorine. • Non-PFAS materials – Plastic materials recognized as non-PFAS contain ≤50 ppm of fluorine and <25 ppb of specific PFAS content (listed in Table 8.2 of UL 746G) and ≤250 ppb of total specific PFAS content.
Green Seal Certified	Consumer products (4 main categories)	• Prohibiting any intentionally added PFAS • Restricting any PFAS to 100ppm when present as a contaminant
Intertek PFAS-Free	Industrial and consumer products	• Total organic fluorine < 20 ppm • Targeted PFAS: <12.5 ppb
US.EPA-Safer Choice	Industrial and consumer products	• PFAS are not allowed in certified products, as they do not meet the Safer Choice Standard.
BPI Certified	Compostable products and packaging	• Safety data sheets for all ingredients establish that product formula does not contain fluorinated chemicals. • Test results from a BPI-Approved lab showing a maximum of 100ppm total organic fluorine. • A statement of no intentionally added fluorinated chemicals, signed by the manufacturer.

presented August 3, 2026.

Comparison of PFAS Certifications (Cont'd)

Some commercial PFAS testing labs have their own PFAS-free criteria.

E.g. *Measurlabs*' "PFAS-free" criteria:

- Total organic fluorine content is less than 50 ppm
- Individual PFAS compounds are not present in concentrations above 25 ppb
- The sum of individual PFAS compounds is less than 250 ppb

Other labels

- TUV Rheinland Green Products Mark (PFOS <0.01% or 1 ug/m^2)
- NSF ANSI/336 2018 – Commercial Furnishings Fabric (No PFOS)
- UL 2777 – Hard Floor Care Products (No PFOS, <100 ppm F-surfactants)
- SMART – Sustainable Materials Ratings Technology (PFOS <Stockholm POPs)

Note: PFAS testing criteria for products is quite different than drinking water standards.

presented August 3, 2026.

Why problematic: “PFAS-free” means something different every time

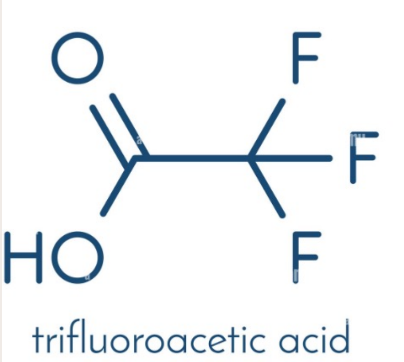
- No US federal legal definition of the term “PFAS-free”
- Any company can print “PFAS-free” on packaging with no standardized testing behind it, and with their own interpretations
- Even if certified by third-party programs, the certifications cover different scopes, testing methods, and detection limits if any.

Solstice

WHAT IS TFA?

presented August 3, 2026.

WHAT IS TFA?



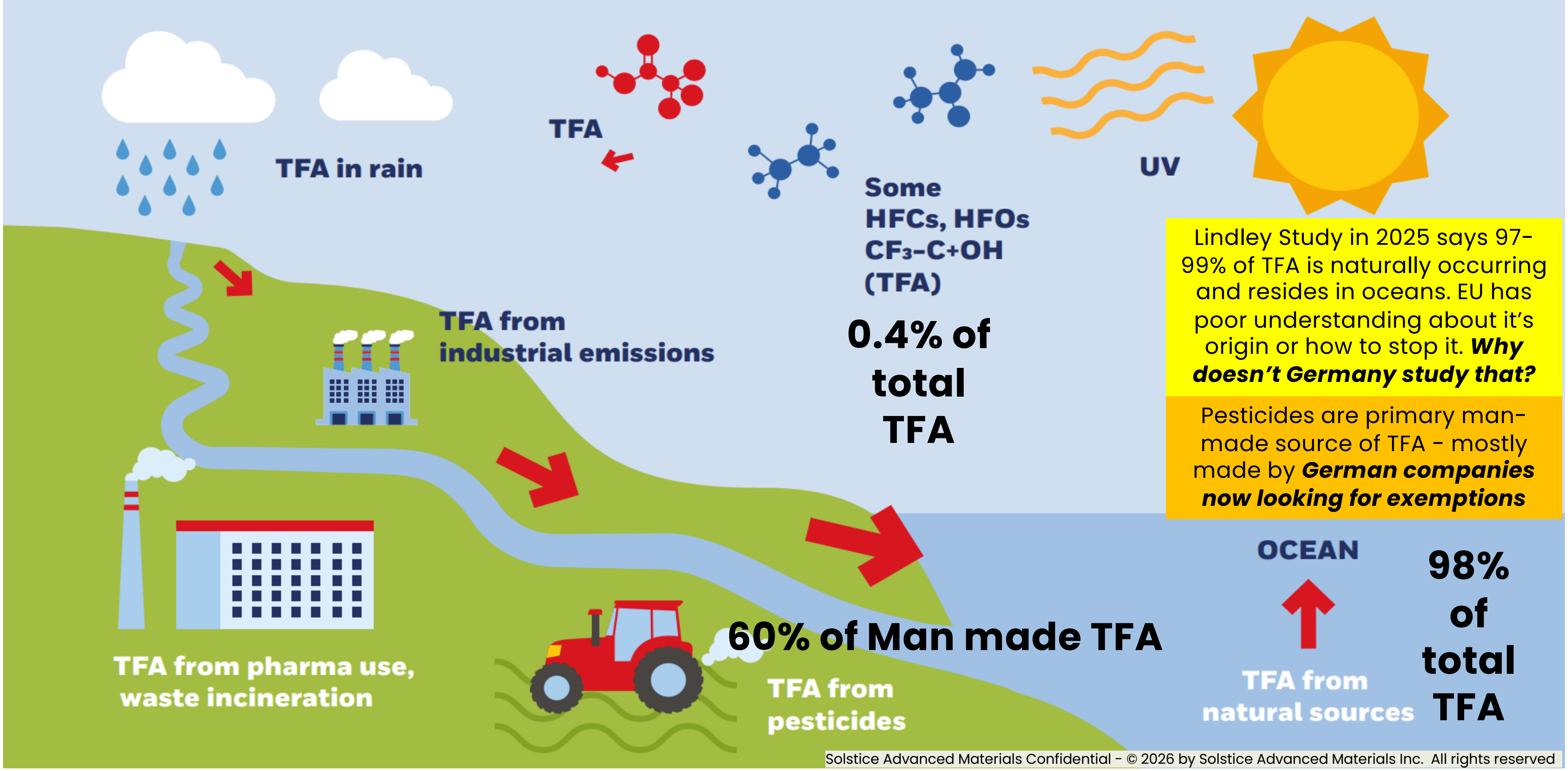
TFA is a naturally occurring substance, which has been **present in our environment for thousands of years**. There is evidence that the quantity of TFA measured in the oceans are mostly of natural origin.

TFA can be formed by use of agricultural pesticides and herbicides, incinerators, pharmaceutical by-product and a breakdown product of **some** HFOs.

While TFA can enter the environment as a breakdown product of some HFOs – the amounts are **well below the threshold for concern** with respect to human and environmental health according to UNEP (United Nations Environment Programme).

presented August 3, 2026.

TFA Key Contributors To The Environment



TFA in rain

TFA

Some HFCs, HFOs CF_3–C+OH (TFA)

UV

TFA from industrial emissions

0.4% of total TFA

Lindley Study in 2025 says 97-99% of TFA is naturally occurring and resides in oceans. EU has poor understanding about it's origin or how to stop it. ***Why doesn't Germany study that?***

Pesticides are primary man-made source of TFA - mostly made by ***German companies now looking for exemptions***

TFA from pharma use, waste incineration

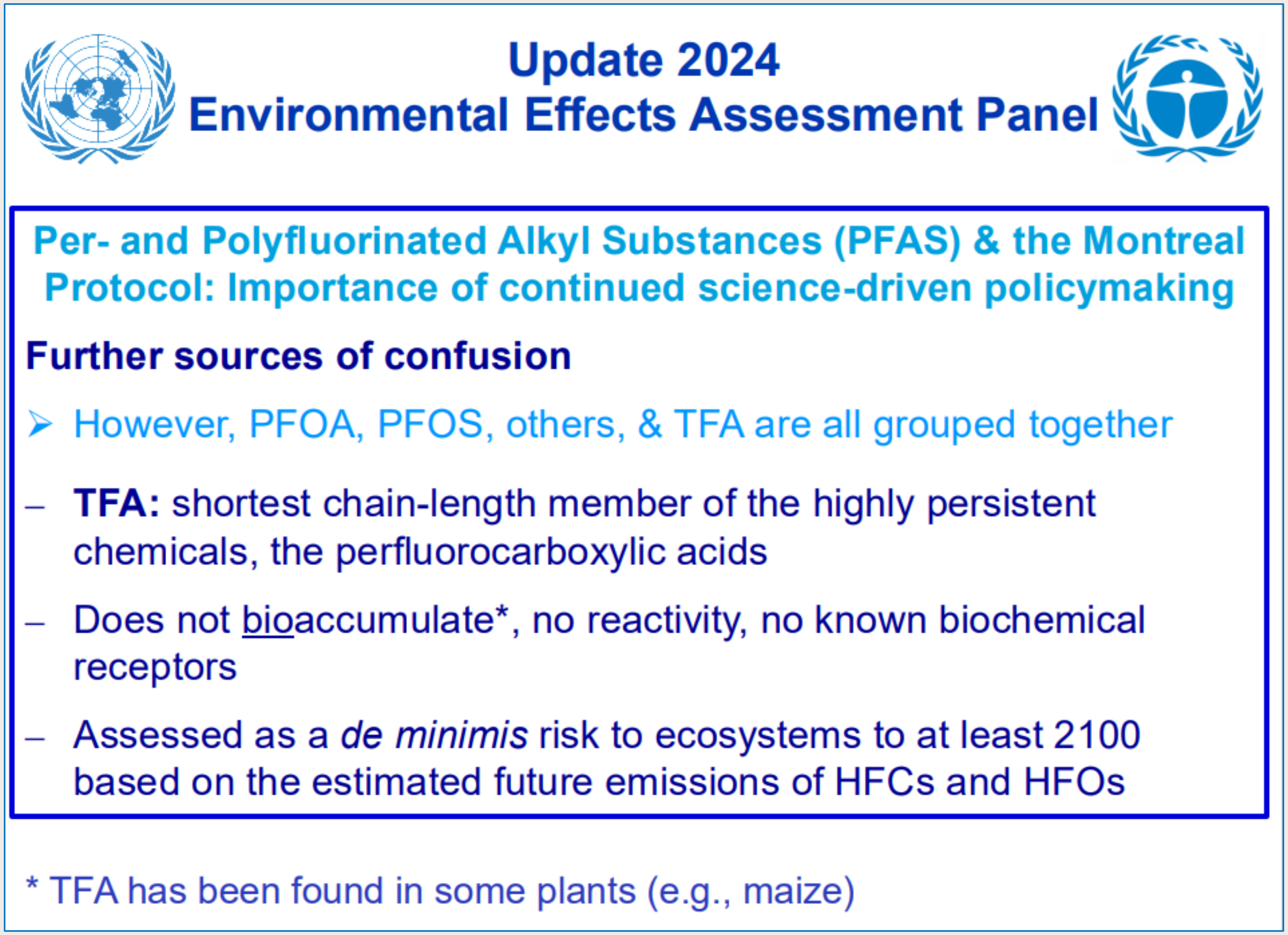
60% of Man made TFA

TFA from pesticides

OCEAN

TFA from natural sources

98% of total TFA



Update 2024
Environmental Effects Assessment Panel

Per- and Polyfluorinated Alkyl Substances (PFAS) & the Montreal Protocol: Importance of continued science-driven policymaking

Further sources of confusion

- However, PFOA, PFOS, others, & TFA are all grouped together
  - **TFA:** shortest chain-length member of the highly persistent chemicals, the perfluorocarboxylic acids
  - Does not bioaccumulate*, no reactivity, no known biochemical receptors
  - Assessed as a *de minimis* risk to ecosystems to at least 2100 based on the estimated future emissions of HFCs and HFOs

* TFA has been found in some plants (e.g., maize)

*Environmental Effects of Stratospheric Ozone Depletion, UV Radiation, and Interactions with Climate Change; 2022 Assessment Report (EEAP 2022)

Chemical and Physical Properties of TFA

Name	TFA	PFOA (For comparison)
# of carbons	2	8
Physical state	Liquid	Liquid
Boiling point °C	73	189
Vapor pressure (Pa)	11	1.72
Solubility in water (g/L) at 25 °C	miscible	3.3
pKa	0.3	<1
Koc (L/kg)	0.17-20	30,440
log Kow	0.5	5.905
Bioaccumulation	No	Yes
Half-life in human body	16 hours	2.7 years
Toxicity	No/Extremely low	Yes
Persistence	Yes	Yes

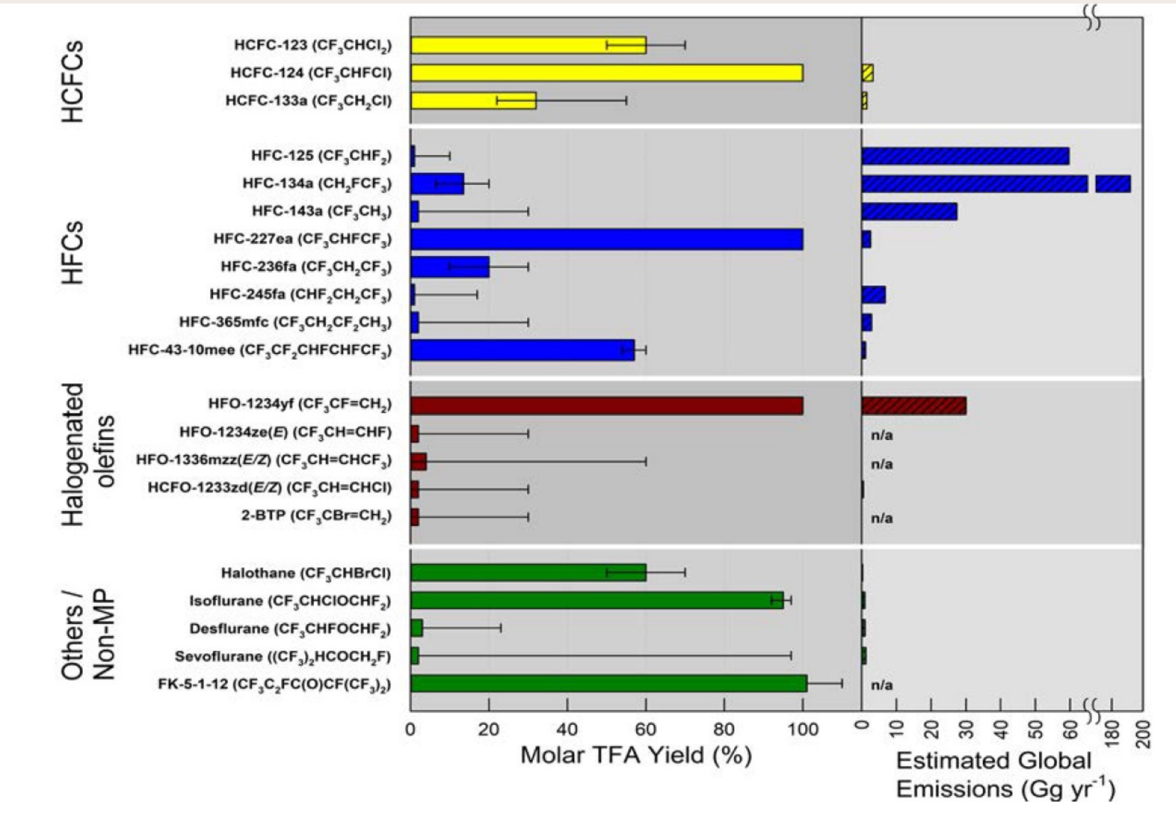
- **pKa:** acid dissociation constant, a quantitative measure of the strength of an acid in solution.
- **KOC :**a measure of adsorption to soil and sediment.
- **log KOW:** a measure of partitioning between lipids in organisms and water.
- **Half-life in humans:** related to chronic exposure and chronic toxicity.

Properties of TFA support:

- ✓ Mobile, and transport with water
- ✓ Rapid dissociation in water---trifluoroacetate
- ✓ No/Negligible accumulation in soils and sediment
- ✓ No bioaccumulation

Ref.: 1). Environmental effects of stratospheric ozone depletion, UV radiation, and interactions with climate change: UNEP Environmental Effects Assessment Panel, 2022 Assessment Report. 2). Boutonnet, Jean Charles, Pauline Bingham, Davide Calamari, Christ de Rooij, James Franklin, Toshihiko Kawano, Jean-Marie Libre et al. "Environmental risk assessment of trifluoroacetic acid." Human and Ecological Risk Assessment: An International Journal 5, no. 1 (1999): 59-124. 3). Burns, Darcy C., David A. Ellis, Hongxia Li, Colin J. McMurdo, and Eva Webster. "Experimental p K a determination for perfluorooctanoic acid (PFOA) and the potential impact of p K a concentration dependence on laboratory-measured partitioning phenomena and environmental modeling." Environmental science & technology 42, no. 24 (2008): 9283-9288.

The yields of TFA from individual compounds are estimated based on evaluations of the available literature



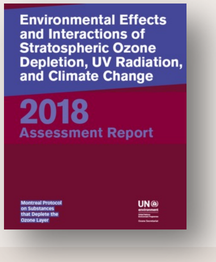
Reference:
Environmental Effects Assessment Panel, Environmental Effects of Stratospheric Ozone Depletion, UV Radiation, and Interactions with Climate Change: 2022 Assessment Report. Nairobi, Kenya: United Nations Environment Programme, 2023.

TFA Generation is combination of molecule and emissions

presented August 3, 2026.

Experts agree, TFA poses minimal risk

UNEP



Environmental Effects and Interactions of Stratospheric Ozone Depletion, UV Radiation, and Climate Change

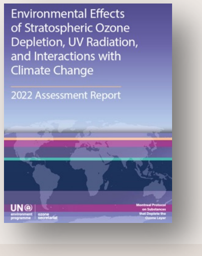
2018 Assessment Report

TFA has been present in our environment for thousands of years with no indication of impact on human health.

. UNEP; Feb 2016; Sources, Fates, Toxicity, and Risks of Trifluoroacetic Acid and Its Salts: Relevance to Substances Regulated Under the Montreal and Kyoto Protocols

- Effects and Interactions of Stratospheric Ozone Depletion, UV Radiation, and Climate Change: 2018 Assessment Report, https://ozone.unep.org/sites/default/files/2019-04/EEAP_assessmentreport-2018%20%282%29.pdf

EEAP



Environmental Effects of Stratospheric Ozone Depletion, UV Radiation, and Interactions with Climate Change

2022 Assessment Report

Every year since 2014, The Environmental Effects Assessment Panel (EEAP) of the Montreal Protocol (EEAP) has consistently concluded that TFA linked to HFC/HFO emissions does not pose risks to human health or the environment.

"TFA has biological properties that differ significantly from the longer chain PFAS and inclusion of TFA in this larger group of chemicals for regulation would be inconsistent with the risk assessment of TFA"

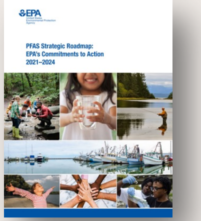
- EEAP 2022 Assessment Report, published March 2023: Environmental Effects of Stratospheric Ozone Depletion, UV Radiation, and Interactions with Climate Change

U.S. EPA SNAP 25

"Based on current information, EPA does not consider the overall risk [of TFA] to human health and the environment due to listings in this final rule to be significantly greater than other potentially available substitutes for the same uses."

-Protection of Stratospheric Ozone: Listing of Substitutes Under the Significant New Alternatives Policy Program in Refrigeration, Air Conditioning, and Fire Suppression. US Environmental Protection Agency. https://www.epa.gov/system/files/documents/2023-04/SAN%206399_Final%20SNAP%20Rule%2025_signed%20pre-publication.pdf

U.S. EPA Strategic PFAS Roadmap



PFAS Strategic Roadmap: EPA's Commitments to Action 2021–2024

Per the U.S. EPA's 2021 PFAS Strategic Roadmap, "trifluoroacetic acid (TFA) is a well-studied non-PFAS."

- Identification of Candidate Per- and Poly-fluoroalkyl Substances (PFAS) for Testing October 2021, U.S. Environmental Protection Agency, available at National PFAS Testing Strategy, www.epa.gov

PROPOSED EU TFA RECLASSIFICATION*

Ongoing process to update the classification of TFA through the **Classification, Labelling and Packaging (CLP) Regulation, Annex VI.** In their June meeting RAC adopted an opinion in favor of updating the harmonized hazard classification (CLH) of TFA as follows:

- Toxic to reproduction 1B (*presumed to be toxic*)
- Persistent, mobile and toxic (PMT) – *new designation*
- very Persistent and very Mobile (vPvM) – *new designation*

Estimate two years before this new classification is implemented in CLP Annex VI by the EU: it will update labelling requirements for TFA itself but not for HFOs/HFCs, and this is not a restriction.

*** RAC/M/77/2026, Minutes of the 77th Meeting of the Committee for Risk Assessment (RAC-77), 5 June 2026**.

It is Literal Impossibility for a Single Person to Consume Enough Water to Experience Negative Effects from TFA

The amount of water you could drink without any health effects from TFA is one hundred and twenty-five times greater than the impact threshold for water as a stand-alone substance.

Conservative (low) body weight of 60 kg for a human being, resulting in a safe exposure level to TFA of (0.03 mg/kg bw/day) x (60 kg bw) = 1.8 mg/day

0.014 ←

The median amount of TFA in drinking water (German study, 2022) is 0.0009 mg/liter

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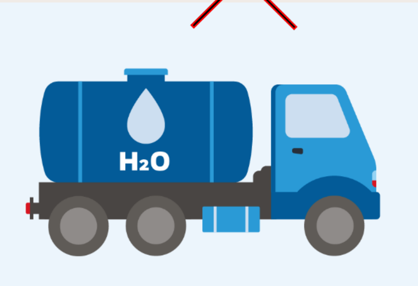
As such the safe exposure level of drinking water is: (1.8 mg/day) / (0.0009 mg/liter) = 933 liters/day

~~2,000 LITRES~~ → **933 LITRES**



Volume of water human could drink every day without experience any adverse effects from TFA*

*Based upon the Acceptable Daily Intake (ADI) – scientifically defined as the safe dietary exposure level, as determined by EFSA, and upon the reported median amount of TFA in drinking water (German study,2022)

The Lists

Red List- Living Future *

Living Building Challenge (LBC) Red List Established 2006

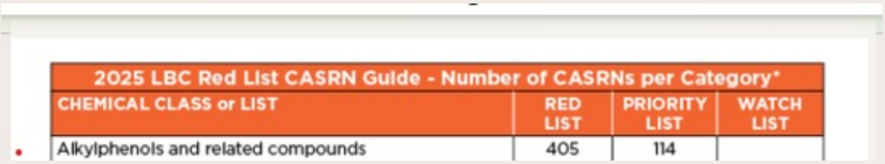
List of worst in class" substances t in the building industry that pose serious risks to human health and the environment.

Red List/ Priority List/ Watch List

Guideline for architects, designers, builders, and product manufacturers to avoid harmful chemicals in construction materials.

Buildings seeking LBC certification must **exclude Red List chemicals**

Declare product labeling program, which requires manufacturers to disclose all intentionally added chemicals and their compliance with the Red List



2025 LBC Red List CASRN Guide - Number of CASRNs per Category*

CHEMICAL CLASS or LIST	RED LIST	PRIORITY LIST	WATCH LIST
Alkylphenols and related compounds	405	114	

*he Red List - Living Future

Perkins&Will

https://perkinswill.com/news/perkinswill-releases-advanced-guidance-on-material-health-and-embodied-carbon/

HFOs not Red List on Watch List

HFO not on Perkins&Will List

Customers are aligning purchasing with hazard recognition.

Solstice

Jul 23, 2026

Refrigerants

Air conditioning and heat pump

Bruno Y. K. de Carvalho

Sr. R&D Engineer

presented August 3, 2026.

Outline

- Background/context on refrigerants
- Refrigerant selection criteria
- Refrigerant performance overview
- System design requirements for next-gen refrigerants

presented August 3, 2026.

Refrigerant historical context

History of refrigerant use in air conditioning / heat pump systems:

- 1900 – 1950s: Ammonia (R-717), CO_2 (R-744), SO_2 – Replaced due to toxicity, flammability, high operating pressures, and the emergence of safer synthetic refrigerants.

- 1930s – 1990s : R-12, R-11 – Phased out under the Montreal Protocol due to severe ozone depletion potential (ODP)

- 1960s – 2000s : R-22 – Dominant refrigerant for residential AC and heat pumps for decades; phased out because of ozone depletion concerns, although lower than CFCs

- 2000s – 2020s : R-410A, R-134a – Currently being phased out due to global warming concerns (high global warming potential (GWP))

- 2020s – Future :
  - R-454B, R-32, R-452B, R-513A – GWP<700
  - R-515B – GWP<300
  - R-454C, R-516A – GWP < 150
  - R-1234ze(E), R-1234yf, Propane, CO_2, Ammonia – Ultra low GWP

Refrigerant selection criteria

Refrigerant selection must consider safety, environmental impact, performance, compatibility

- Safety
    - Classification (ASHRAE 34 / ISO 817) – flammability and toxicity
    - Lower flammability limit (LFL) and allowable charge calculations (UL 60335-2-40 and EN/IEC 60335-2-40) and application codes (ASHRAE 15 and EN 378)
- Global warming potential (GWP) and environmental impact
    - Effects from direct (leakages, EOL) and indirect (energy consumption, manufacturing) emissions
- Performance:
    - Boiling point and operating pressure range
    - Volumetric capacity and compressor sizing
    - Thermodynamic efficiency
    - Heat transfer/pressure drop effect on performance
- Compatibility:
    - Lubricant miscibility and oil return behavior
    - Material compatibility and long-term reliability

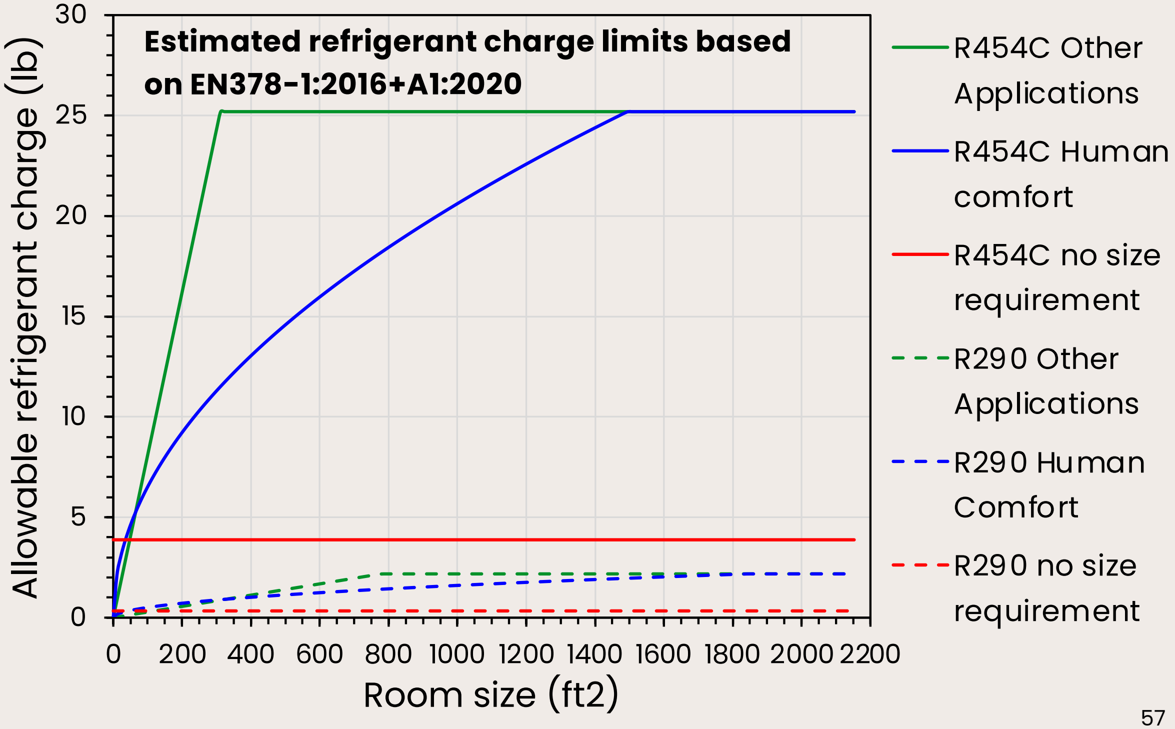
Each criteria is based on multiple aspects which can influence the refrigerant selection process

Safety criteria

Residential and commercial heat pump applications require class A toxicity

However, flammability has been extended to class 2L (mildly flammable), and class 3 in some applications in EU

Refrigerant	**Safety classification**
R410A, R134a, CO_2	A1
R454B, R32, R452B, R454C, R516A, R1234ze(E), R1234yf	A2L
Ammonia	B2L
Propane	A3



Charge limits based on PL/RCL/LFL and standards must be taken into account when selecting A2L/A2/A3 refrigerants

presented August 3, 2026.

Global warming potential

Global warming potential is an important factor to be considered in certain regions due to quote restriction and cut-off limits for phasedown

Refrigerant	GWP_{100} (AR4)
R410A	2088
R134a	1430

Refrigerant	GWP_{100} (AR4)
R452B	698
R32	675
R513A	573
R454B	466
R515B	293

Refrigerant	GWP_{100} (AR4)
R454C	148
R516A	140

Refrigerant	GWP_{100} (AR4)
R1234ze(E)	<1
R1234yf	<1
Propane	<1
CO_2	1
Ammonia	0

presented August 3, 2026.

Global warming potential restrictions

Navigating US federal/state, EU and country-based restrictions can be difficult, requires keeping track of evolving regulations.

US EPA

Subsector	GWP 100 Limit (AR 4)	Compliance date
Residential and light commercial A/C, H/P	700	January 1, 2025
VRF systems	700	January 1, 2027
A/C and H/P chillers	700	January 1, 2025

US NY (NY regulations may change due to recent legal developments)

Subsector	GWP 20 Limit (AR6)	Compliance date
A/C chillers	20	January 1, 2030
H/P chillers	20	January 1, 2034
Residential and light commercial A/C, H/P	10	January 1, 2034
VRF systems	10	January 1, 2030
All other residential HVAC	10	January 1, 2027
All other commercial HVAC	10	January 1, 2034
Industrial process refrigeration chillers	2690	January 1, 2026
	10	January 1, 2030

US CA

Subsector	GWP 100 Limit (AR5)	Compliance date
Self-contained residential and light commercial A/C, H/P	700	January 1, 2025
Chillers	700	January 1, 2025
Residential and light commercial A/C, H/P	700	January 1, 2026
VRF systems	700	January 1, 2026
Industrial process refrigeration chillers (Te>-22°F)	700	January 1, 2026

EU F-GAS

Subsector	GWP 100 Limit (AR 4)	Compliance date
Self-contained A/C, H/P Q<50 kW	150	January 1, 2027
Other self-contained A/C, H/P	150	January 1, 2030
Split A/C, H/P charge<3 kg (6.6 lbs)	750	January 1, 2025
Split ATW	150	January 1, 2027
Split ATA	150	January 1 2029
Split Q> 12 kW	750	January 1, 2029
Split Q>12 kW	150	January 1, 2033
Chillers Q<12 kW	150	January 1, 2027
Chillers Q>12 kW	750	January 1, 2027

presented August 3, 2026.

LCCP based refrigerant selection

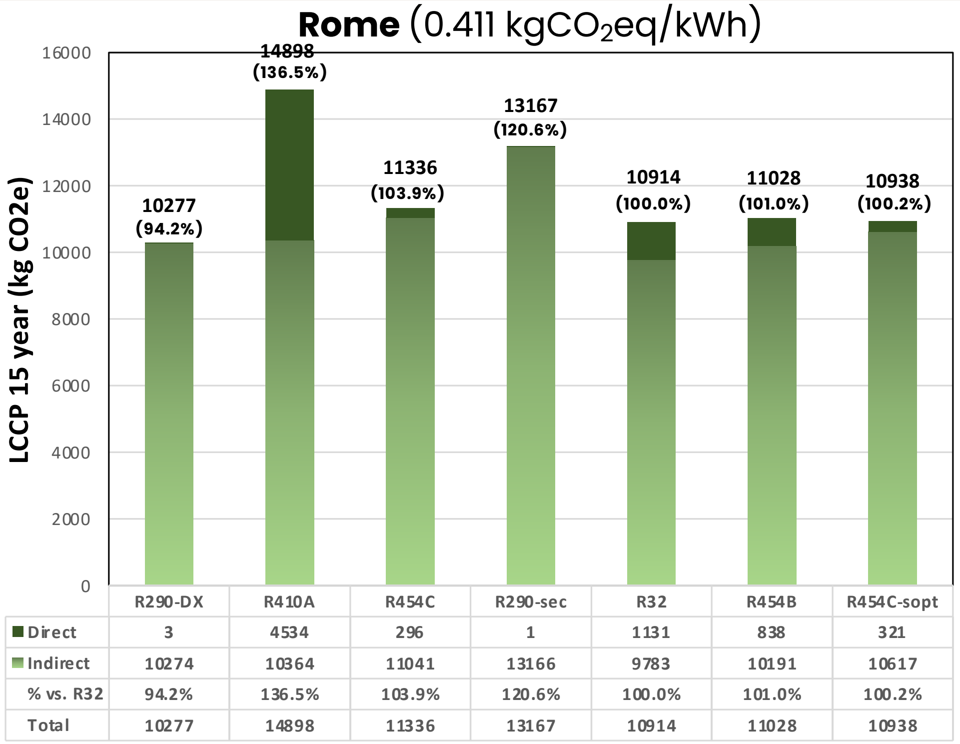
Refrigerant selection based on GWP alone may not provide a full picture on emission reductions. Energy efficiency plays more relevant role as refrigerant GWP decreases.

Data reproduced based on simulation of residential split systems from ORNL/TM- 2023/3041.

Direct emissions: 4% annual refrigerant leakage, 15% EOL.

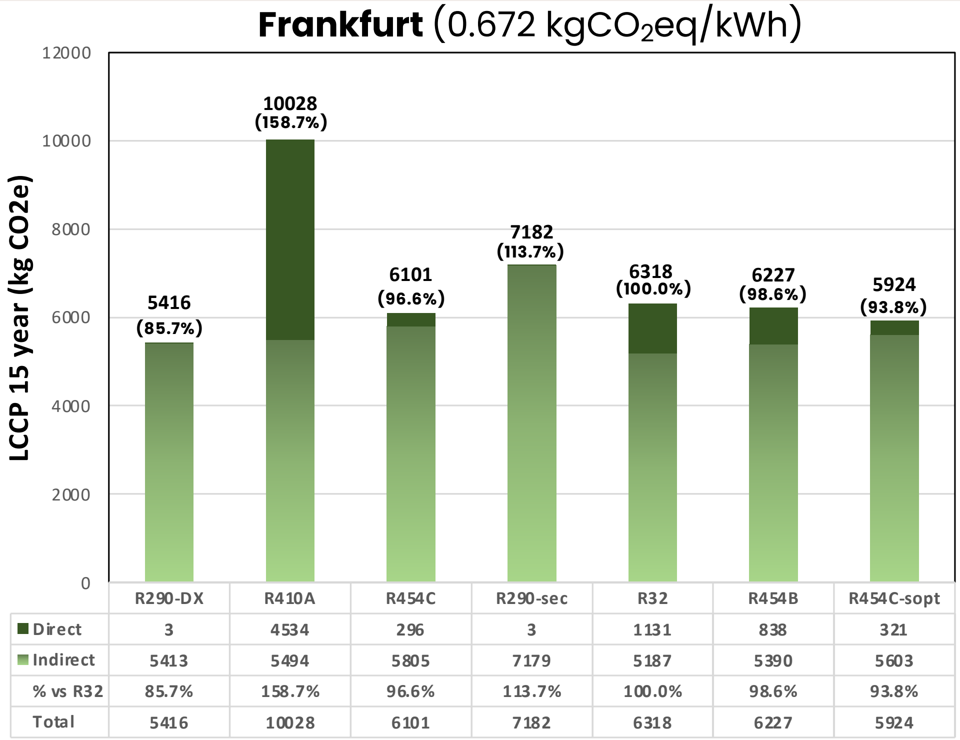
Indirect emissions: Energy consumption (~80-90% of indirect emissions), equipment manufacturing and EOL (~10-20% constant for all refrigerants), refrigerant manufacturing (negligible < 0.2%)

Rome (0.411 kgCO$_2$eq/kWh)



	R290-DX	R410A	R454C	R290-sec	R32	R454B	R454C-sopt
■ Direct	3	4534	296	1	1131	838	321
■ Indirect	10274	10364	11041	13166	9783	10191	10617
% vs. R32	94.2%	136.5%	103.9%	120.6%	100.0%	101.0%	100.2%
Total	10277	14898	11336	13167	10914	11028	10938

Frankfurt (0.672 kgCO$_2$eq/kWh)



	R290-DX	R410A	R454C	R290-sec	R32	R454B	R454C-sopt
■ Direct	3	4534	296	3	1131	838	321
■ Indirect	5413	5494	5805	7179	5187	5390	5603
% vs R32	85.7%	158.7%	96.6%	113.7%	100.0%	98.6%	93.8%
Total	5416	10028	6101	7182	6318	6227	5924

presented August 3, 2026.

***Calculations based on air-air system models and bin data for specified regions using assumptions from ORNL/TM- 2023/3041**

LCCP based refrigerant selection

LCCP calculation can account for direct/indirect emission sources

Region	Rome							Frankfurt						
Refrigerant System type	R-290 DX	R-410A DX	R-454C DX	R-290 SEC	R-32 DX	R-454B DX	R-454C DX s.opt.	R-290 DX	R-410A DX	R-454C DX	R-290 SEC	R-32 DX	R-454B DX	R-454C DX s.opt.
System charge (kg)	1.17	2.76	2.57	0.67	2.23	2.40	2.90	1.17	2.76	2.57	1.51	2.23	2.40	2.90
Total lifetime emissions (kg CO2e)	**10277**	**14898**	**11336**	**13167**	**10914**	**11028**	**10938**	**5416**	**10028**	**6101**	**7182**	**6318**	**6227**	**5924**
Total lifetime emissions (% vs. R-32 DX)	94.2%	136.5%	103.9%	120.6%	100.0%	101.0%	100.2%	85.7%	158.7%	96.6%	113.7%	100.0%	98.6%	93.8%
Total direct emissions (kg CO2e)	**2.8**	**4534**	**295.7**	**1.0**	**1131**	**837.5**	**321.4**	**2.8**	**4534**	**295.7**	**3.4**	**1131**	**837.5**	**321.4**
Total direct emissions (% vs. R-32 DX)	0.2%	401.0%	26.2%	0.1%	100.0%	74.1%	28.4%	0.2%	401.0%	26.2%	0.3%	100.0%	74.1%	28.4%
Annual refrigerant leakage (kg CO2e)	2.2	3627	236.6	0.8	904.6	670.0	257.1	2.2	3627	236.6	2.7	904.6	670.0	257.1
EOL Refrigerant Leakage (kg CO2e)	0.6	906.8	59.1	0.2	226.2	167.5	64.3	0.6	906.8	59.1	0.7	226.2	167.5	64.3
Total Indirect Emissions (kg CO2e)	**10274**	**10364**	**11041**	**13166**	**9783**	**10191**	**10617**	**5413**	**5494**	**5805**	**7179**	**5187**	**5390**	**5603**
Total indirect emissions (% vs. R-32 DX	105.0%	105.9%	112.9%	134.6%	100.0%	104.2%	108.5%	104.4%	105.9%	111.9%	138.4%	100.0%	103.9%	108.0%
Energy Consumption (kg CO2e)	9378	9395	10101	12267	8866	9263	9677	4517	4525	4865	6763	4270	4461	4663
Equipment Mfg (kg CO2e)	881.9	881.9	881.9	884.9	881.9	881.9	881.9	881.9	881.9	881.9	408.7	881.9	881.9	881.9
Equipment EOL (kg CO2e)	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	6.5	13.9	13.9	13.9
Refrigerant Mfg (kg CO2e)	0.1	73.7	44.0	0.1	21.6	32.4	44.0	0.1	73.7	44.0	0.1	21.6	32.4	44.0

Life-cycle climate performance

$$LCCP = Direct\ emissions + Indirect\ emissions$$

$$Direct\ emissions = C \times (L \times ALR + EOL) \times (GWP + \cancel{Adp\ GWP})$$

C = Refrigerant charge (kg)
L = Average lifetime equipment (yr)
ALR = Annual leakage rate (Percent of refrigerant charge)
EOL = End of life refrigerant leakage (Percent of refrigerant charge)
GWP = Global warming potential (kg CO2e/kg)
~~$Adp\ GWP$ = GWP of refrigerant atm. degradation (kg CO2e/kg)~~

$$Indirect\ emissions = L \times AEC \times EM + \sum(m \times MM) + \cancel{\sum(mr \times RM)} + C \times (1 + L \times ALR) \times RFM + C \times (1 - EOL) \times RFD$$

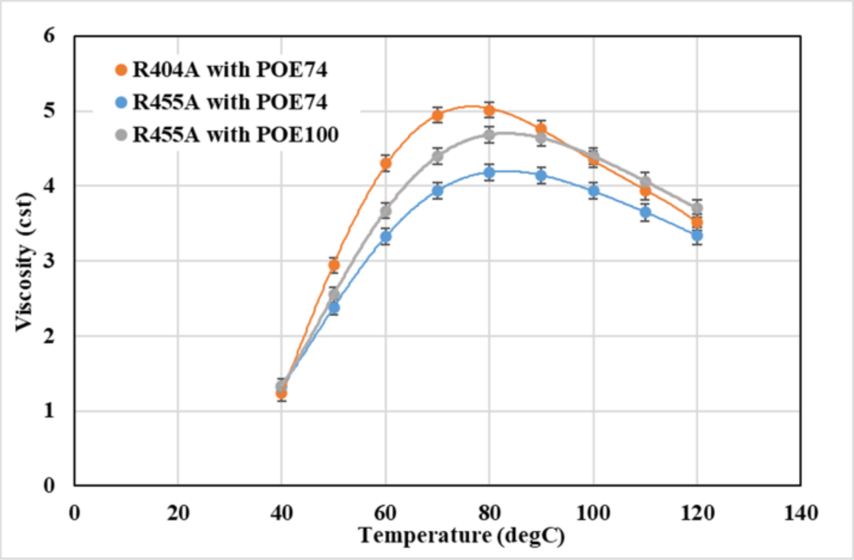
L = Average lifetime equipment (yr)
AEC = Annual energy consumption (kWh)
EM = CO2 produced/kWh (kg CO2e/kWh)
m = Mass of unit (kg)
MM = CO2 produced/material (kg CO2e/kg)
~~mr = Mass of recycled material (kg)~~
~~RM = CO2 produced/recycled material (kg CO2e/kg)~~
C = Refrigerant charge (kg)
ALR = Annual leakage rate (Percent of refrigerant charge)
RFM = Refrigerant manufacturing emissions (kg CO2e/kg)
EOL = End of life refrigerant leakage (Percent of refrigerant charge)
RFD = Refrigerant disposal emissions (kg CO2e/kg)

- Only Adp.GWP and equipment recycling are excluded from calculations due to lack of available data.
- Variables marked in grey have negligible effect on results.

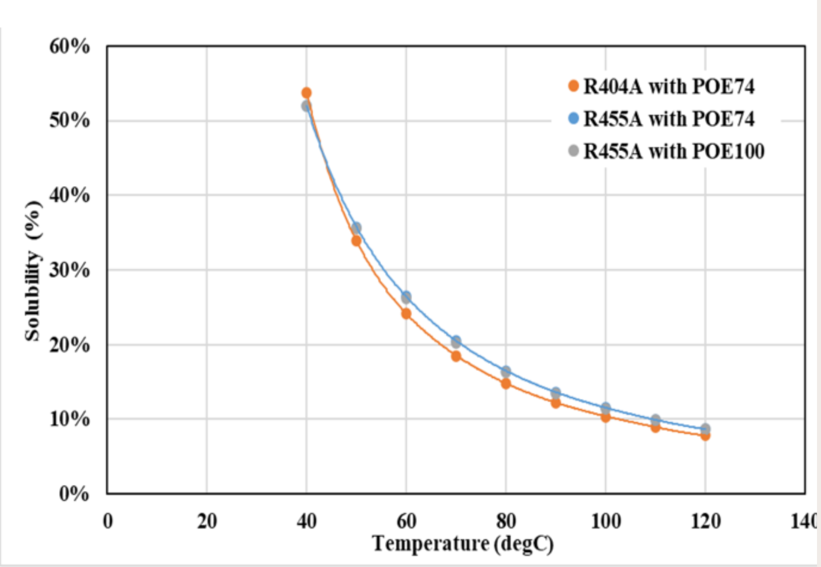
presented August 3, 2026.

Oil solubility/miscibility selection

New refrigerants may have solubility/miscibility/viscosity profiles that require new oil selections to guarantee oil return and reliable compressor operation



Viscosity Effect in Heat Pump Application
(Pressure @ 45 °C Sat. Evap.)



Solubility Effect in Heat Pump Application
(Pressure @ 45 °C Sat. Evap.)

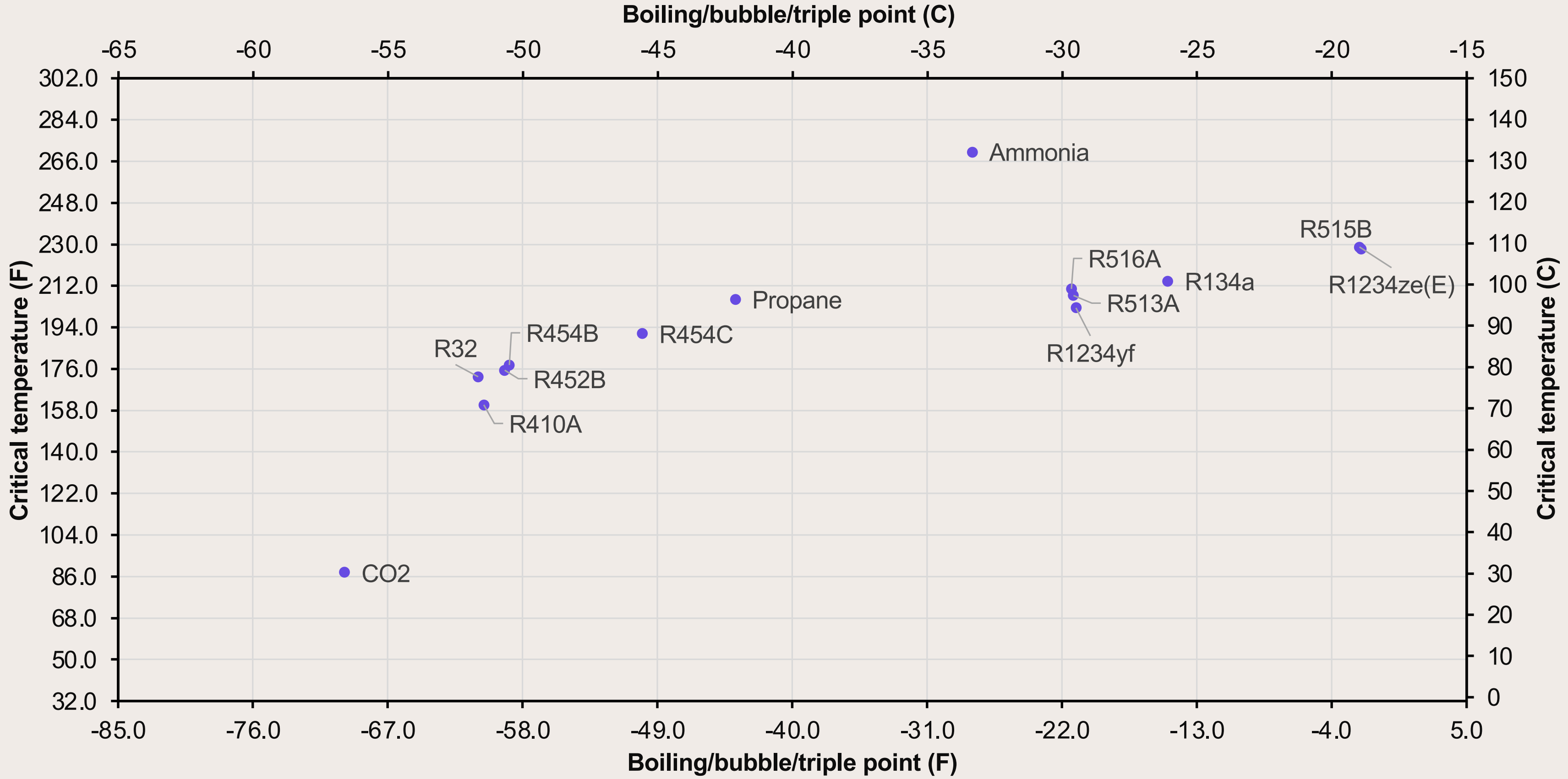
R455A/POE 74 shows a significant drop in viscosity to R404a/POE 74 and R455A/POE 100 shows improvement at typical compressor sump temperature

Example:
R455A reduces oil viscosity.
Recommended high viscosity oil (POE74 -> POE100)

presented August 3, 2026.

Boiling point and critical points

Balancing boiling point and critical point of refrigerants plays a role in achieving high efficiency, cold-climate operation and domestic hot water production



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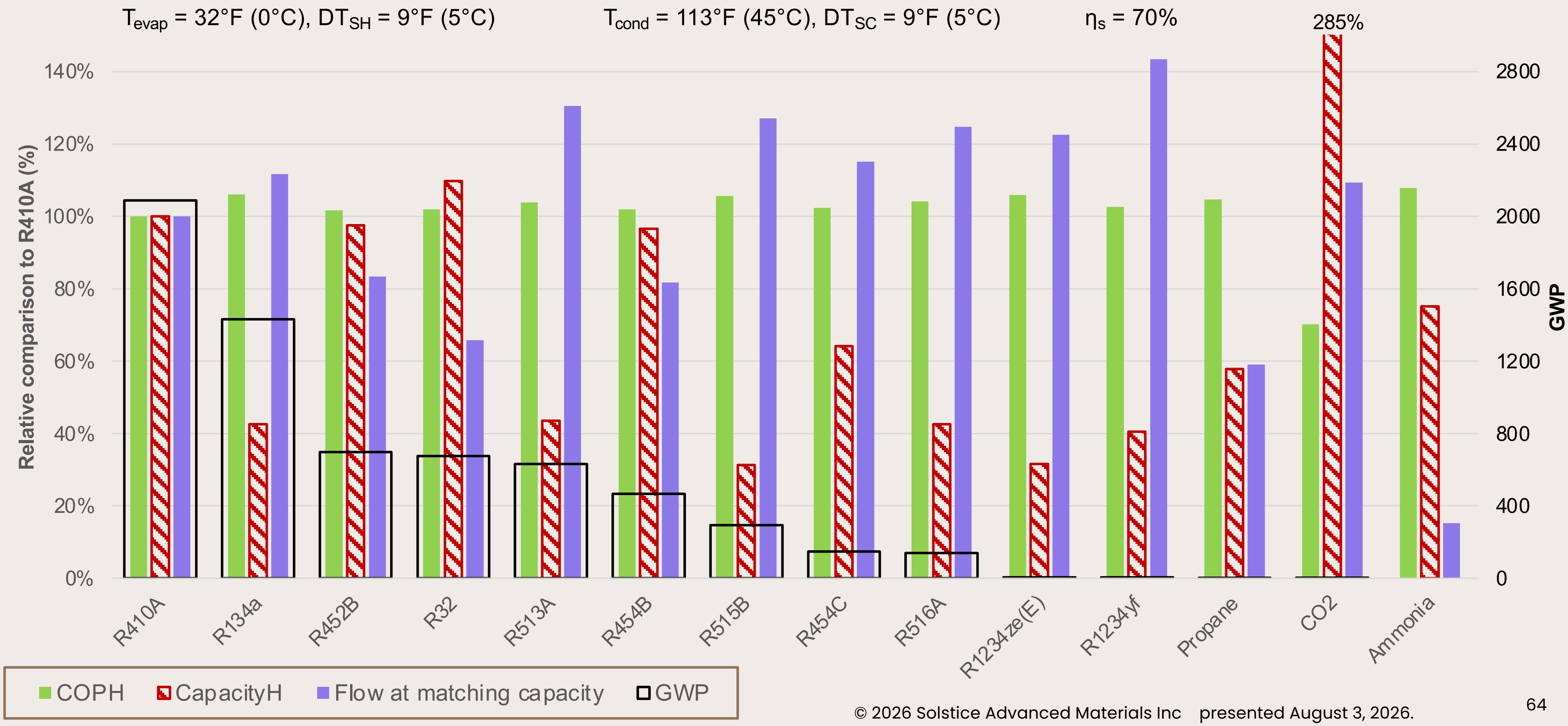
Refrigerant thermodynamic performance - Heating

Effective refrigerant selection requires determining the best fluid to deliver required COP (coefficient of performance), capacity and low direct emissions

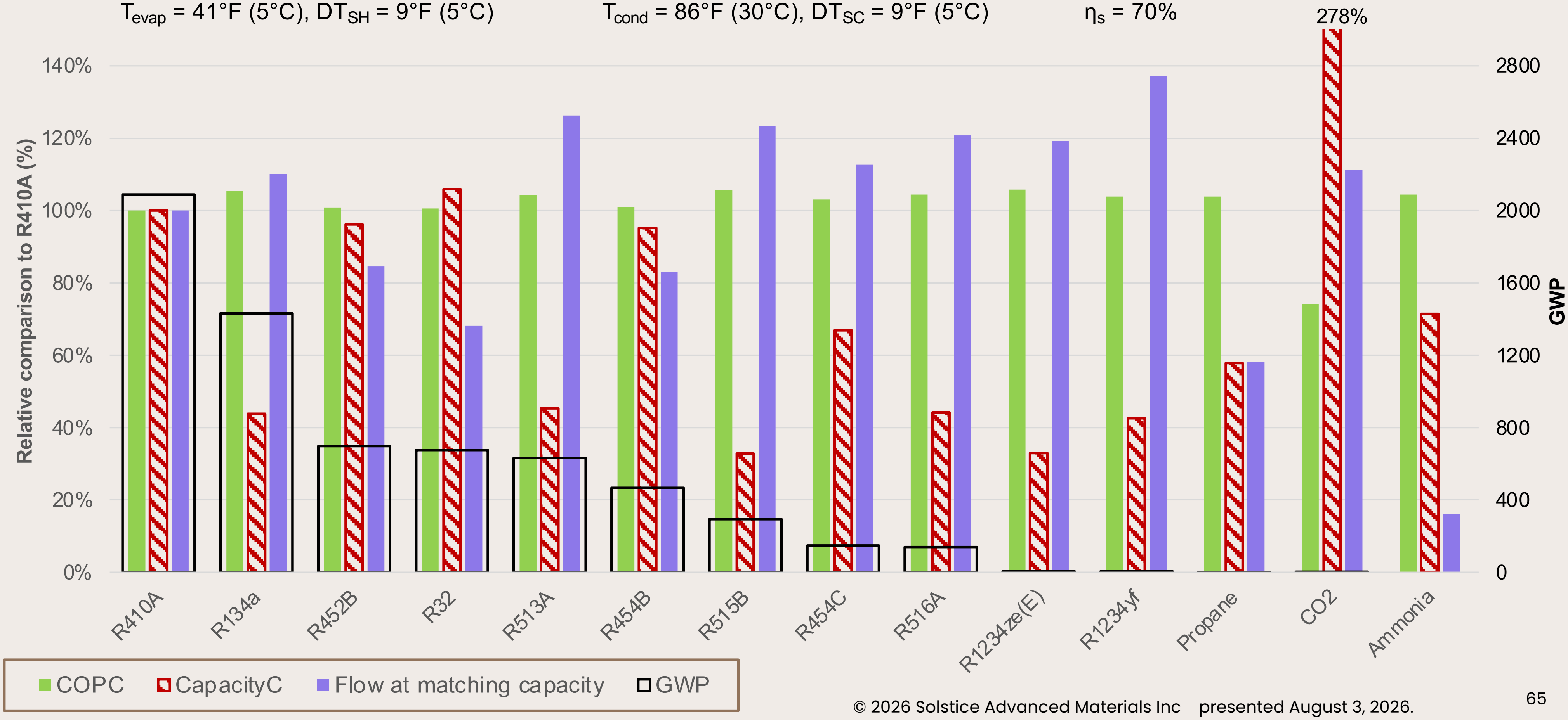


T_{evap} = 32°F (0°C), DT_{SH} = 9°F (5°C) T_{cond} = 113°F (45°C), DT_{SC} = 9°F (5°C) η_s = 70%

Refrigerant thermodynamic performance - Cooling

Cooling/heating performance are usually similar, but it’s important to evaluate both modes for issues, such as, high discharge temperature or decrease in capacity, especially at cold-climate conditions

T_{evap} = 41°F (5°C), DT_{SH} = 9°F (5°C) T_{cond} = 86°F (30°C), DT_{SC} = 9°F (5°C) η_s = 70%



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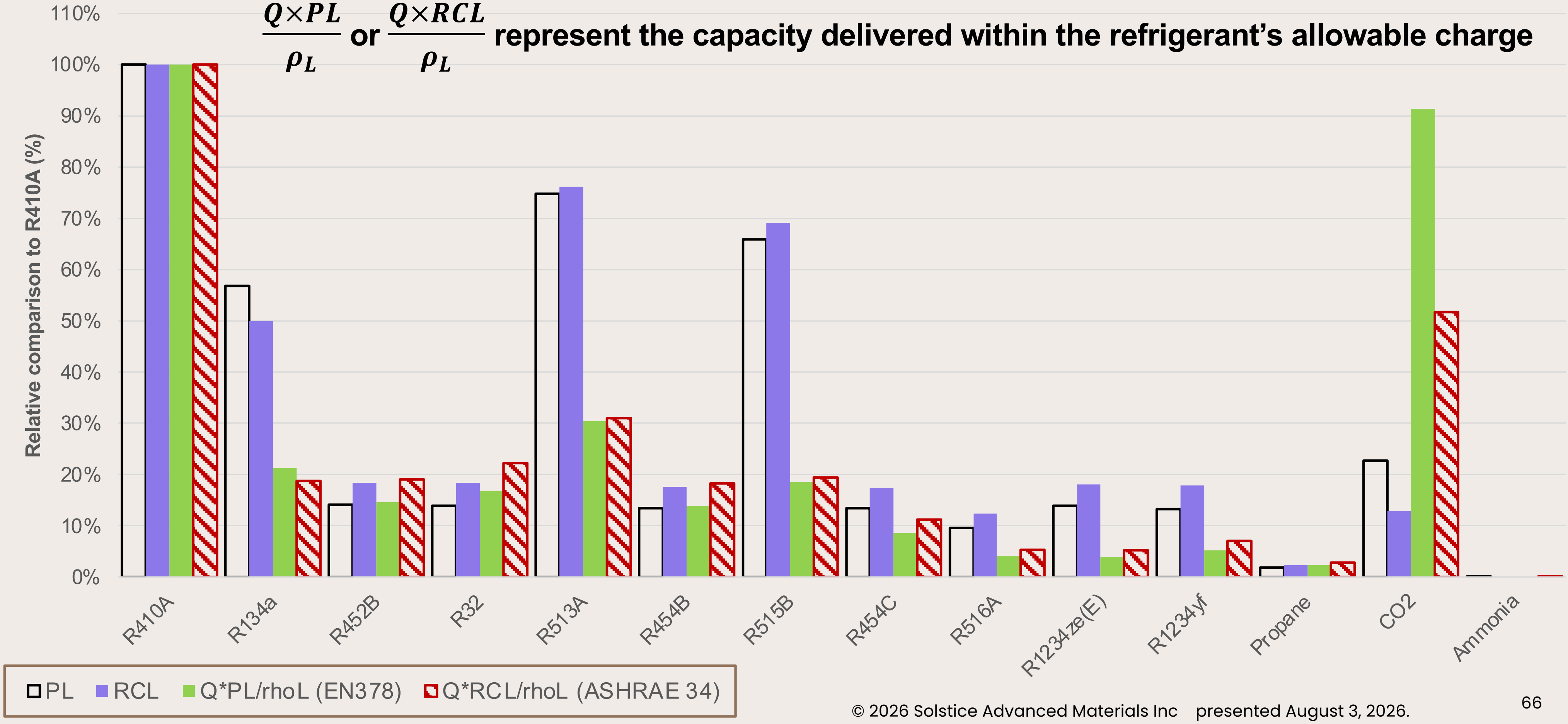
Safety and performance trade-offs

PL: Practical limit (EN378) [kg/m³]
RCL: Refrigerant concentration limit (ASHRAE 34) [kg/m³]

To reflect potential trade-offs in safety and performance a simple metric was defined to present an adjusted capacity delivered per allowable charge.



$\frac{Q\times PL}{\rho_L}$ **or** $\frac{Q\times RCL}{\rho_L}$ **represent the capacity delivered within the refrigerant's allowable charge**

Safety and performance trade-offs

PL: Practical limit (EN378) [kg/m^3]
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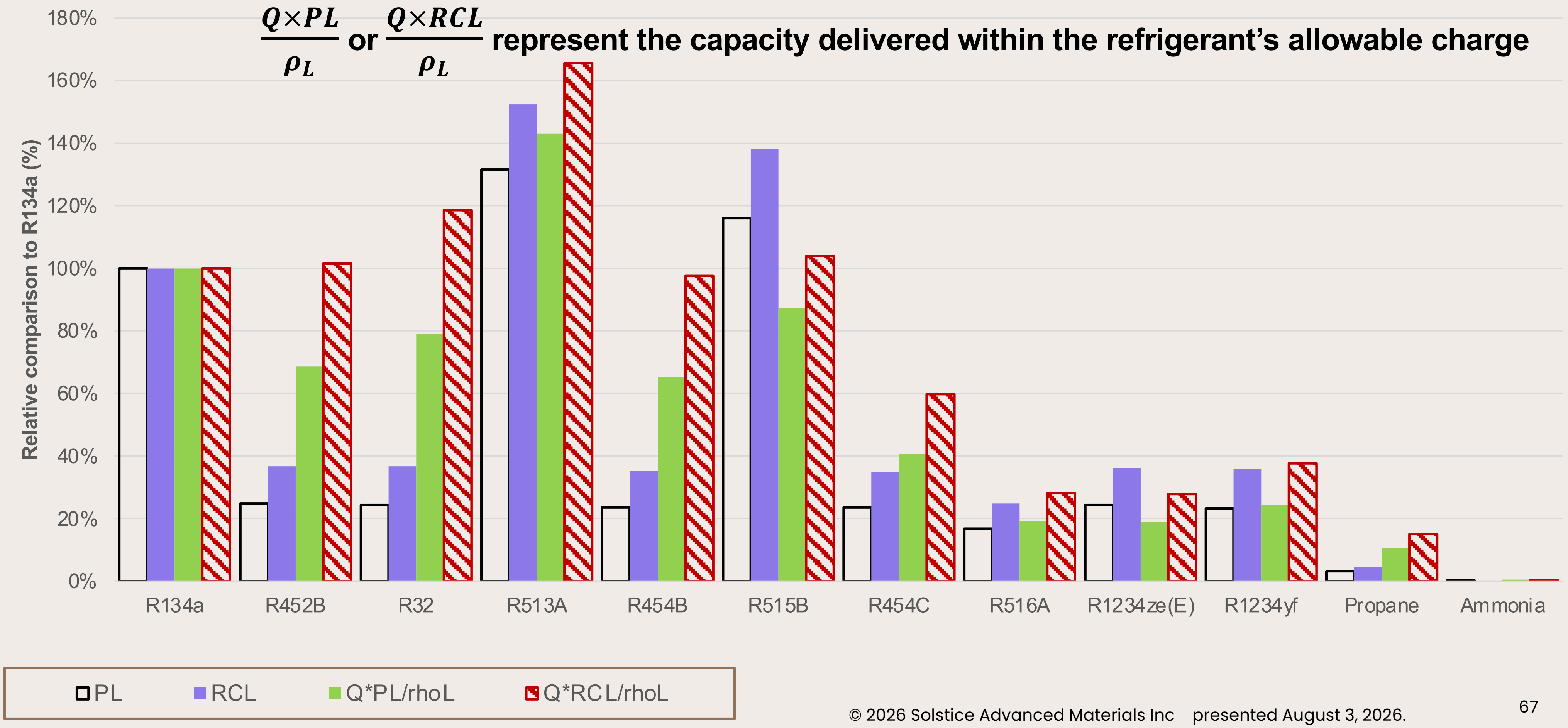
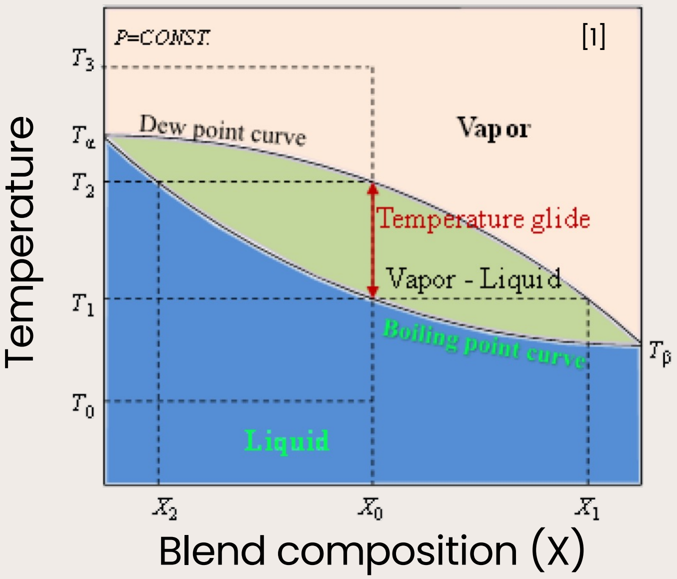


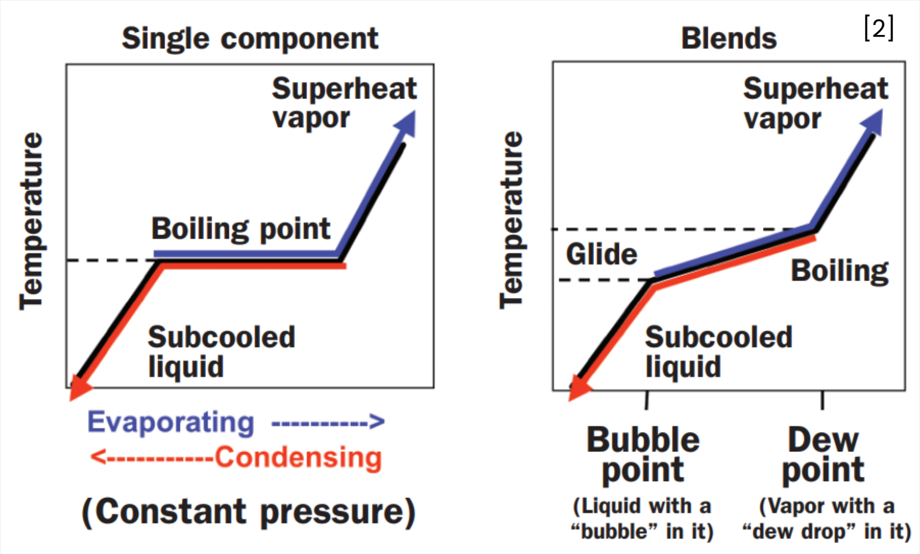
$\frac{Q \times PL}{\rho_L}$ or $\frac{Q \times RCL}{\rho_L}$ represent the capacity delivered within the refrigerant's allowable charge

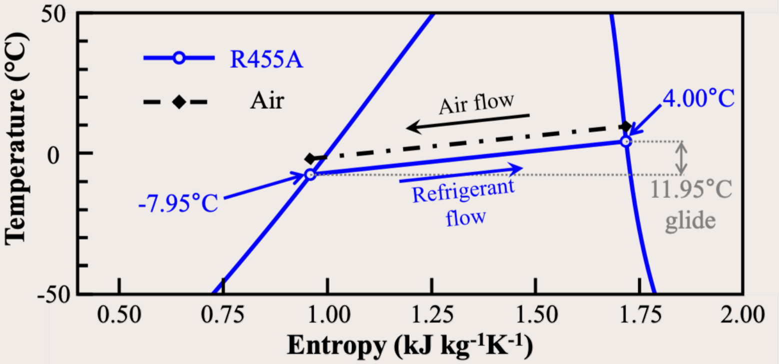
presented August 3, 2026.

System redesign for next-gen refrigerants - Glide

- Some refrigerant mixtures are zeotropic
  - Components with different boiling points (pressures)
  - Heat exchangers must be optimized for this
  - Reversible systems are more difficult to design
  - May increase frosting chance







Air and refrigerant temperature change example

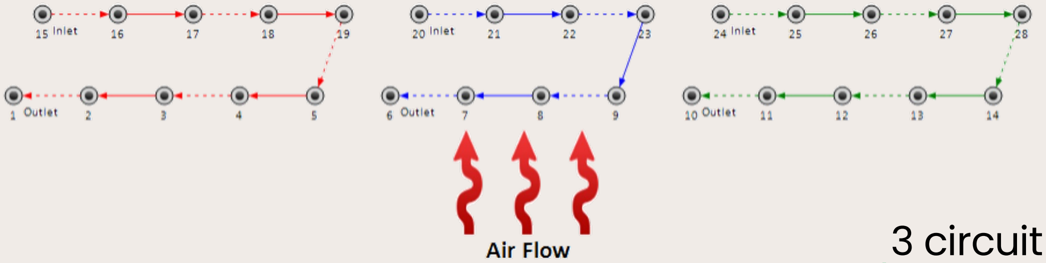
[1] https://www.mdpi.com/energies/energies-15-08082/article_deploy/html/images/energies-15-08082-g004.png
[2] https://nationalref.com/wp-content/uploads/2019/05/RSES-Article-Part-3-Mar06.pdf

System redesign for next-gen refrigerants - Glide

- Designing heat exchangers to balance cooling/heating performance for R-454C

Cooling mode (A1 condition 35.0C/26.7C DB 19.4C WB)		
Cooling counter	Heating counter	Balanced counter
COP	COP	COP
3.64	3.41	3.58
Heating mode (H1 condition 8.3C/21.0C)		
Cooling counter	Heating counter	Balanced counter
COP	COP	COP
3.18	3.53	3.35

Indoor HX (A/C)

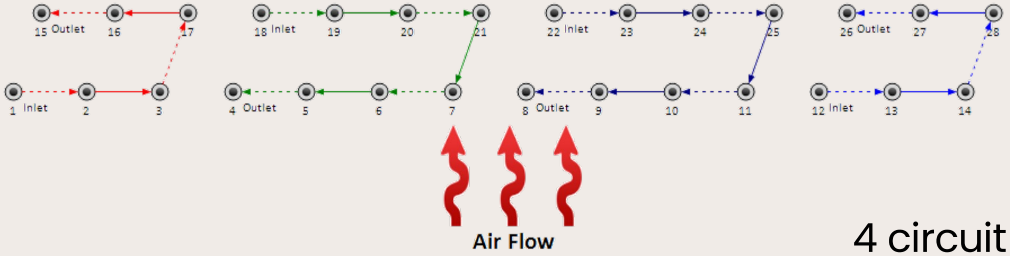


3 circuit

Cross-counter in A/C mode

Parallel-counter in H/P mode

Indoor HX (A/C)



4 circuit

2 8-tube cross-counter in A/C mode

2 6-tube cross-counter in H/P mode

Solution:

Optimize heat exchanger design or modify cycle to mitigate penalties

System redesign for next-gen refrigerants - flammability

- Highly flammable refrigerants (propane) are being used in EU
- Due to safety their indoor refrigerant charge is limited
- Air-to-water (ATW) or hydronic systems are being adopted
  - Add one layer of protection to keep high-pressure flammable gases from entering the building
  - Allow for under-floor heating or conventional radiator use
  - Increase thermal resistance, heat/cool water to then heat/cool building
  - May require use of glycol/water mixture, further decreasing heat transfer effectiveness
  - Cannot cool/dehumidify using radiators, requires water coils ducted or installed in each room
  - Potential 15-25% efficiency reduction can lead to system that cannot meet efficiency standards
  - Increase system cost significantly

System redesign for next-gen refrigerants - flammability

Trane has presented two studies at Purdue 2026 evaluating R-290 for the US market: modeling and experimental

- Modeling: comparing the performance of optimized **R-454B (ATA)**, **R-454C (ATA)** and **R-290 (ATW)**
- Estimated efficiency loss for R-290 ranges from 12-20%, with capacity dropping about 15%
- R454C matches capacity at most conditions but shows a COP drop of 6-12%.
- 30% PG mixture used for secondary loop

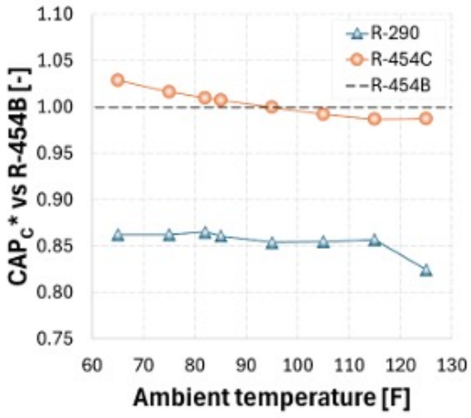


Figure 5: Cooling capacity with different refrigerants in direct (R-454B, R-454C) and indirect (R-290) expansion mode

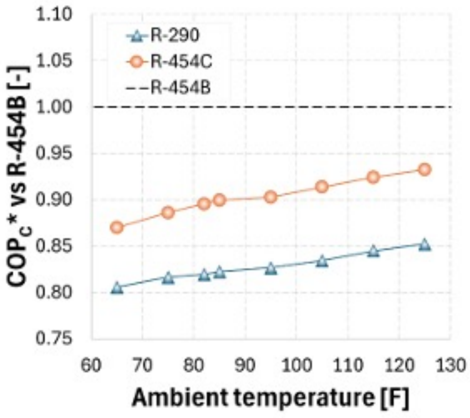


Figure 6: Cooling COP with different refrigerants in direct (R-454B, R-454C) and indirect (R-290) expansion mode

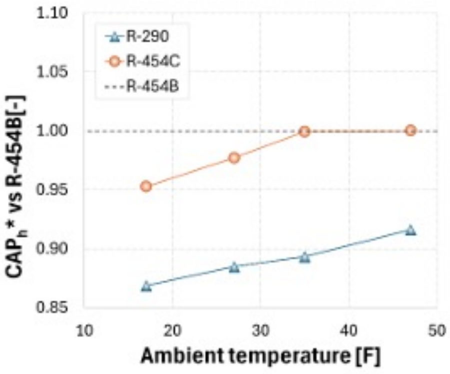


Figure 7: Heating capacity with different refrigerants in direct and indirect expansion mode

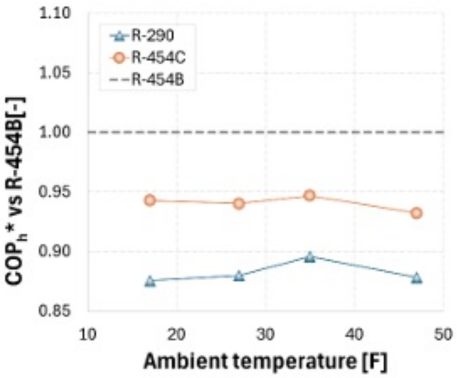


Figure 8: Heating COP with different refrigerants in direct and indirect expansion mode

Nayak et al., 2026. Understanding The Performance Limitations Of R-290 Air To Water Heat Pumps. 21st International Refrigeration and Air Conditioning Conference at Purdue, West Lafayette, IN.

presented August 3, 2026.

System redesign for next-gen refrigerants - flammability

- Trane's experimental investigation on R-290 ATW systems for the US market corroborated the modeling results
- Prototype 1: 26% lower COP in cooling, 20% lower COP in heating
- 16% lower COP in cooling, 15% lower COP in heating achieved by optimizing refrigerant-to-water HX
- Potential enhancements were proposed along with estimated improvements
- Authors indicate a significant cost increase to possibly achieve 95% of the baseline COP

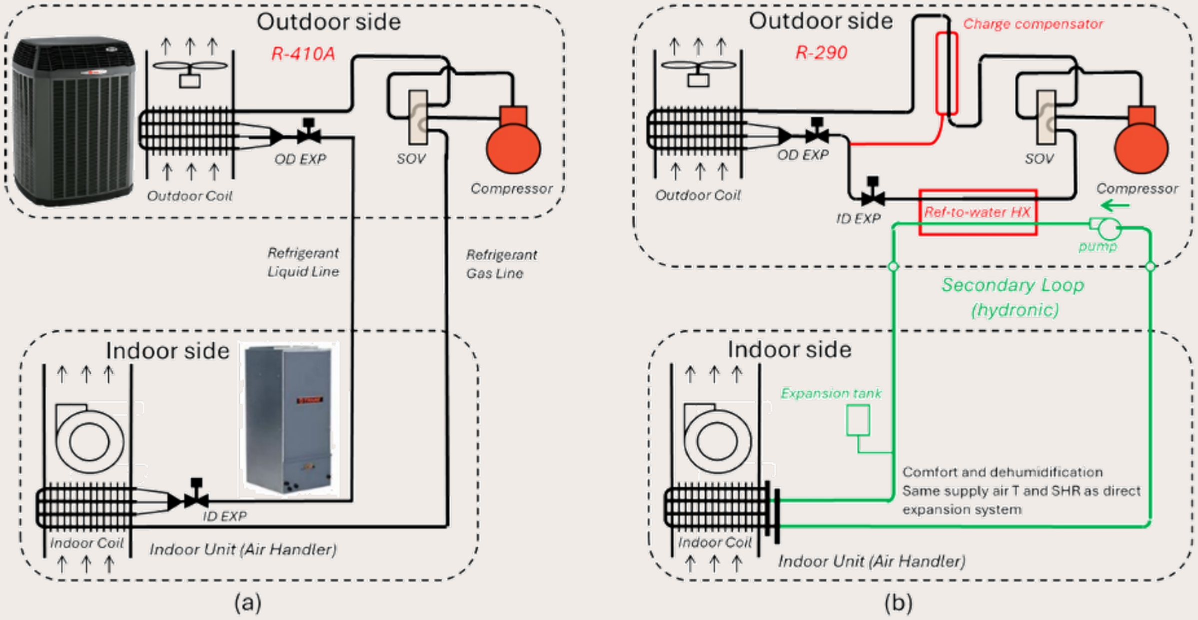


Figure 1: a) R-410A baseline b) R-290 prototype

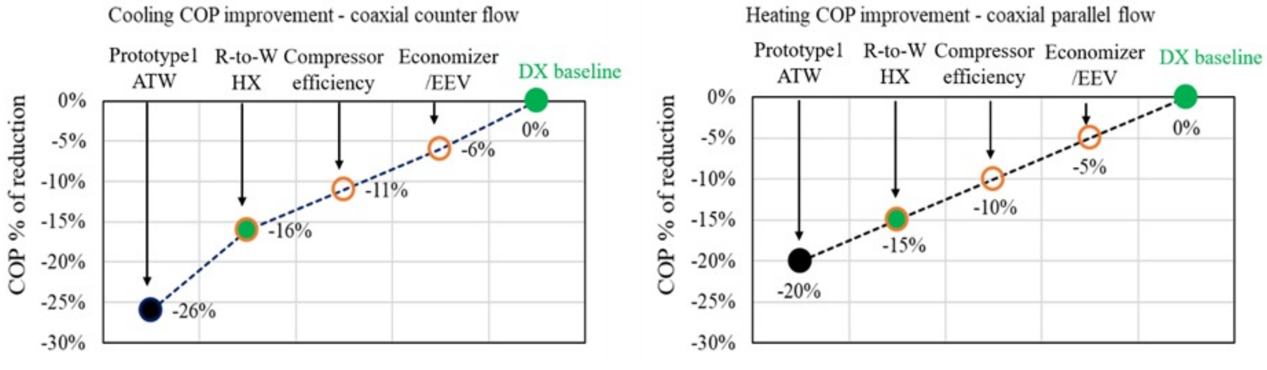


Figure 3: R-290 secondary-loop performance optimization opportunities: balanced cooling and heating

Che et al., 2026. Opportunities and Challenges of using Propane in Air-to-Water Heat Pump in North American Residential Applications. 21st International Refrigeration and Air Conditioning Conference at Purdue, West Lafayette, IN.

presented August 3, 2026.

Conclusion

- Next generation refrigerants for GSHP require a balance of: efficiency, safety, decreased environmental impact, and compatibility
- All aspects can be mutually dependent. For example, safety can affect system design which will influence overall efficiency.
- There’s no solution that fits all cases; applications must be independently evaluated to define the best refrigerant based on the constraints
- Development of new molecules/mixtures has become more challenging, especially to meet emission requirements which account for both fluid GWP and system efficiency, while also guaranteeing safe operation.

Solstice

Insulation & Fluorocarbons:

- Comparison of Insulation Materials
- What is a blowing agent
- Where are fluorocarbons used and why
- How is performance measured and why
- How does fluorocarbon insulation perform long term and why
- Application Embodied Carbon

presented August 3, 2026.

R-Value Comparison of Insulation Materials

Material	**R-Value Per Inch**	**R-Value at 3.5" (2×4)**	**R-Value at 5.5" (2×6)**
Closed-Cell Spray Foam*	R-6.0 – R-7.0	R-21 – R-24.5	R-33 – R-38.5
Polyisocyanurate (Polyiso)	R-5.6 – R-6.5	R-19.6 – R-22.8	R-30.8 – R-35.8
XPS Rigid Foam*	R-4.5 – R-5.0	R-15.8 – R-17.5	R-24.8 – R-27.5
High-Density Fiberglass Batt	R-3.7 – R-4.3	R-13 – R-15	R-20 – R-23.7
Mineral Wool / Rockwool	R-3.8 – R-4.3	R-13.3 – R-15	R-20.9 – R-23.7
EPS Rigid Foam	R-3.6 – R-4.4	R-12.6 – R-15.4	R-19.8 – R-24.2
Dense-Pack Cellulose	R-3.5 – R-3.8	R-12.3 – R-13.3	R-19.3 – R-20.9
Open-Cell Spray Foam	R-3.5 – R-3.8	R-12.3 – R-13.3	R-19.3 – R-20.9
Standard Fiberglass Batt	R-3.0 – R-3.7	R-11 – R-13	R-19 – R-20.4
Loose-Fill Cellulose	R-3.2 – R-3.8	R-11.2 – R-13.3	R-17.6 – R-20.9
Blown-In Fiberglass (Attic)	R-2.2 – R-2.7	R-7.7 – R-9.5	R-12.1 – R-14.9

* Contain fluorocarbon

Insulation materials are not equivalent- Energy is more than R-value

presented August 3, 2026.

Reference: Insulation R-Value Chart: Complete Guide to Every Material (2026) | InsulationRValues.com

Attributes of A Good Blowing Agent

- Odor Free
- Low Toxicity
- Low Environmental Impact
- Non-Corrosive
- Non-Flammable
- Low Thermal Conductivity
- Small Size Cells
- Compatible with Other Raw Materials
- Thermally Stable
- No Effect on Polymer
- Compatible With Foam Manufacturing Processes

Balance of properties for each application

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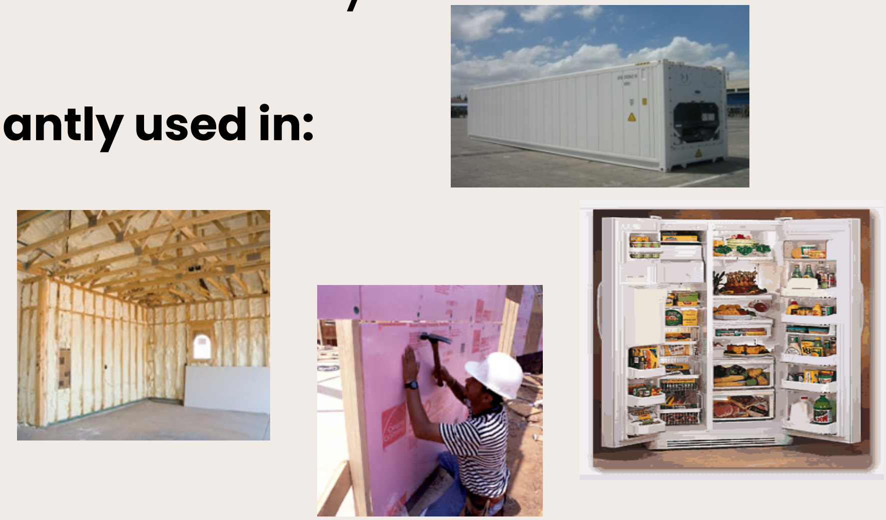
Where Does Solstice Advanced Materials Play?

Fluorocarbon blowing agents are predominantly used in:

- Thermoset, closed cell, rigid, insulation foam
- Thermoplastic, closed cell, rigid, insulation foam



Also used in certain non-insulation uses where flammability or other property of the blowing agent has value

- One component foam
- Integral skin foam

Fluorocarbons used where they add value

presented August 3, 2026.

Common Blowing Agents

Thermoset Foam

Pentanes

Highly flammable
Cheap, widely used
Lower performance vs HFOs

HFC 245fa*

Industry standard
Non-flammable
Application flexibility

HFC 365mfc

Flammable
Lower performance
High GWP

HFC-134a

High GWP
Propellant and blowing agent

HFO-1233zd(E)

LGWP
High R-value
Commercially Available

Water --> CO_2

Cheap
Lower performance vs HFO
Used where insulation value is less important

Formic Acid / Methyl Formate, Low boiling ethers, esters, alcohols, etc.

Thermoplastic Foam

Butanes

- Highly flammable
- Cheap
- Widely used – egg cartons, meat trays, etc

HFC-134a

- Was widely used

HFC-152a

- Flammable
- Inexpensive

HFO-1234ze(E)

- LGWP gaseous blowing agent
- Commercially available

CO_2

- Cheap
- Very difficult to process
- Used where insulation value is less important

Low boiling ethers, esters, alcohols, etc

- Cheap
- Lower performance vs HFO
- Used where insulation value is less

Variety of products used by industry and application

Solutions for Insulating Foam Applications

Solstice Advanced Material Blowing Agents

Solstice LBA	**Solstice GBA**
GWP 1	**GWP<1**
Bpt 19C/66F	**Bpt -19C/-22F**

Non- Flammable, Non-ODP, VOC- Exempt

Refrigerator / Freezer

Spray Foam

Froth / Refillable Foam

Laminate Insulation

One Component Foam

Extruded Polystyrene

Walk in Coolers

Transportation

Insulated Metal Panels

Solstice LBA & Solstice GBA solutions for foam applications

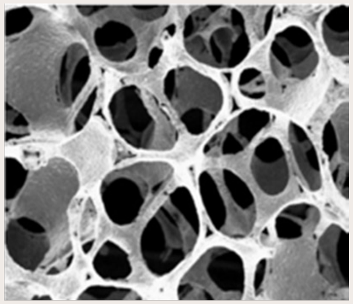
presented August 3, 2026.

What is Foam Plastic ?

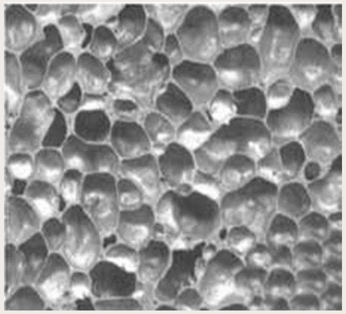
A mass of gas bubbles, or cells, in a matrix
In a plastic foam, a plastic (polymer) is the matrix

- *Open cell foams*
  - Gas in cells not critical
  - Properties of polymer matrix critical

- *Closed cell foams*
  - Typically, 97+% (by volume) gas
  - Gas in cell contributes to properties of foam
  - The gas (the blowing agent)
    - expands the foam
    - contributes to foam properties, especially for thermal insulation foams



Open Cell Foam



Closed Cell Foam

Bubbles are the key to success

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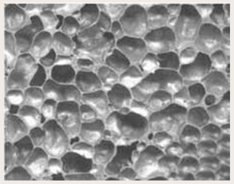
Foam Insulation Designed For Use



Closed Cell Foam

Solstice LBA used in a wide variety of applications.

Solstice LBA allows for lower energy usage

As we move beyond GWP the Energy Performance becomes key

Solstice LBA in Foam Insulation drives Energy Efficiency

- Solstice LBA drives ~60% of the foam insulation value
- Creates a mass of gas bubbles, or cells, in a polymer matrix
- Typically, 97+% (by volume) gas

Key considerations for Blowing Agent:

- **Blowing Agent Flammability –** Particularly in spray foam must be non-flammable
- **Blowing Agent Gas Thermal conductivity-** improved thermal performance
- **Blowing Agent Boiling point-** Needs to be gas at cold environmental temperature
- **Blowing Agent Molecular weight-** use less blowing agent
- **Solstice LBA meets all criteria. Others blowing agent options such as pentane, CO_2 and water less energy efficient.**

Solstice LBA has low GWP and provides energy efficient option

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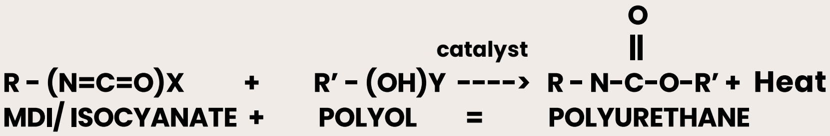
Two Types of Thermoset Blowing Agents

Physical

Example: Fluorocarbon

Chemical Reaction:
One Primary chemical reaction to manage



$$\text{R - (N=C=O)X} + \text{R' - (OH)Y} \xrightarrow{\text{catalyst}} \text{R - N-}\overset{\overset{\text{O}}{\|}}{\text{C}}\text{-O-R'} + \text{Heat}$$

MDI/ ISOCYANATE + POLYOL = POLYURETHANE

Observations

Blowing agent present/ vaporizes slowly as foam temperature rises from exotherm
Controlled reaction
Primary reaction for closed cell foam
Higher density foam
Stronger foam
Uses less MDI

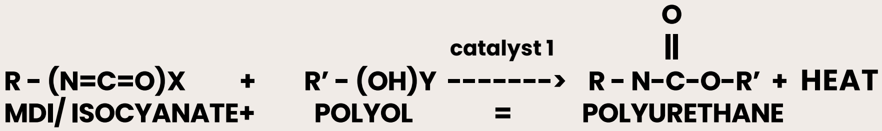
Chemical

Example: Water

Chemical Reactions:
Two Chemical reactions to manage

$$\text{2R - N=C=O} + \text{H2O} \longrightarrow \text{R-N-C-N-R} + CO_2$$

2 MDI ISOCYANATE + water = Urea + Carbon dioxide



$$\text{R - (N=C=O)X} + \text{R' - (OH)Y} \xrightarrow{\text{catalyst 1}} \text{R - N-}\overset{\overset{\text{O}}{\|}}{\text{C}}\text{-O-R'} + \text{HEAT}$$

MDI/ ISOCYANATE+ POLYOL = POLYURETHANE

Observations

Chemical reaction produces blowing agent
Difficult to control- quickly produces gas
Primary reaction for open cell foam
Visible gases escape during application
Uses more MDI

Blowing agent and chemistry impact insulation performance

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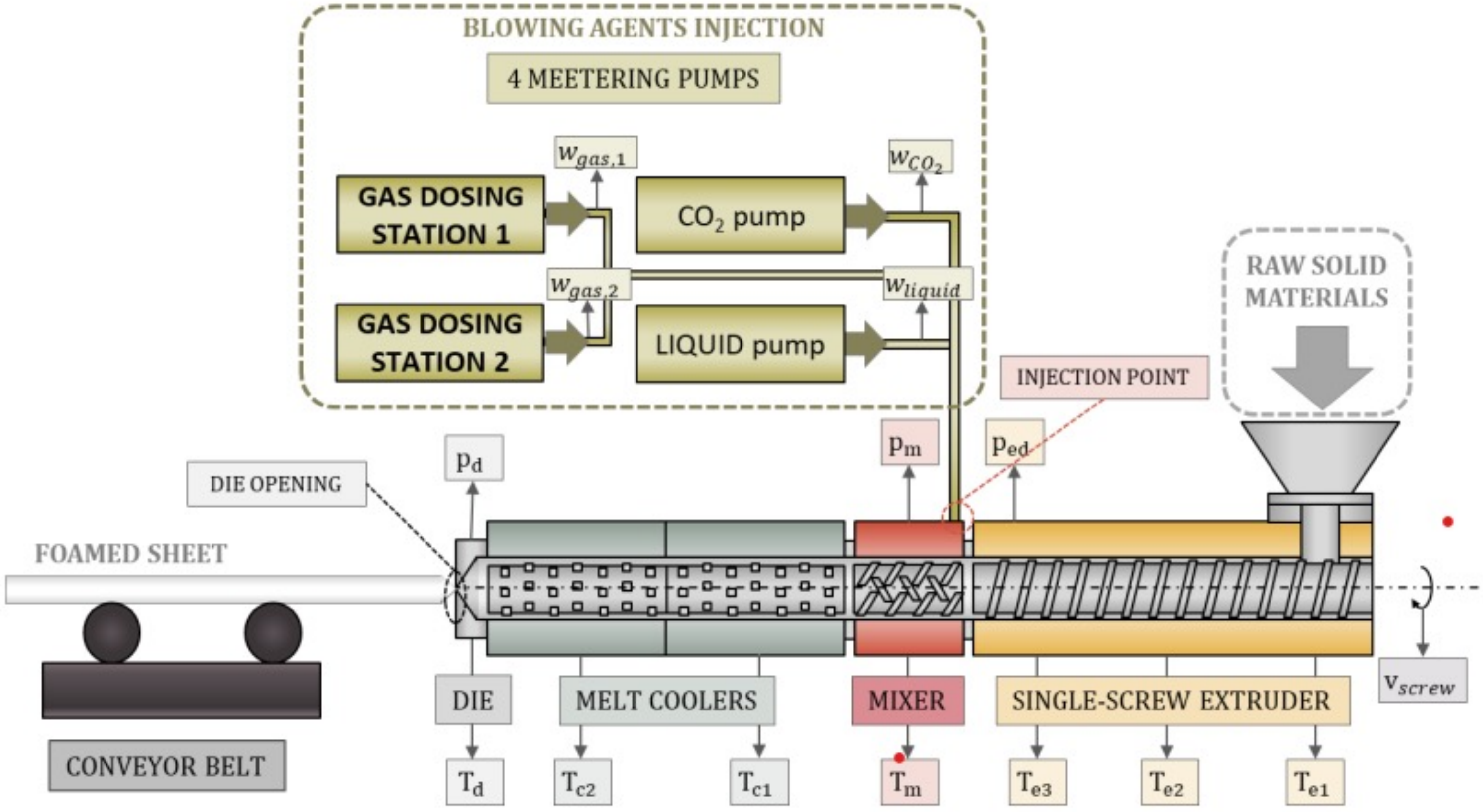
Thermoplastic Foams-

Melting & Blending Not Reacting



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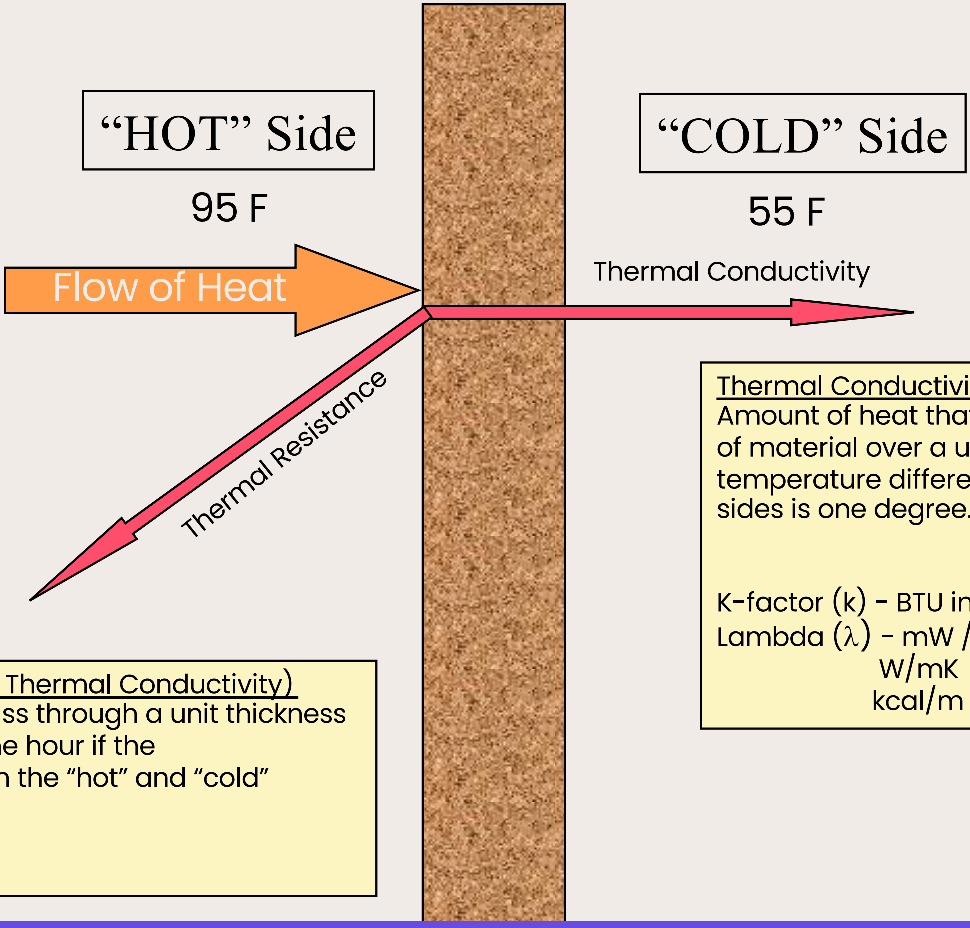
Foam Thermal Conductivity Measurements

FTC R-Value Rule : 1979 Standardized testing methods. at a **mean temperature of 75°F** using ASTM standards such as **C518** two metal plates, one warm (95°F) and one cold (55°F), to simulate heat flow and determine thermal resistance Additional R-values at 25°F or 40°F may also be provided for specific climate considerations



<u>Thermal Conductivity -</u>
Amount of heat that passes through a unit thickness of material over a unit area in one hour if the temperature differential between the "hot" and "cold" sides is one degree.

	Typical values
K-factor (k) - BTU in / hr ft² °F	0.140
Lambda (λ) - mW / mK	20.0
W/mK	0.020
kcal/m °C hr	0.017

<u>Thermal Resistance - (inverse of Thermal Conductivity)</u>
Amount of heat that does not pass through a unit thickness of material over a unit area in one hour if the temperature differential between the "hot" and "cold" sides is one degree.

R-Value - 1 / k-factor

Primary function of insulation is to minimize flow of heat

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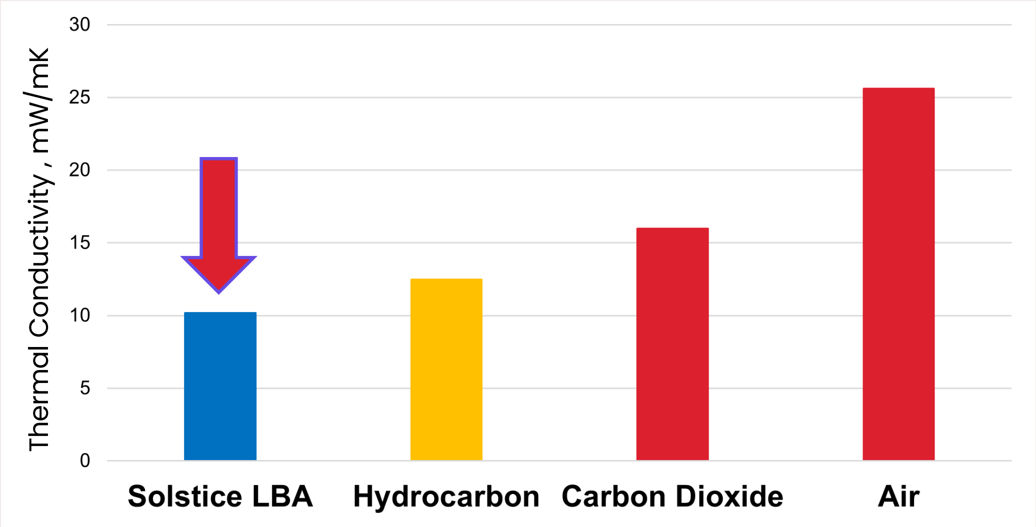
How Does Blowing Agent (BA) Choice Impact R-Value

$$\lambda_{\text{foam}} = \underbrace{\lambda_{\text{conduction(gas)}}}_{\sim 60\%} + \lambda_{\text{convection (gas)}} + \lambda_{\text{conduction(solid polymer)}} + \lambda_{\text{radiation}}$$

Vapor Thermal Conductivity



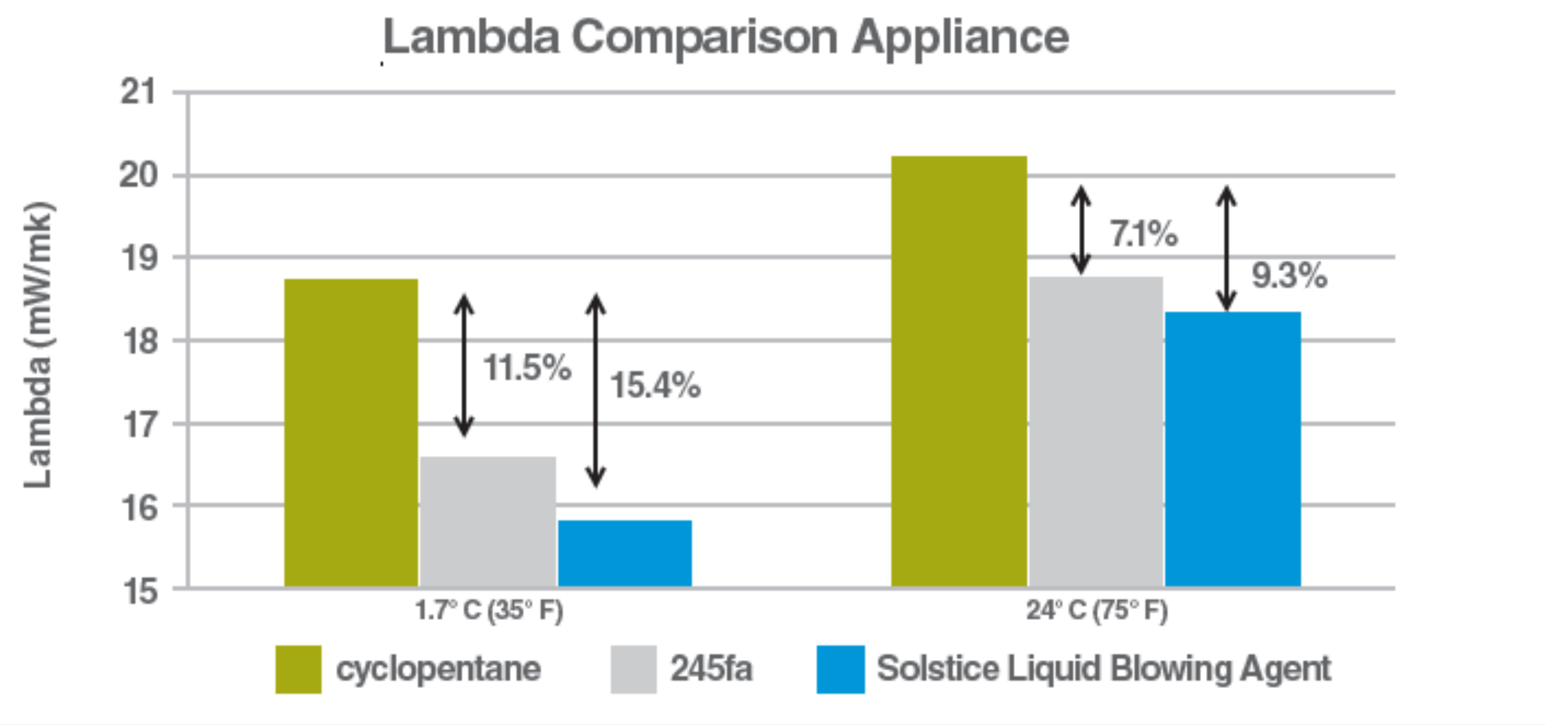
BA Considerations Influencing R-Value

- Must be in the gas phase to be effective
  - ✓ Solstice LBA has desirable boiling point
- Vapor phase thermal conductivity of the gas
  - ✓ Solstice LBA is lower than hydrocarbon blowing agents
  - ✓ Air/CO_2 have higher thermal conductivity

Solstice LBA has lowest thermal conductivity

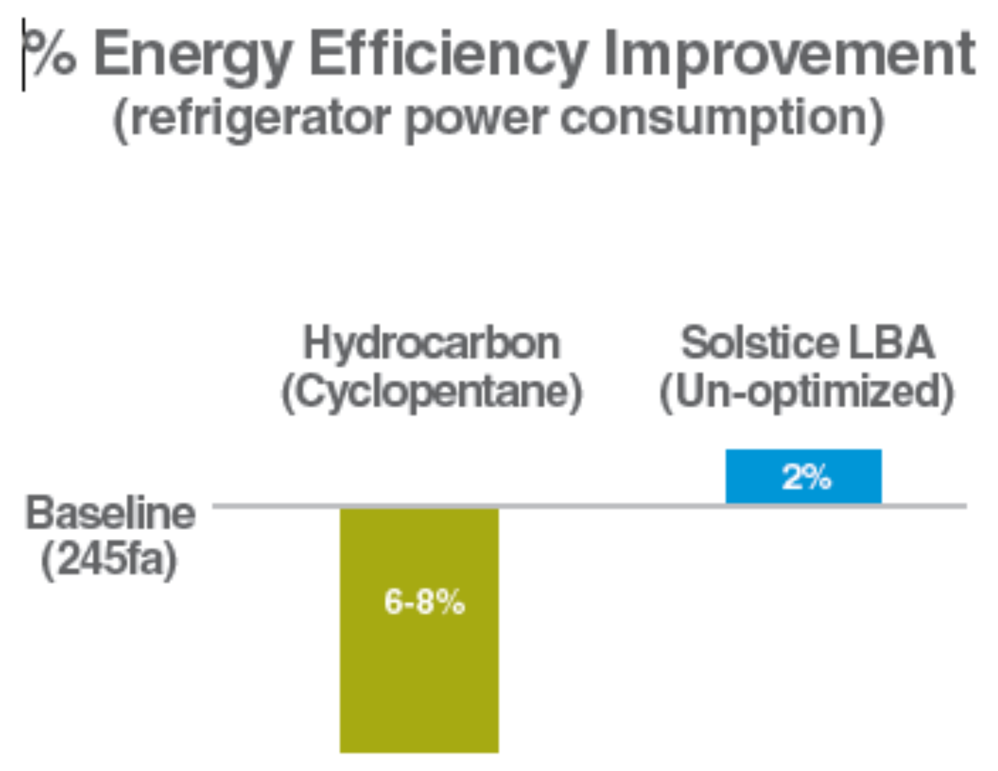
presented August 3, 2026.

Solstice® LBA in Appliances



Essential USE: Many factors impact the change in long-term R-value

Comparison of Energy Efficiency



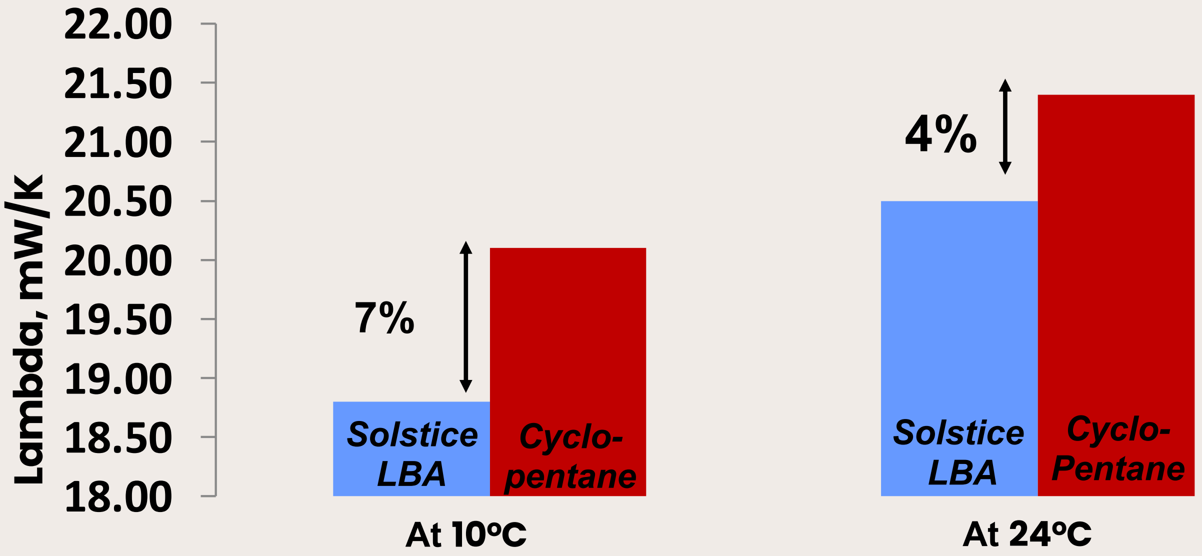
Essential Use: Solstice LBA Superior Energy Performance

Reefer Container: Lambda

Reefer Container
12.2m x 2.9m x 2.4m
(40.0ft x 9.5ft x 7.9ft.)

Discontinuous Process

Initial Lambda: Solstice® LBA Provides Better Lambda



Essential Use: Solstice® LBA 7% Better Lambda Than Cyclopentane

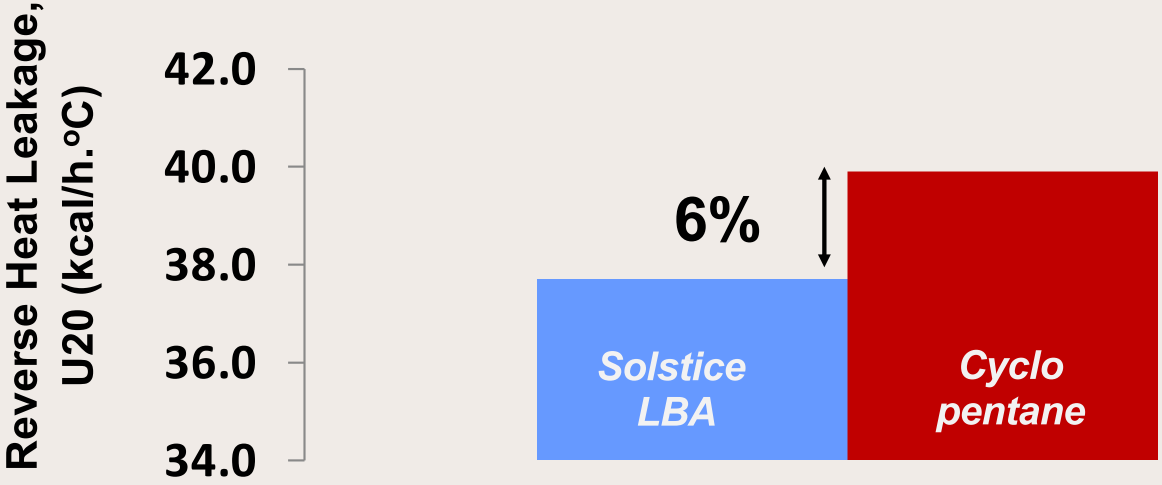
Reefer Container: Reverse Heat Leakage

Solstice® LBA Provides Lower Reverse Heat Leakage

Evaluated Parameters	
Inside Temperature	30°C
Outside Temperature	10°C
Reverse Heat Leakage, kcal/h.ºC	37.7

Reefer Container
12.2m x 2.9m x 2.4m
(40.0ft x 9.5ft x 7.9ft.)

Discontinuous Process



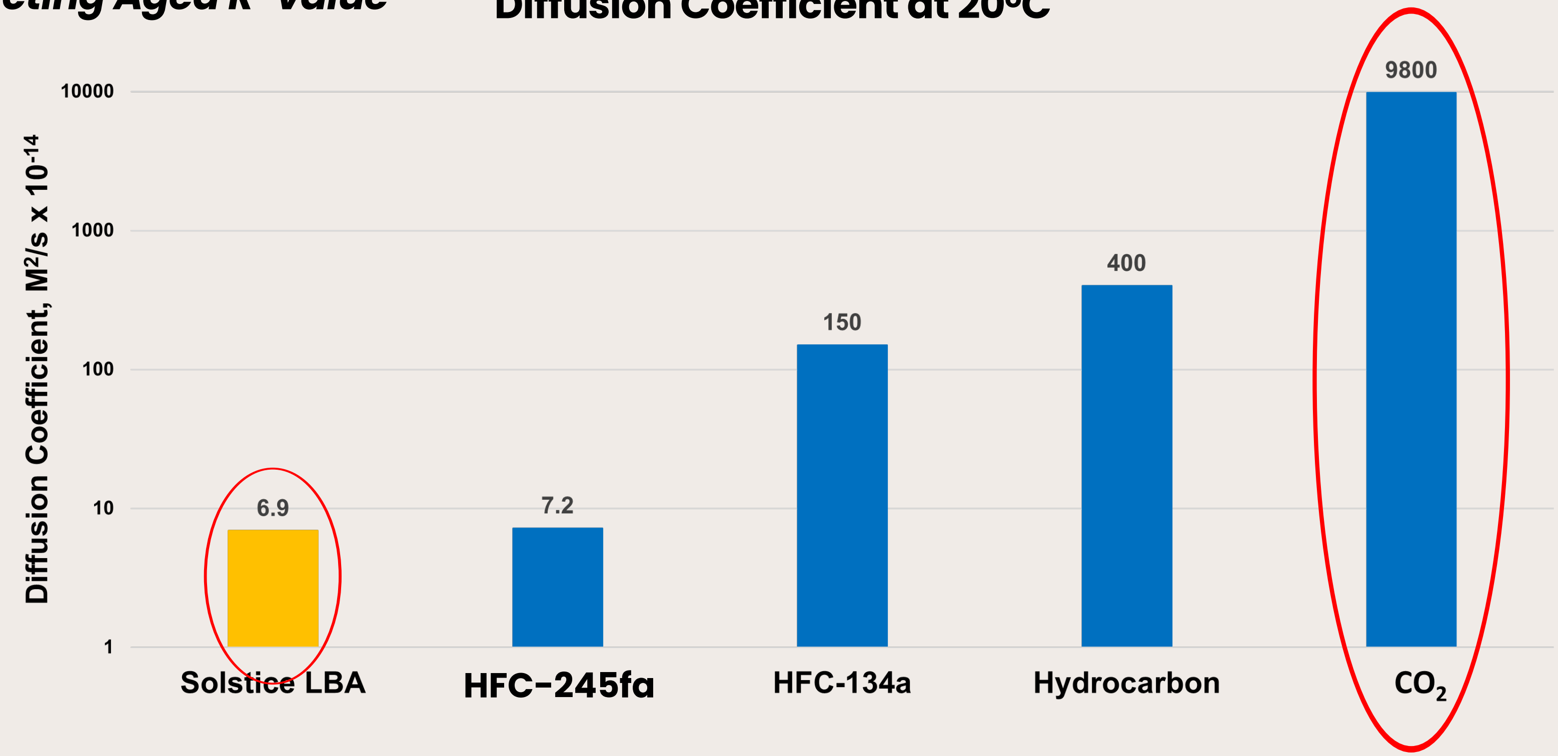
Essential Use: Lower k-Factor Translates to Better Energy Efficiency

presented August 3, 2026.

Comparisons of Blowing Agent Diffusion Coefficient

Impacting Aged R-value

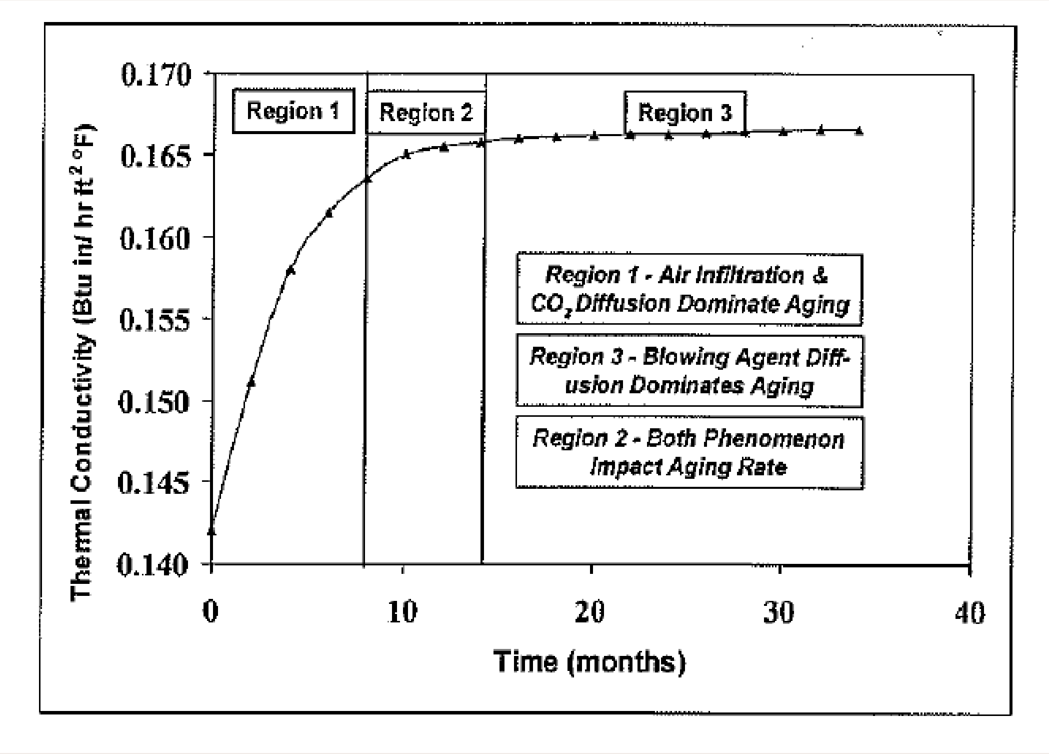
Diffusion Coefficient at 20°C



Solstice LBA has one of the lowest diffusion coefficients

presented August 3, 2026.

How Blowing agent diffusion impact thermal conductivity



Introduction: Understanding Diffusion over Time in Insulation

Diffusion Mechanism is Dependent on a Number of Factors

Environmental (Installation Dependent)

- Temperature
- Humidity
- Weather and UV Exposure

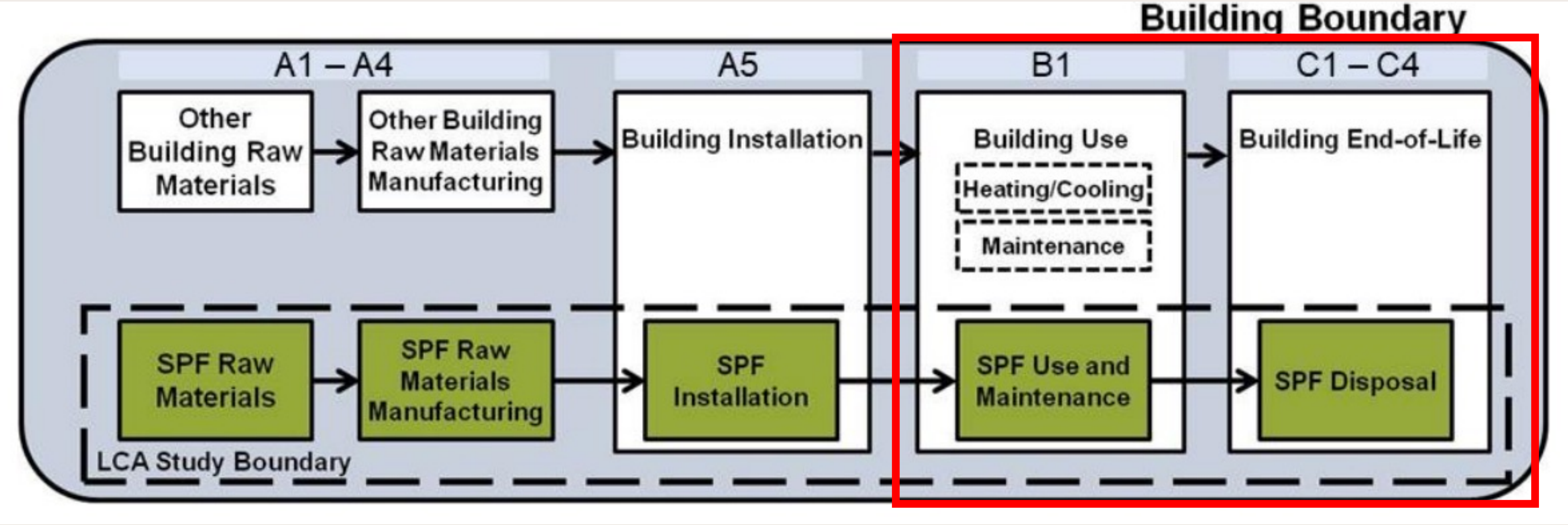
Physical (Foam Product Dependent)

- Blowing Agent Composition
- Blowing Agent Concentration
- Exposed Area Surface
- Sample Thickness

Essential USE: Many factors impact the change in long-term R-value

presented August 3, 2026.

EPD – Environment Product Declaration



Building Boundary

A1 – A4

Other Building Raw Materials

Other Building Raw Materials Manufacturing

A5

Building Installation

B1

Building Use

Heating/Cooling

Maintenance

C1 – C4

Building End-of-Life

SPF Raw Materials

SPF Raw Materials Manufacturing

SPF Installation

SPF Use and Maintenance

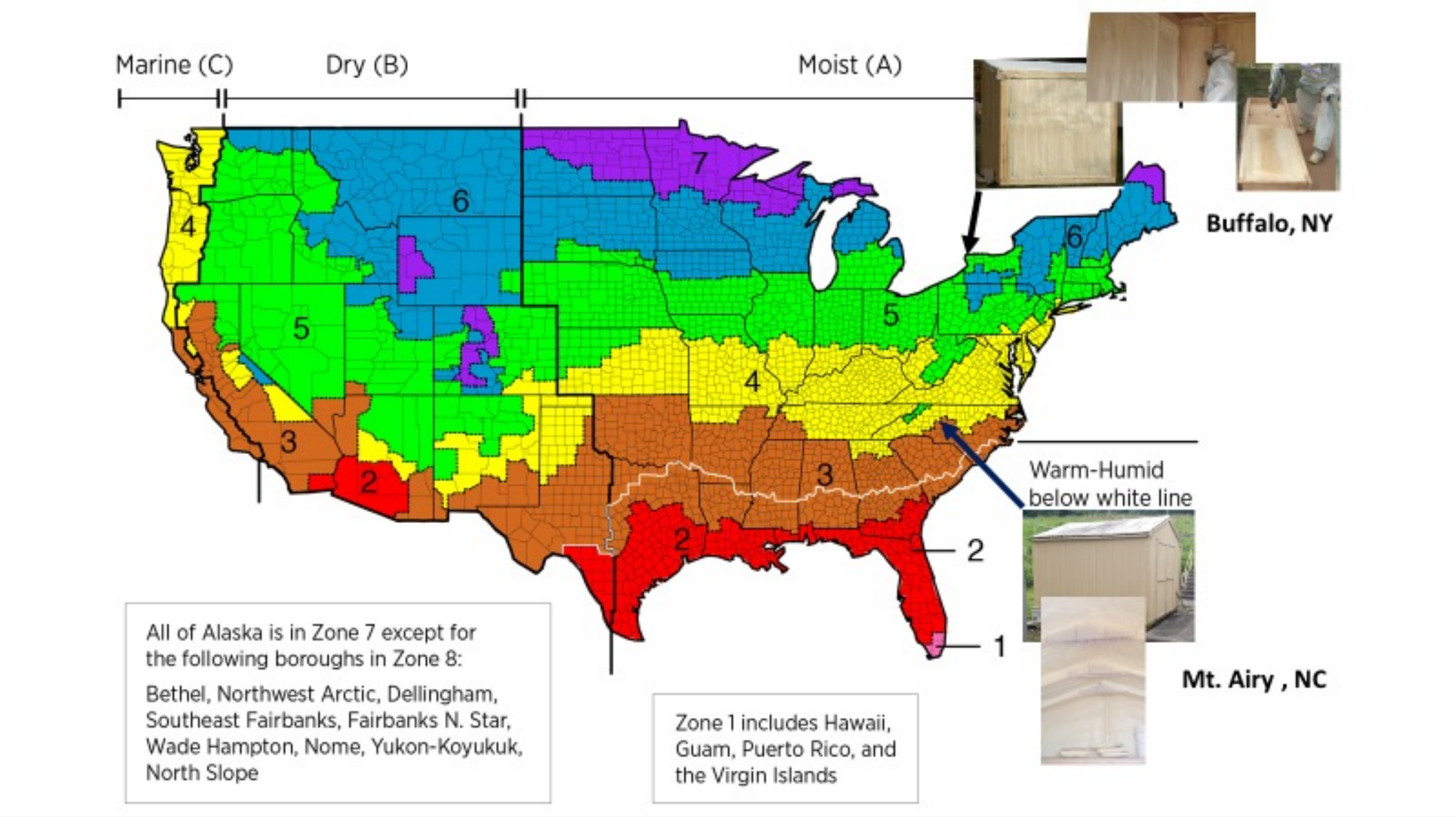
SPF Disposal

LCA Study Boundary

Areas that impact environment as the building ages

presented August 3, 2026.

A Real-World Field Study- Test Shed Sites*



All of Alaska is in Zone 7 except for the following boroughs in Zone 8:

Bethel, Northwest Arctic, Dellingham, Southeast Fairbanks, Fairbanks N. Star, Wade Hampton, Nome, Yukon-Koyukuk, North Slope

Zone 1 includes Hawaii, Guam, Puerto Rico, and the Virgin Islands

Lets see how HFO insulation performs over 8 years

presented August 3, 2026.

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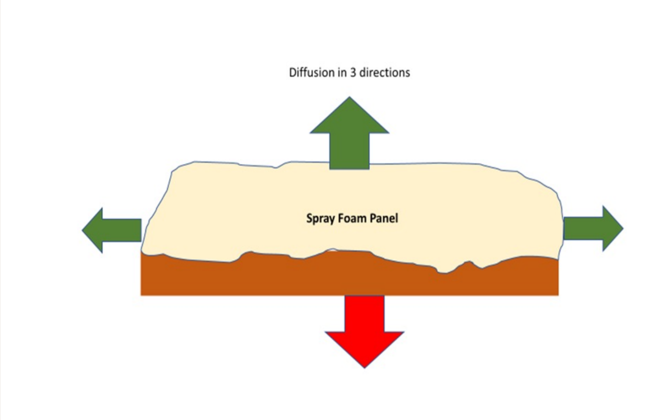
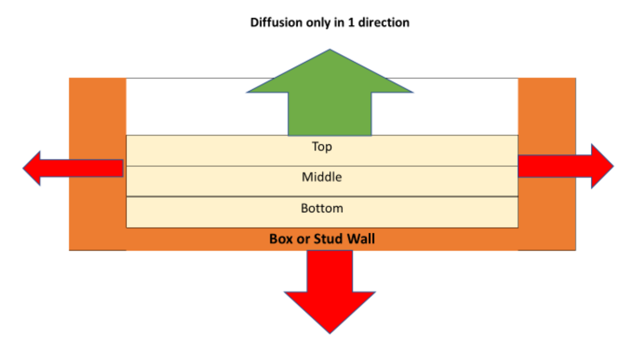
* CPI 2021 Comparison of Field vs Laboratory Long-Term Thermal Conductivity of Closed-cell SPF, Mary Bogdan, Stephanie Holborne

K-factor vs Thickness/ Location in the Foam at 8 Years

Sample ID	**Sample Thickness (in)**	**Panel**		**Stud wall**	
	BTU in/hr ft² °F | R-value				
Total Sample thickness	3.31	0.1677	5.96	0.1609	6.22
Sample Location Across Foam Thickness*					
Top	1.05	0.1649	6.06	0.1712	5.84
Middle	1.05	0.1667	6.00	0.1554	6.44
Bottom @ wood surface	1.03	0.1569	6.37	0.1495	6.69

- Initial R-value 6.71

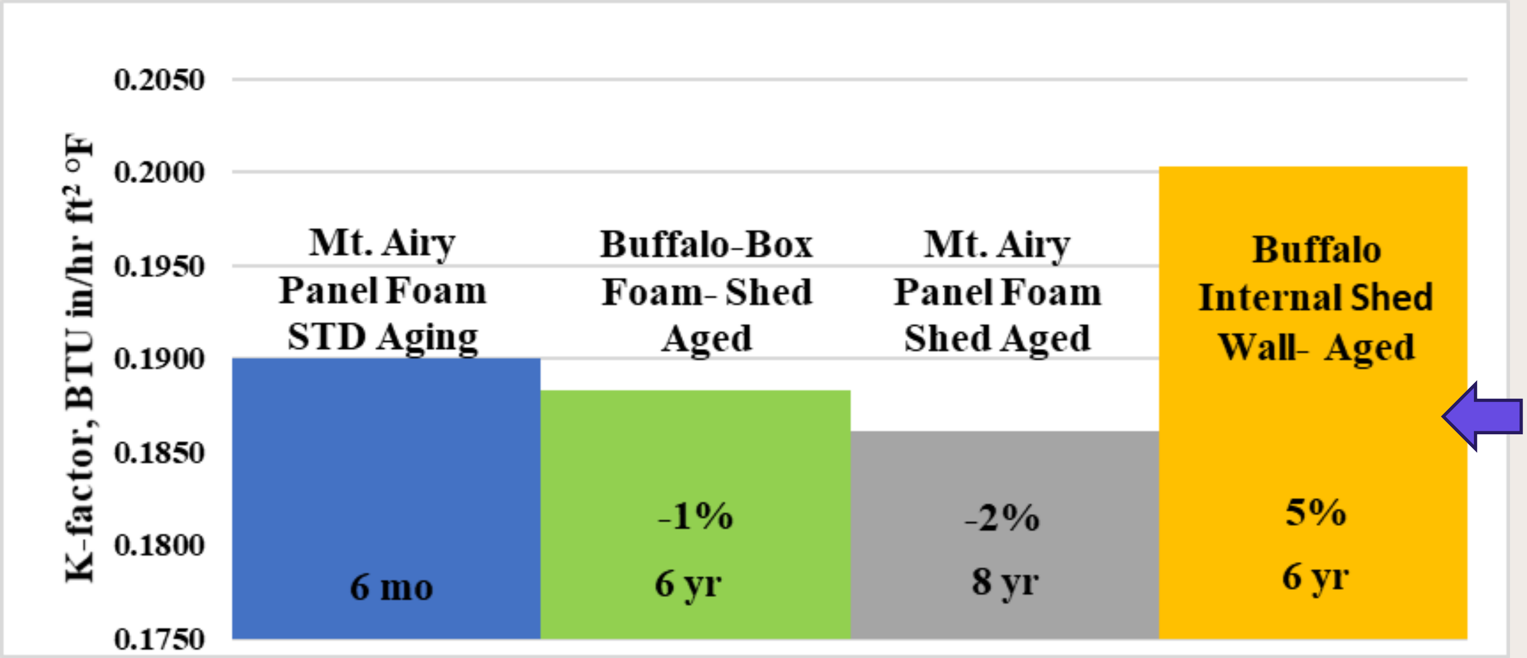




Foam aging & long-term emissions is dependent upon permeable surfaces

presented August 3, 2026.

Wall Foam: Comparison of 2" Long-term K-factor

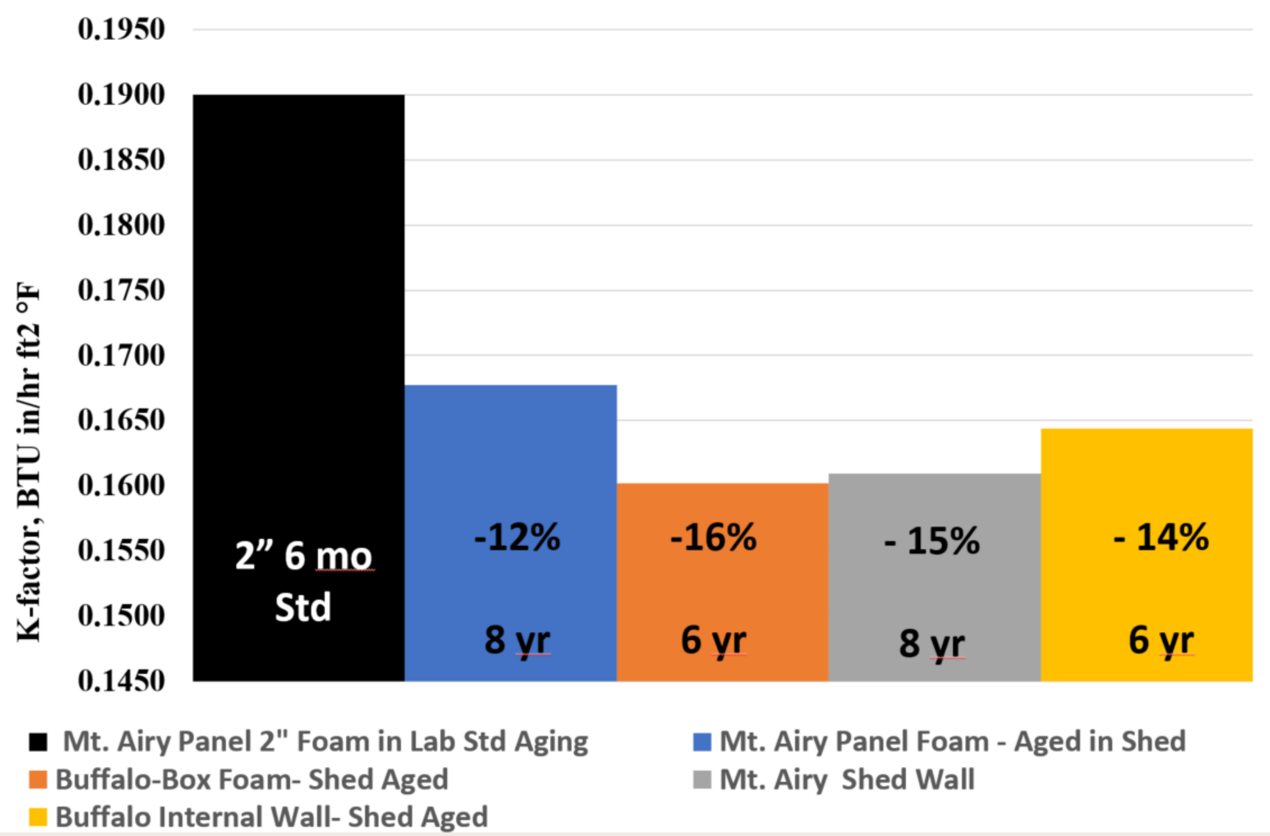


Impact of weather

- Difference between 6 and 8-year K-factors are within 5% of the 6-month aging results
- Different climate zones did not appear to effect the change in K-factor over time.

presented August 3, 2026.

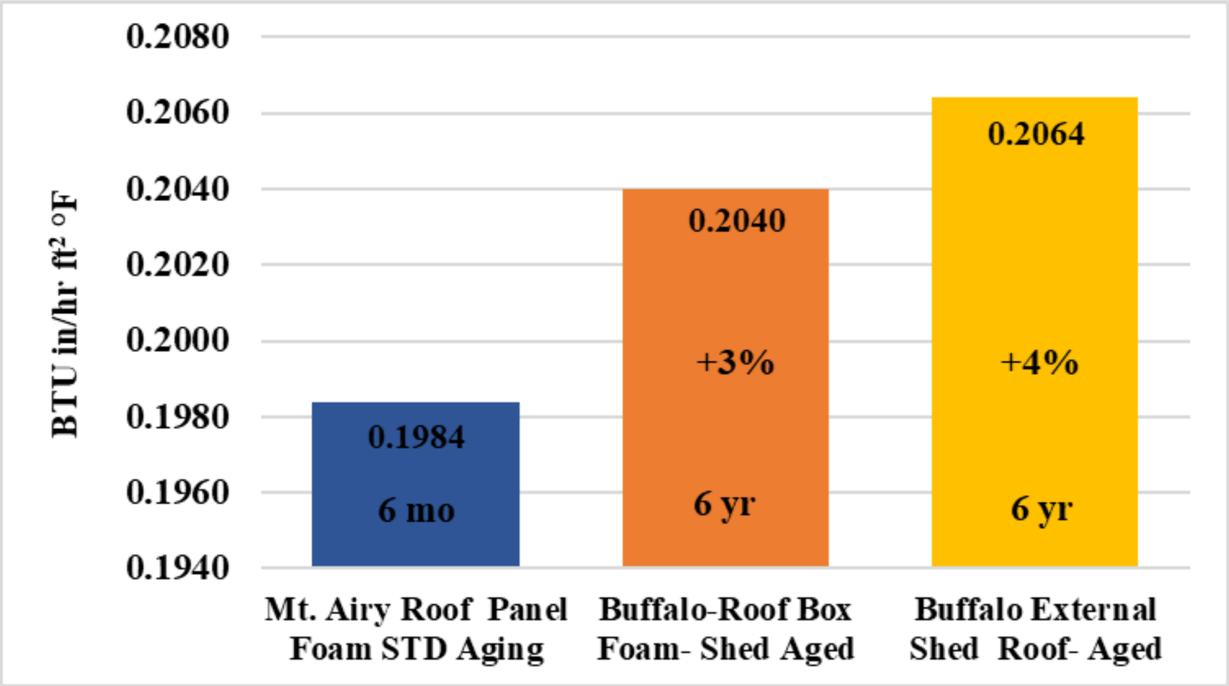
Wall Foam: Comparison of 4” Long-term K-factor



Thicker foam ages slower both in panel and box configuration

presented August 3, 2026.

Roofing Foam: Comparison of 2” Long Term K-factor



- At 6 years both internal boxed and external aged foam are not only within the 10% of the 6-month laboratory aged foam samples but 3% and 4% respectively.
- Acrylic coating did not affect diffusion.

presented August 3, 2026.

Blowing Agent Retention in Refrigerator Foam Over Time

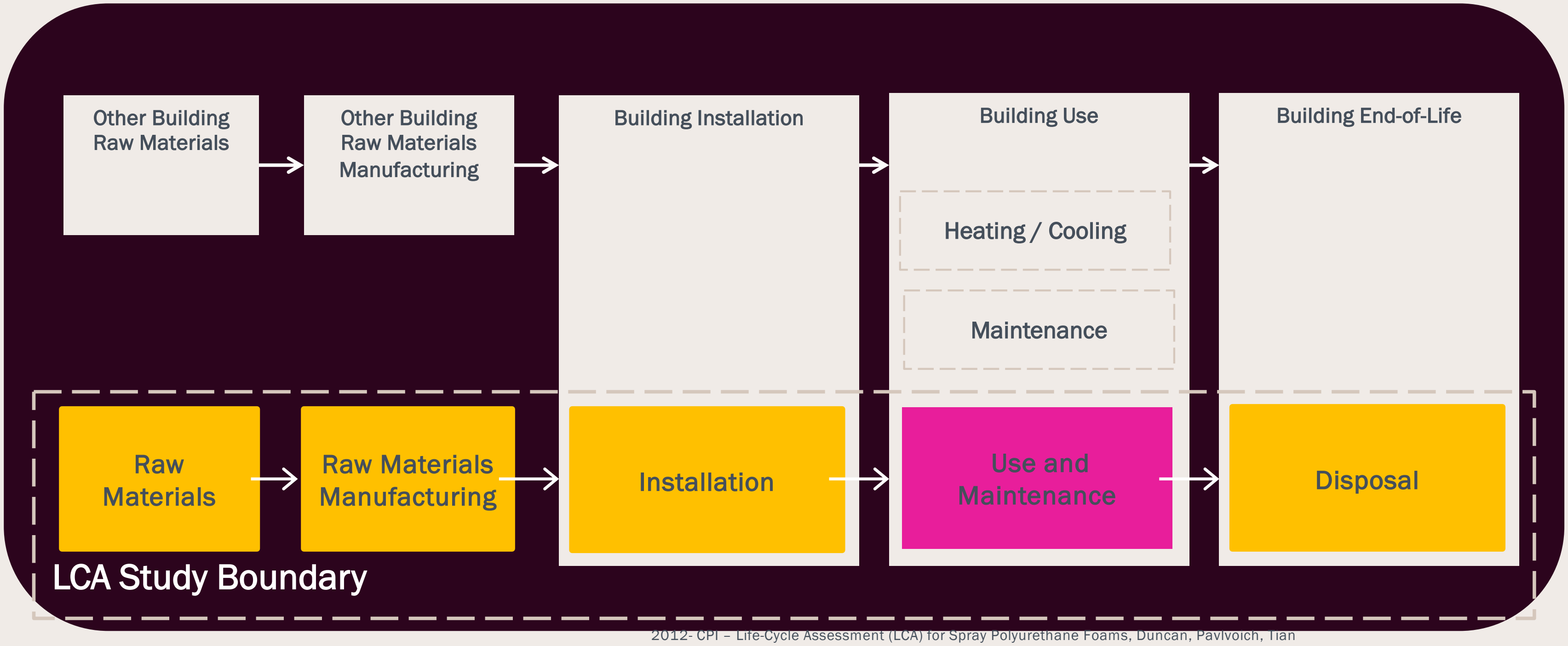
Date Manufactured	Blowing Agent	Wt %			
		Estimated % in formulation	Total Blowing Agent in Foam	Calculated % in Formulation	% Loss
2008	Enovate 245fa	28.7	11.3	28.1	2.09
2016	Solstice LBA	31.9	11.6	31.3	1.88
2012	Cyclo-pentane	13.3	5.1	13.0	2.26

Industry estimates only a 2% loss of blowing agent during manufacture
Losses ~ manufacturing losses
Minimal loss during use

Minimal blowing agent loses if blowing agent diffusion is not possible

How Do We Improve Our Environmental Footprint?

Inventory Analysis



Other Building Raw Materials

Other Building Raw Materials Manufacturing

Building Installation

Building Use

Heating / Cooling

Maintenance

Building End-of-Life

Raw Materials

Raw Materials Manufacturing

Installation

Use and Maintenance

Disposal

LCA Study Boundary

2012- CPI – Life-Cycle Assessment (LCA) for Spray Polyurethane Foams, Duncan, Pavlvoich, Tian

By Looking At Each Part of the LCA

presented August 3, 2026.

Solstice

Embodied Carbon

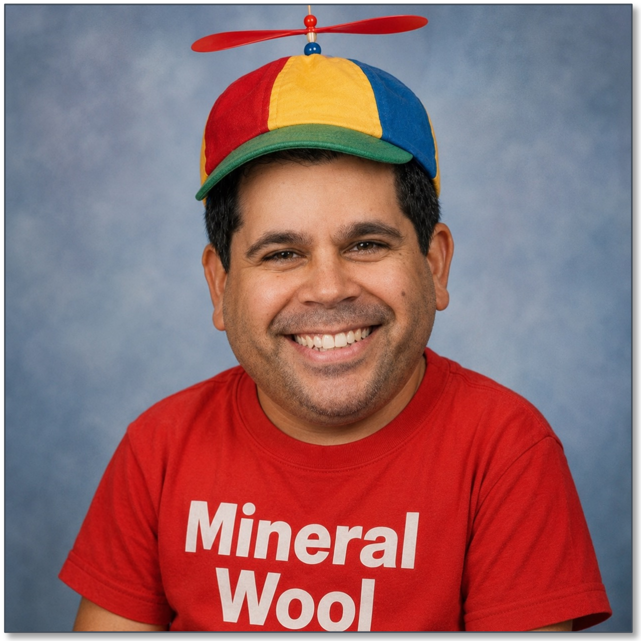
Funding Research and Educational Campaigns

presented August 3, 2026.

Architectural “Environmental Perception” of Spray Foam, based on a person in a position to comment on the Architectural “Environmental Perception” of Spray Foam

Rockford Boyer, B. Arch. Sc., MBSc., BSS
Building Science & Sustainability Manager, Elastochem

In The Beginning



Worked 5 Years in the field as a building science inspector for an Engineering firm… received a call one day asking if I wanted to work for a mineral wool manufacturer.

"I Know The Architectural Perception Of Spray Foam!"

“Spray Foam is carbon heavy and bad for the environment”

How do I know this? In past 10 years I probably did over 200 lunch and learns and heard the architects talk.

Putting The Chemistry To Bed......

Architect

I will never put spray foam in any of my buildings

Rocky

Here we go 🙄

So Why The Hatred?

1) It Comes in an Oil Drum!

2) It's a Plastic!

3) It's High in Carbon!

4) You Can't Recycle It!

5) It's Toxic – You Need Full PPE!

McHypocrisy!

Many people look at the product and not the over all system.

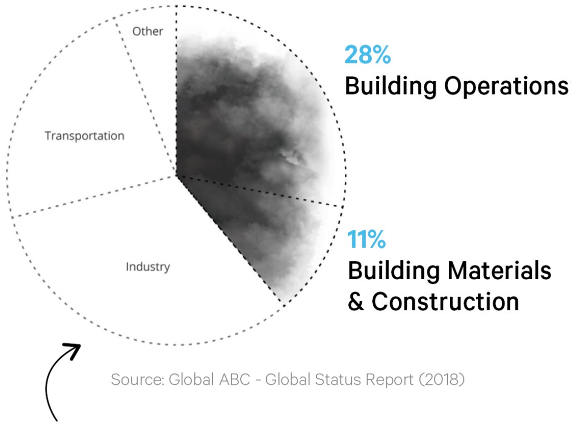
Marketing usually takes precedent over technical in the early stages.

Utilize the tools that are currently on the market.

Use McScience when designing.

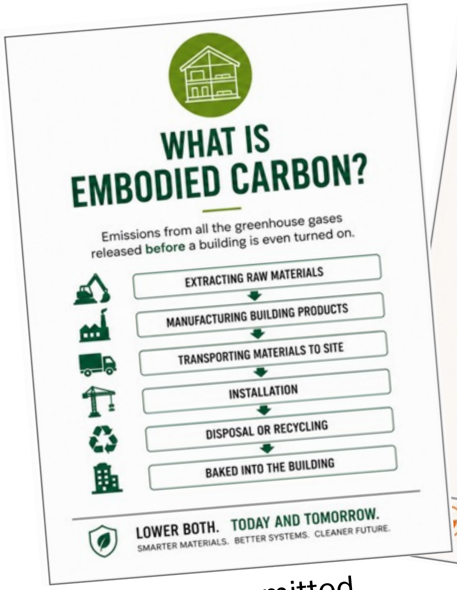
Embodied Carbon vs. Operational Carbon

Annual Global CO_2 Emissions



Source: Global ABC - Global Status Report (2018)

The construction industry is responsible for roughly 40% of worldwide carbon emissions. Each phase of building construction and maintenance leaves behind a substantial carbon footprint. Choosing an energy efficient insulation is one of the best ways to reduce our environmental impact.



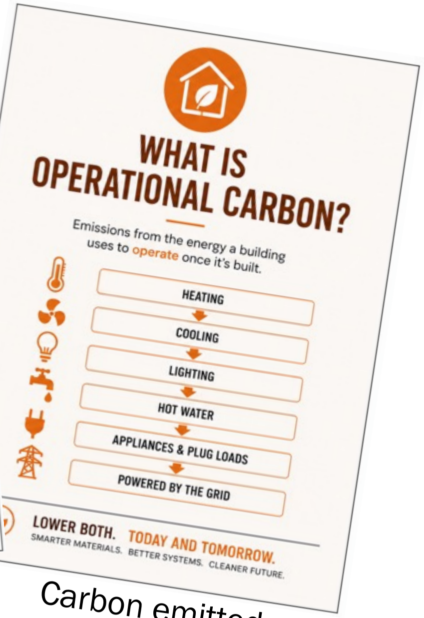
WHAT IS EMBODIED CARBON?

Emissions from all the greenhouse gases released **before** a building is even turned on.

- EXTRACTING RAW MATERIALS
- MANUFACTURING BUILDING PRODUCTS
- TRANSPORTING MATERIALS TO SITE
- INSTALLATION
- DISPOSAL OR RECYCLING
- BAKED INTO THE BUILDING

LOWER BOTH. TODAY AND TOMORROW.
SMARTER MATERIALS. BETTER SYSTEMS. CLEANER FUTURE.

Carbon emitted **before** a building is occupied



WHAT IS OPERATIONAL CARBON?

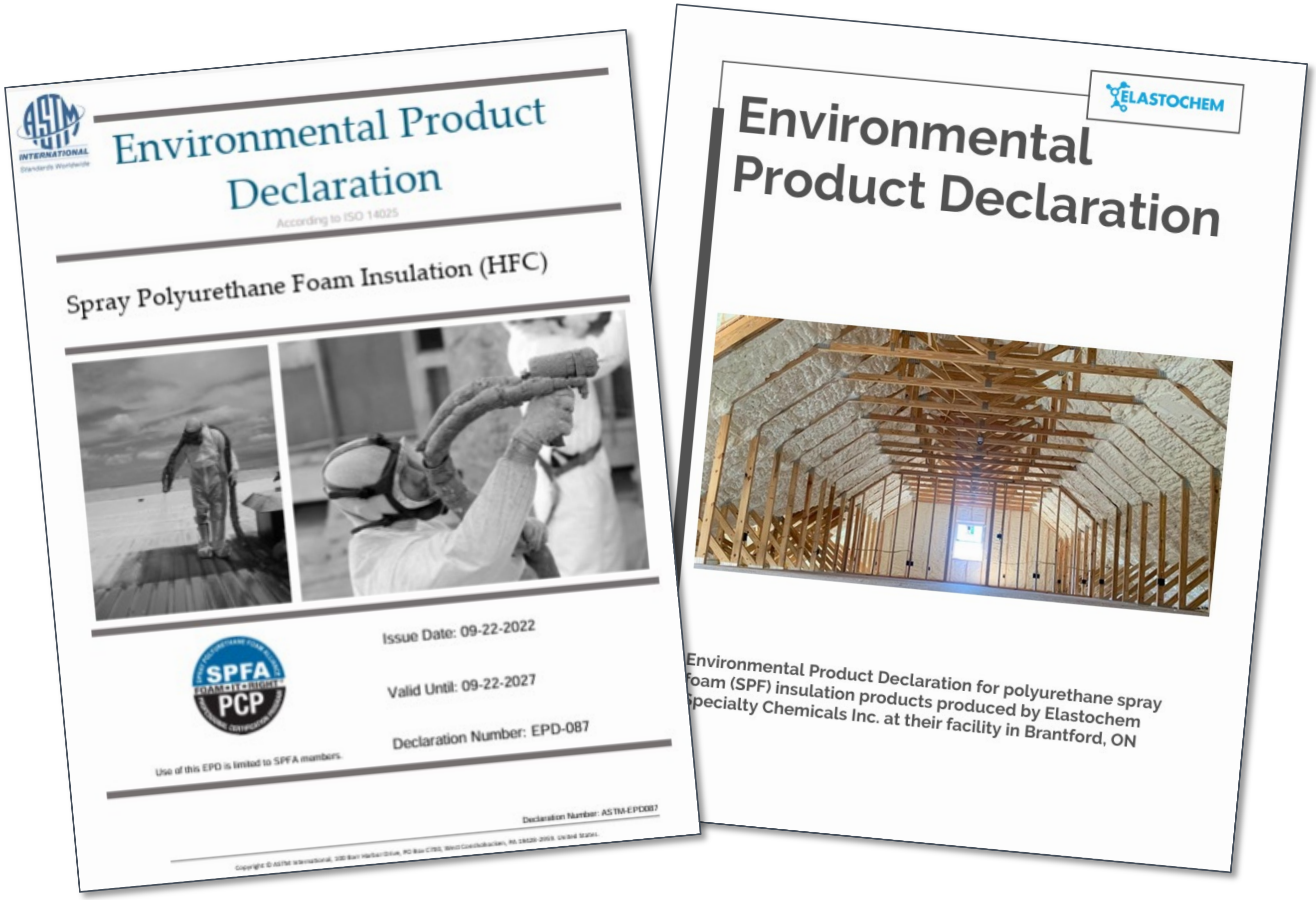
Emissions from the energy a building uses to **operate** once it's built.

- HEATING
- COOLING
- LIGHTING
- HOT WATER
- APPLIANCES & PLUG LOADS
- POWERED BY THE GRID

LOWER BOTH. TODAY AND TOMORROW.
SMARTER MATERIALS. BETTER SYSTEMS. CLEANER FUTURE.

Carbon emitted **while** a building is in use

Carbon In Reality.....Useful Tools (Product)



ASTM INTERNATIONAL
Standards Worldwide

Environmental Product
Declaration

According to ISO 14025

Spray Polyurethane Foam Insulation (HFC)

Issue Date: 09-22-2022

Valid Until: 09-22-2027

Declaration Number: EPD-087

Use of this EPD is limited to SPFA members.

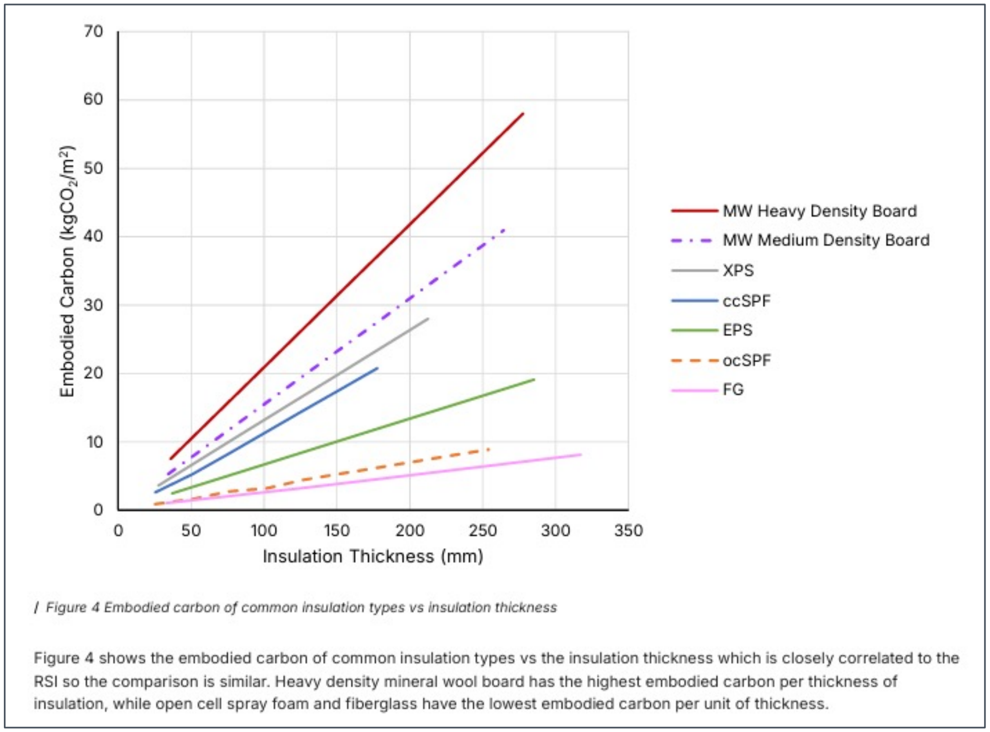
Declaration Number: ASTM-EPD087

ELASTOCHEM

Environmental
Product Declaration

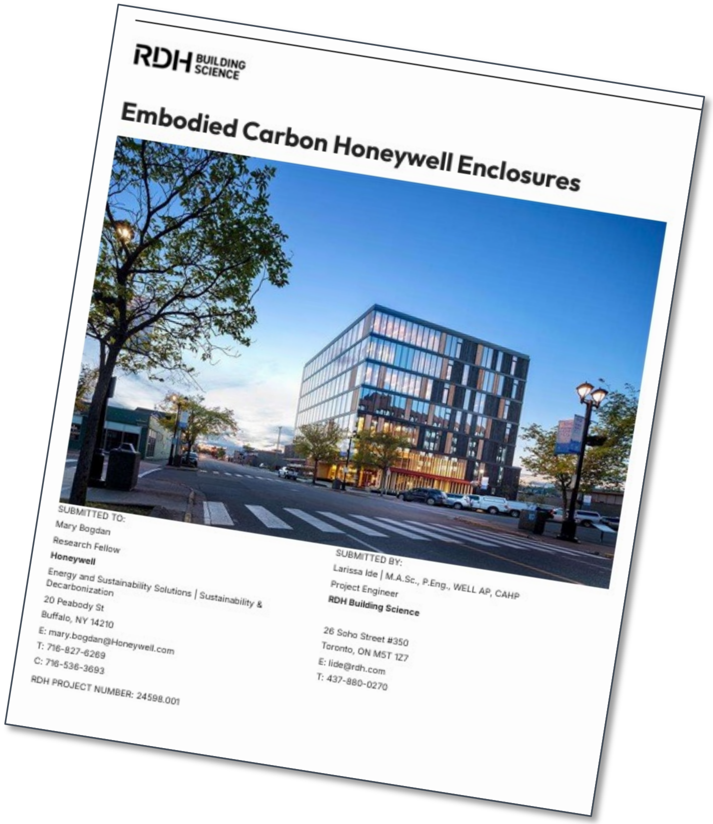
Environmental Product Declaration for polyurethane spray
foam (SPF) insulation products produced by Elastochem
Specialty Chemicals Inc. at their facility in Brantford, ON

Carbon In Reality.....Useful Tools (System)



/ *Figure 4 Embodied carbon of common insulation types vs insulation thickness*

Figure 4 shows the embodied carbon of common insulation types vs the insulation thickness which is closely correlated to the RSI so the comparison is similar. Heavy density mineral wool board has the highest embodied carbon per thickness of insulation, while open cell spray foam and fiberglass have the lowest embodied carbon per unit of thickness.



RDH BUILDING SCIENCE

Embodied Carbon Honeywell Enclosures

SUBMITTED TO:
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SUBMITTED BY:
Larissa Ide | M.A.Sc., P.Eng., WELL AP, CAHP
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RDH Building Science

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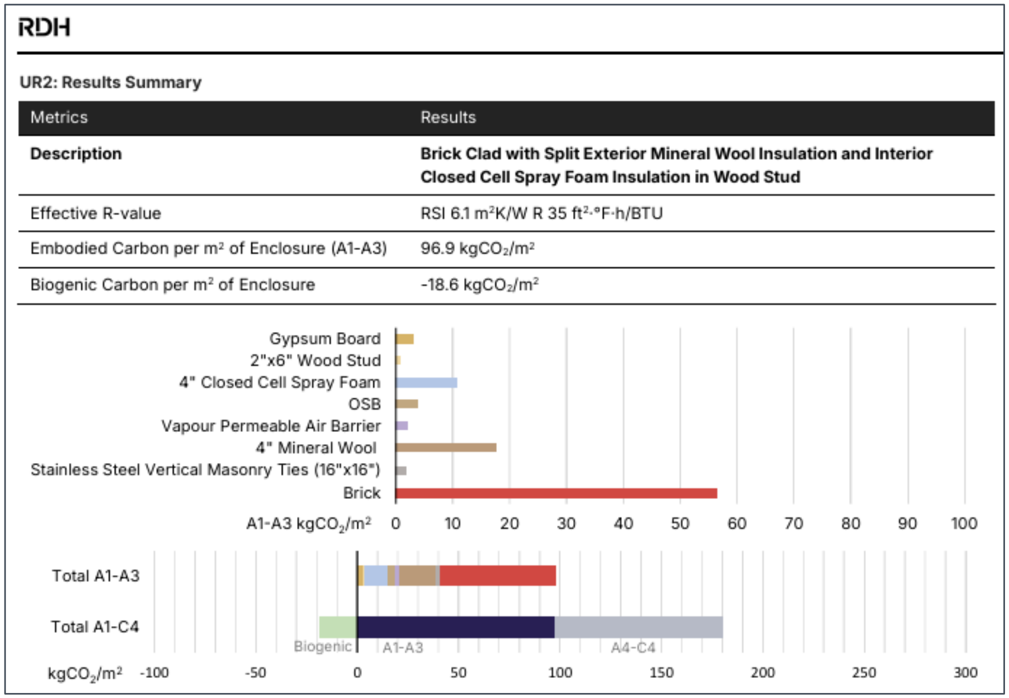
RDH PROJECT NUMBER: 24598.001

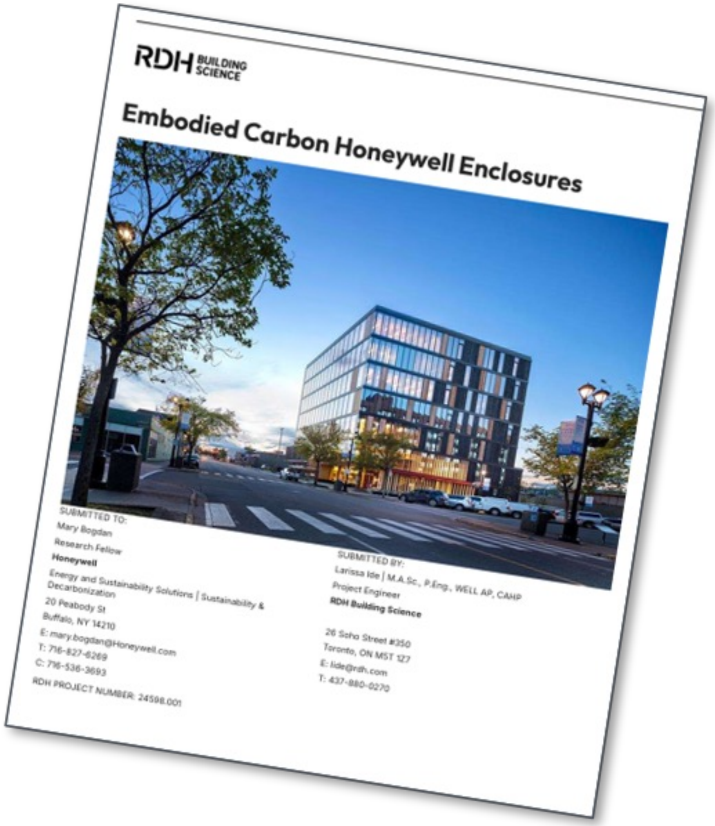
Carbon In Reality.....Useful Tools (System)



RDH

UR2: Results Summary

Metrics	Results
Description	**Brick Clad with Split Exterior Mineral Wool Insulation and Interior Closed Cell Spray Foam Insulation in Wood Stud**
Effective R-value	RSI 6.1 m²K/W R 35 ft²·°F·h/BTU
Embodied Carbon per m² of Enclosure (A1-A3)	96.9 $kgCO_2/m^2$
Biogenic Carbon per m² of Enclosure	-18.6 $kgCO_2/m^2$



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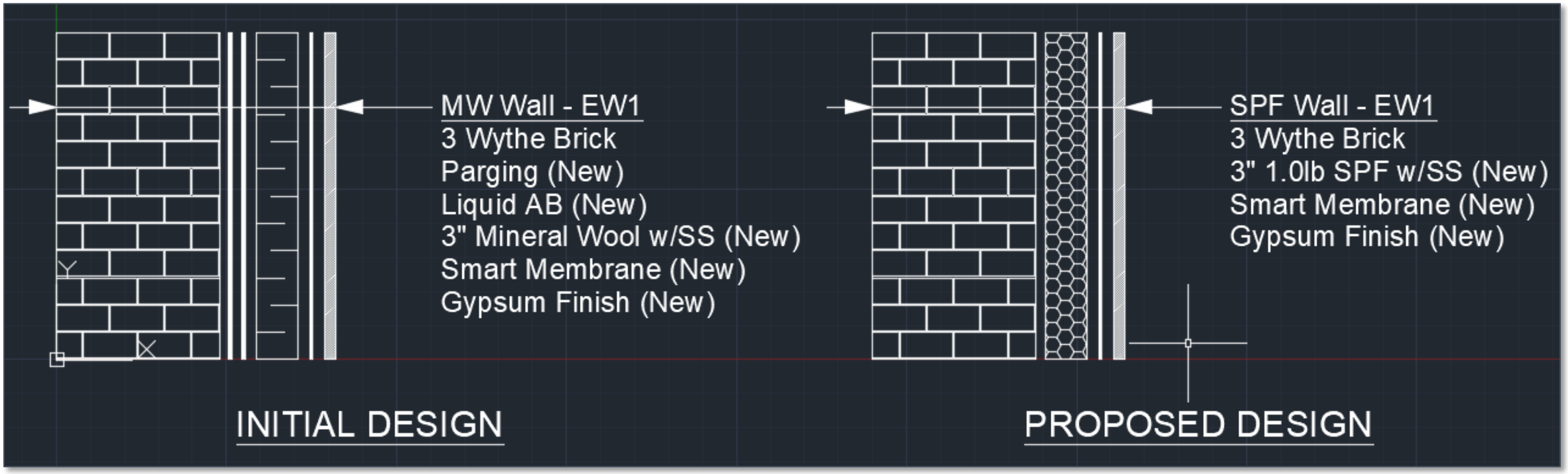
Carbon In Reality….. But In Actual Reality

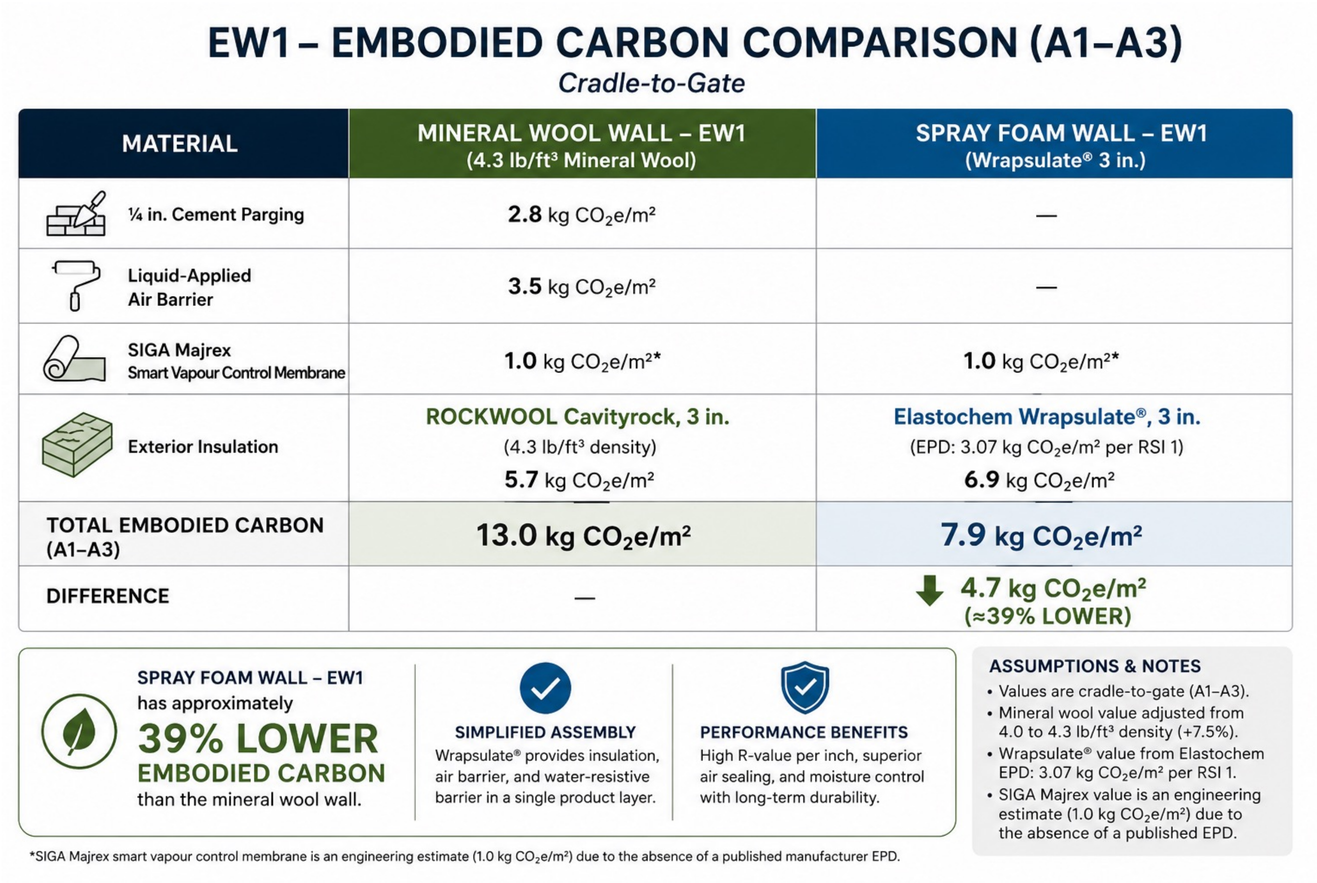
Designing a High-Performance Assembly for a Hospital Renovation

Carbon In Reality.....But In Actual Reality



The material that wins on a product-level EPD comparison is not always the material that delivers the best outcome when the full enclosure is considered

Carbon In Reality.....But In Actual Reality



EW1 – EMBODIED CARBON COMPARISON (A1–A3)

Cradle-to-Gate

MATERIAL	MINERAL WOOL WALL – EW1 (4.3 lb/ft³ Mineral Wool)	SPRAY FOAM WALL – EW1 (Wrapsulate® 3 in.)
¼ in. Cement Parging	**2.8** kg CO_2e/m^2	—
Liquid-Applied Air Barrier	**3.5** kg CO_2e/m^2	—
SIGA Majrex Smart Vapour Control Membrane	**1.0** kg CO_2e/m^2*	**1.0** kg CO_2e/m^2*
Exterior Insulation	**ROCKWOOL Cavityrock, 3 in.** (4.3 lb/ft³ density) **5.7** kg CO_2e/m^2	**Elastochem Wrapsulate®, 3 in.** (EPD: 3.07 kg CO_2e/m^2 per RSI 1) **6.9** kg CO_2e/m^2
TOTAL EMBODIED CARBON (A1–A3)	**13.0 kg CO_2e/m^2**	**7.9 kg CO_2e/m^2**
DIFFERENCE	—	⬇ **4.7 kg CO_2e/m^2** **(≈39% LOWER)**

SPRAY FOAM WALL – EW1
has approximately
39% LOWER
EMBODIED CARBON
than the mineral wool wall.

SIMPLIFIED ASSEMBLY
Wrapsulate® provides insulation, air barrier, and water-resistive barrier in a single product layer.

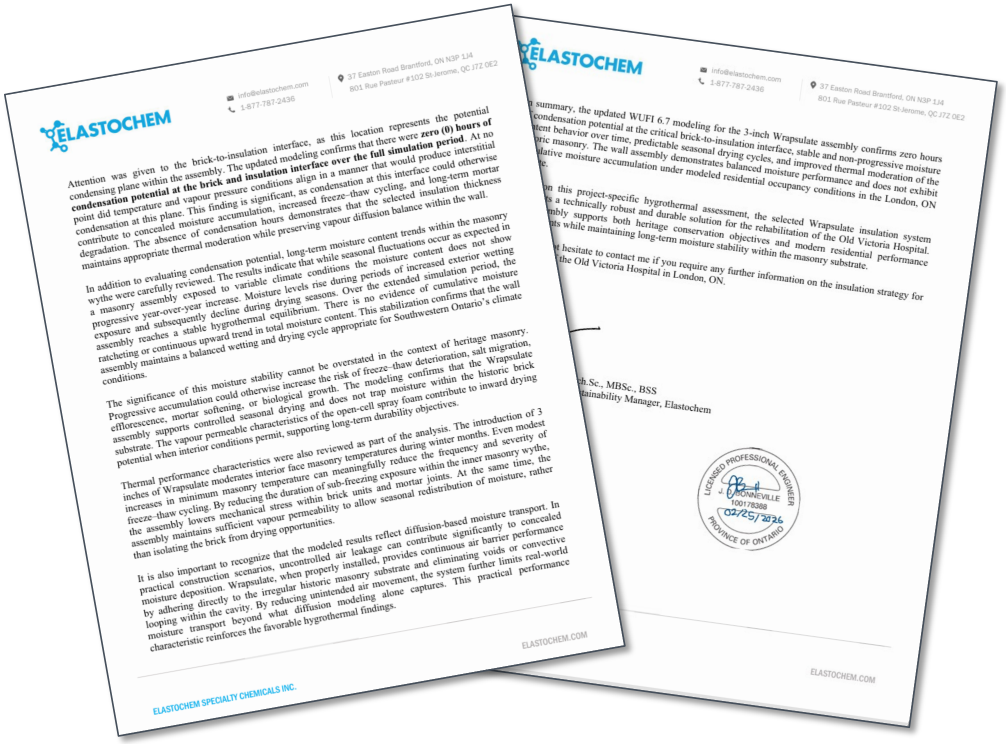
PERFORMANCE BENEFITS
High R-value per inch, superior air sealing, and moisture control with long-term durability.

ASSUMPTIONS & NOTES

- Values are cradle-to-gate (A1–A3).
- Mineral wool value adjusted from 4.0 to 4.3 lb/ft³ density (+7.5%).
- Wrapsulate® value from Elastochem EPD: 3.07 kg CO_2e/m^2 per RSI 1.
- SIGA Majrex value is an engineering estimate (1.0 kg CO_2e/m^2) due to the absence of a published EPD.

*SIGA Majrex smart vapour control membrane is an engineering estimate (1.0 kg CO_2e/m^2) due to the absence of a published manufacturer EPD.

Carbon In Reality..... But In Actual Reality



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Attention was given to the brick-to-insulation interface, as this location represents the potential condensing plane within the assembly. The updated modeling confirms that there were **zero (0) hours of condensation potential at the brick and insulation interface over the full simulation period**. At no point did temperature and vapour pressure conditions align in a manner that would produce interstitial condensation at this plane. This finding is significant, as condensation at this interface could otherwise contribute to concealed moisture accumulation, increased freeze–thaw cycling, and long-term mortar degradation. The absence of condensation hours demonstrates that the selected insulation thickness maintains appropriate thermal moderation while preserving vapour diffusion balance within the wall.

In addition to evaluating condensation potential, long-term moisture content trends within the masonry wythe were carefully reviewed. The results indicate that while seasonal fluctuations occur as expected in a masonry assembly exposed to variable climate conditions the moisture content does not show progressive year-over-year increase. Moisture levels rise during periods of increased exterior wetting exposure and subsequently decline during drying seasons. Over the extended simulation period, the assembly reaches a stable hygrothermal equilibrium. There is no evidence of cumulative moisture ratcheting or continuous upward trend in total moisture content. This stabilization confirms that the wall assembly maintains a balanced wetting and drying cycle appropriate for Southwestern Ontario's climate conditions.

The significance of this moisture stability cannot be overstated in the context of heritage masonry. Progressive accumulation could otherwise increase the risk of freeze–thaw deterioration, salt migration, efflorescence, mortar softening, or biological growth. The modeling confirms that the Wrapsulate assembly supports controlled seasonal drying and does not trap moisture within the historic brick substrate. The vapour permeable characteristics of the open-cell spray foam contribute to inward drying potential when interior conditions permit, supporting long-term durability objectives.

Thermal performance characteristics were also reviewed as part of the analysis. The introduction of 3 inches of Wrapsulate moderates interior face masonry temperatures during winter months. Even modest increases in minimum masonry temperature can meaningfully reduce the frequency and severity of freeze–thaw cycling. By reducing the duration of sub-freezing exposure within the inner masonry wythe, the assembly lowers mechanical stress within brick units and mortar joints. At the same time, the assembly maintains sufficient vapour permeability to allow seasonal redistribution of moisture, rather than isolating the brick from drying opportunities.

It is also important to recognize that the modeled results reflect diffusion-based moisture transport. In practical construction scenarios, uncontrolled air leakage can contribute significantly to concealed moisture deposition. Wrapsulate, when properly installed, provides continuous air barrier performance by adhering directly to the irregular historic masonry substrate and eliminating voids or convective looping within the cavity. By reducing unintended air movement, the system further limits real-world moisture transport beyond what diffusion modeling alone captures. This practical performance characteristic reinforces the favorable hygrothermal findings.

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n summary, the updated WUFI 6.7 modeling for the 3-inch Wrapsulate assembly confirms zero hours
condensation potential at the critical brick-to-insulation interface, stable and non-progressive moisture
tent behavior over time, predictable seasonal drying cycles, and improved thermal moderation of the
ric masonry. The wall assembly demonstrates balanced moisture performance and does not exhibit
ulative moisture accumulation under modeled residential occupancy conditions in the London, ON
te.

on this project-specific hygrothermal assessment, the selected Wrapsulate insulation system
ts a technically robust and durable solution for the rehabilitation of the Old Victoria Hospital.
mbly supports both heritage conservation objectives and modern residential performance
ts while maintaining long-term moisture stability within the masonry substrate.

t hesitate to contact me if you require any further information on the insulation strategy for
the Old Victoria Hospital in London, ON.

ch.Sc., MBSc., BSS
tainability Manager, Elastochem

LICENSED PROFESSIONAL ENGINEER
J. BONNEVILLE
100178388
02/25/2026
PROVINCE OF ONTARIO

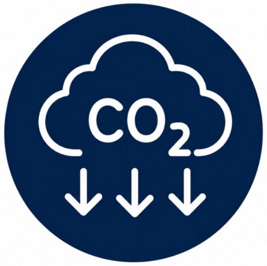
ELASTOCHEM.COM

Conclusion – Moving From Perception To Performance

1

DESIGN ASSEMBLIES, NOT MATERIALS

Every material has strengths and weaknesses. The goal isn't to find the "greenest" product, it is to design the lowest impact, highest performing building assembly



2

CARBON IS MORE THAN AN EPD

Transportation, installation, durability, maintenance, and material reduction all influence the true environmental impact of a building

3

EMBODIED VS. OPERATIONAL CARBON

Focus on reducing embodied carbon today while designing for low operational energy tomorrow. Smart choices across the full life cycle create the greatest impact

4

LET DATA REPLACE PERCEPTION

Use verified tools, whole-building analysis, and building science, not marketing to make informed decisions

The question isn't whether spray foam is good or bad. The question is whether we're evaluating buildings with science .....or with stereotypes

Rocky Boyer
B. Arch. Sc., MBSc, BSS
Building Science and Sustainability Manager

—

rboyer@elastochem.com
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ELASTOCHEM®

Solstice

Questions

presented August 3, 2026.

THANK YOU

Solstice

presented August 3, 2026.