EMBRACING CIRCULAR ECONOMY: INNOVATIVE APPROACHES AND BUSINESS MODELS IN THE HVAC INDUSTRY

Debajyoti Maitra[1], Jenelle Shapiro, Tiffany Waymer, Cal Krause, Shannon Sajdak, Swathy Ramaswamy, Richard Jameson

Trane Technologies
Phone[1]: 270-889-3932
Email[1]: deba.maitra@tranetechnologies.com

Abstract

HVAC (Heating, Ventilation, and Air Conditioning) Original Equipment Manufacturers (OEMs) are increasingly integrating circular economy strategies into their operations to address environmental concerns and

regulatory compliance while maintaining high performance and efficiency standards. This paper uses Trane Technologies® as a lens to examine the innovative approaches and business models the HVAC industry can adopt to integrate circular economy principles, focusing on resource efficiency, waste minimization, and economic growth. Trane Technologies®, employs a strategic approach to improve circularity business capabilities, reduce embodied carbon emissions and design systems for circularity across all our products, solutions, and operational facilities to realize waste reduction, conserve resources, and create shared value with suppliers and customers.

The paper encompasses multiple aspects of the circular economy, including optimization of secondary material use, increasing circularity considerations during design, and incentivizing the value chain to reuse, repair and remanufacture. Several strategies for circular transformation such as Product-as-a-service (PaaS), reverse logistics and energy efficiency are elaborated in the paper. The development of reverse logistics systems for the take-back of old HVAC units for refurbishment, recycling, or remanufacturing plays a vital role in the circular economy within the HVAC industry.

Case studies from Trane Technologies discussing the strategies, challenges, and outcomes of successfully adopting circular economy principles are included. The paper will also identify technical challenges in designing and implementing circular HVAC systems, highlighting regulatory barriers and industry quality standards that may hinder the adoption of circular economy practices for different materials. The potential market resistance and the need for consumer education and engagement are also addressed.

Policy measures such as tax breaks, subsidies, and low-interest loans can significantly motivate manufacturers to adopt sustainable practices, including the use of recycled materials and the implementation of extended producer responsibility (EPR) programs. Collaborative efforts with stakeholders, including suppliers, customers, and reuse partners, are crucial for the successful implementation of circular economy practices and will be addressed. By fostering a circular supply chain, HVAC OEMs can ensure the continuous flow of materials and resources, thereby closing the loop and achieving greater sustainability and reduced embodied carbon across the supply chain.

Introduction

In response to global resource depletion and escalating emissions, HVAC OEMs are adopting a circular economy-centered business model, aimed at long-term environmental stewardship and profitability. Circularity, as defined by the EU Taxonomy, maximizes the utility and value of products, materials, and resources throughout their life cycles while minimizing waste. HVAC OEMs are on a journey to fully integrate circularity across design, procurement, manufacturing, and end of life recovery lifecycle stages. This transition requires cross-functional collaboration, technological innovation, and consistent measurement but offers significant environmental, operational, and commercial benefits. By applying circularity strategies, the HVAC sector is demonstrating measurable reductions in waste and emissions while unlocking new opportunities for growth and resilience. However, the HVAC industry is still in the early stages of adopting circular design principles, compared to many other industries, but momentum is accelerating driven by stronger sustainability commitments and increasing raw material costs. As one of the leading

HVAC OEMs, Trane Technologies has designed its circularity strategy framework around six pillars that span the entire value chain from design through end-of-life:

1. **Sustainable & Circular Design:** We design with the full life of a unit and its components in mind from how they are made, and what materials are used, how they are maintained, reused, remanufactured or even recycled. Because our products are built to last, easy to service, and ready for future innovation, we help customers stay ahead while we minimize waste and resource use.
2. **Sustainable Material Selection:** We choose materials that enable circularity from the start. By sourcing renewable, recycled, and responsibly made materials, we reduce our footprint, build supply chain resilience, and set the foundation for circular innovation.
3. **Maintain, Prolong, Share:** We care for what we make — keeping products performing at their best through maintenance, upgrades, and shared-use models. By staying close to our customers, we ensure they benefit from ongoing improvements and sustainable innovation throughout the product's life.
4. **Reuse, Redistribute:** We keep high-quality components and materials in circulation by recovering, reusing, and redeploying what still performs. This approach helps us avoid unnecessary production, reduce waste, and deliver more value from what already exists.
5. **Remanufacture, Repair:** We restore and rebuild products and parts to perform like new — saving materials, energy, and emissions while maintaining the highest standards of quality. By regenerating existing value, we deliver cost-efficient, reliable solutions that support both business and environmental goals.
6. **Recycle:** We recycle scrap metals, reclaim refrigerants and implement recycling programs at our manufacturing facilities and offices for e-waste, cardboard, wood and pallets.

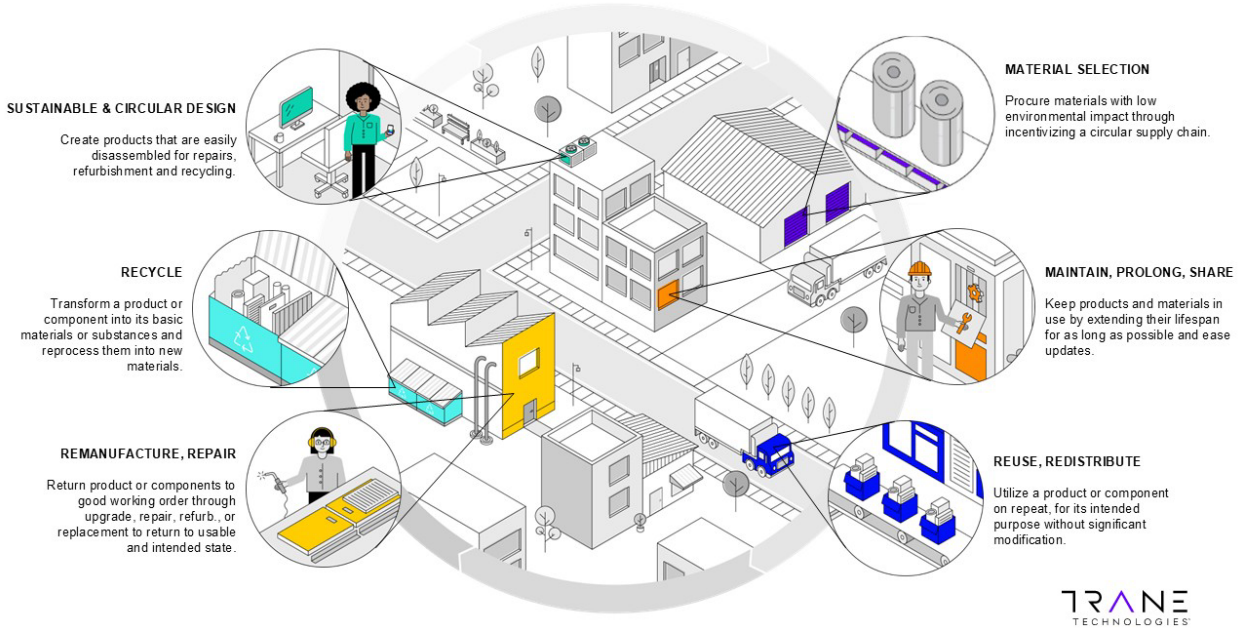

Fig. 1 Six pillars of Trane Technologies' circularity strategy framework

Implementation Mechanisms

HVAC OEMs are taking a comprehensive approach to advance material circularity within their organizations and across the industry. Internally, cross-functional councils and working groups—comprising business leaders and sustainability specialists—are formed to align circularity goals and address organizational barriers. These teams conduct Enterprise-wide circularity assessments to benchmark progress and identify areas for improvement.

Externally, HVAC OEMs are forging partnerships with leading industry alliances and coalitions such as the REMADE Institute, the Remanufacturing Industries Council (RIC), the Circular Economy Coalition, and global sustainability platforms like the World Economic Forum (WEF) and World Business Council for Sustainable Development (WBCSD).

Finally, partnerships with suppliers, and technology development play a pivotal role in implementing the circular economy. Identifying capable skilled partners with new suppliers, helps to incentivize reuse, repair, and remanufacturing across the supply chain. Additionally, technological and operational initiatives, including the adoption of specialized design tools and modules like Design for Sustainability and Circularity (DfSC), help to scale faster. These resources facilitate the integration of circularity objectives throughout product management, engineering, and operations, further advancing sustainability outcomes.

Measurement and KPIs

HVAC OEMs are increasingly implementing enterprise-wide Circularity Key Performance Indicators (KPIs) to transform product design, sourcing, manufacturing, and servicing processes. These initiatives engage business units and functions across the organization, aligning teams around a shared objective of maintaining product and material value to foster business growth and deliver measurable environmental progress.

The development and approval of robust circularity KPIs requires extensive collaboration, cross-functional engagement, and sustained leadership commitment. Achieving alignment across diverse business units, uniting priorities, integrating data, and securing buy-in from key stakeholders are essential steps in the process. These efforts are critical given the complexity of circularity integration and the need to ensure that internal accountability and strategic reporting are supported at every level.

By introducing standardized KPIs, HVAC OEMs strengthen investor accountability and enhance credibility through comparability with external industry reporting standards. KPIs provide teams with the tools necessary to measure and communicate progress both internally and externally, creating transparency around circularity efforts. Circularity initiatives create tangible business value by reducing procurement costs, unlocking new revenue streams, and encouraging customer loyalty. Increased utilization of circular materials minimizes environmental impact, improves cost efficiency, and supports supply chain security, all while preserving product quality. Strategic deployment of KPIs allows for deeper adoption of circular practices, guiding responsible investments and scalable sustainability outcomes.

KPIs identified by Trane Technologies® in 2025 to measure progress and drive business value::

- Circular Material Use: Assessing reductions in virgin material and increases in recycled, renewable, or secondary materials. Trane Technologies® targets more than double circular materials by 2030
- Circular Services and Models: Tracking the expansion of remanufacturing, reconditioning, and asset-sharing services across the industry. Trane Technologies® targets to generate 10% of the revenue from circular products and services by 2030
- Carbon Emissions: Quantifying reductions in greenhouse gas emissions, both upstream in material sourcing and downstream in product use or end-of-life management.

The environmental and business impact of circularity is further reflected through outcomes such as waste reduction, resource conservation, and carbon footprint reduction. The adoption of scrap and circular procurement models helps achieve zero-waste goals in manufacturing, while extending product lifecycles and utilizing recycled inputs reduces the demand for raw materials. Customers also benefit from circular offerings with lower indirect emissions and resource usage. Furthermore, circularity supports the transition to resilient, low-carbon business models, fostering business model innovation through remanufacturing programs, reverse logistics systems, and redesign for repairability and recyclability.

By leveraging these KPIs, HVAC OEMs are integrating circular sourcing and lifecycle management as a strategic advantage—fueling innovation, driving profitability, and guiding future investments toward long-term sustainability and scalable impact.

Six pillars of circularity

1. Sustainable and Circular Design: Example - Repurposing Single-Use Plastics

Plastic Zip Tie Repurposing: Trane Technologies® receives hundreds of thousands of durable plastic zip ties each year used in the delivery of parts and components. Instead of disposal, teams sought ways to upcycle these into new high-value components[1]. The process involved on-site shredding of discarded zip ties. The shredded plastic was then sent to a partner facility, melted, and formed into drain tubes for refrigeration units. The impact of closed-loop material reuse was found to be significant. 450,000 zip ties were able to be repurposed into 50,000 drain tubes, enough to supply 27,000 refrigeration units. Carbon emissions were reduced by 4.3 metric tons (equivalent to eliminating the carbon impact of burning 4,778 pounds of coal or driving a gasoline vehicle for 10,953 miles).

The operational process was designed for easy replication, enabling other manufacturing sites to convert single-use plastics into valuable components—reducing waste and emissions across global OEM operations. This initiative encourages Trane Technologies® product teams to adopt circularity into their daily operations, illustrating how small changes (such as reusing zip ties) can inspire more creative and impactful sustainable design solutions. As regulations for single-use plastics and emissions become stricter, closed-loop methods help future-proof product portfolios and support objectives like zero waste to landfill. In addition, sustainable and circular designs strengthen business resilience, accelerate decarbonization, and add value throughout the HVAC supply chain. This case demonstrates how practical innovations in circularity can spark broader sustainability actions within the HVAC OEM sector, driving continuous improvement and inspiring further global collaboration.

2. Sustainable Material Selection:

The decarbonization of supply chains is increasingly critical for HVAC OEMs seeking to minimize their environmental footprint and enhance operational resilience. One central area of focus is material selection, with particular emphasis on choosing low-impact materials throughout procurement and design processes. This approach directly supports supply chain decarbonization while strengthening resilience against resource shortages and volatile market forces.

A prime example is the adoption of recycled aluminum alloys for residential HVAC heat exchangers[2]. Aluminum is vital for HVAC applications but is notoriously carbon-intensive, with virgin alloy production responsible for a significant proportion of emissions in the manufacturing process. Faced with the challenge of finding recycled alloys that met stringent quality and performance standards, a representative HVAC OEM initiated multi-year research collaborations with external suppliers. These efforts led to the development of a manufacturing process for specialized alloys containing up to 80–84% recycled content, achieving major energy savings equivalent to powering thousands of homes annually. Such advances demonstrate how leveraging circularity creates opportunities to decarbonize even the most challenging supply chain components.

The commitment to decarbonization extends beyond material composition. HVAC OEMs are introducing innovations in manufacturing, such as switching to electric rather than natural-gas-fueled equipment and implementing closed-loop systems for internal aluminum scrap recycling. These actions contribute to the reduction of both direct emissions from manufacturing and indirect emissions associated with suppliers and transport. In partnership with industry-leading suppliers, new advances in sustainable aluminum production are further decarbonizing the supply chain, highlighting the importance of collaboration in achieving sustainability goals.

Circularity is also being expanded to other critical materials, including steel, copper, and plastics. This holistic approach ensures that lessons learned in aluminum decarbonization serve as a model for the broader material portfolio. By pursuing zero-waste-to-landfill operations and developing innovative recycling partnerships, HVAC OEMs are demonstrating leadership in environmental stewardship and operational excellence. Achievements such as sustained zero-waste operations in production facilities underscore the real-world impact of these strategies.

These supply chain decarbonization and circularity practices are integral to meeting ambitious sustainability commitments. For example, Trane Technologies® is designing systems for circularity and targeting 40% embodied carbon reduction by 2030, demonstrating how HVAC OEMs are translating broad sustainability goals into actionable, measurable results. This proactive stance makes a compelling case for how decarbonization can generate business value and drive growth while simultaneously addressing pressing climate challenges within urban and built environments.

In conclusion, the experience of leading HVAC OEMs reveals that supply chain decarbonization through circularity and sustainable material selection is both achievable and impactful. Through persistent research, cross-sector collaboration, and the integration of advanced recycling technologies, these organizations set new standards for environmental performance, resilience, and innovation. Their journey serves as a blueprint for the entire HVAC industry and other sectors aiming to deliver bold climate commitments and sustainability-driven business transformation.

3. Maintain, Prolong, Share:

A fundamental strategy for decarbonization in the HVAC industry centers on extending the lifecycle and utility of equipment through maintenance, upgrades, and innovative business models grounded in circularity. HVAC OEMs are evolving the concept of circularity beyond material use and seeking new ways to keep products, equipment, and resources operating for longer and with reduced waste. By prioritizing proactive service, digital connectivity, and equipment sharing, OEMs demonstrate how decarbonization initiatives can create significant business value for customers while cutting greenhouse gas emissions throughout the operational value chain.

Designed life-extension programs are a cornerstone of this approach[3]. These services involve comprehensive renewal of commercial HVAC equipment, including regular replacement of parts, performance checks, and technology upgrades, allowing systems to operate at near-new efficiency far past their initial lifespan. Data-driven evidence reveals that regular maintenance activities can add up to a decade of useful life for HVAC assets, delaying capital expenditures, and helping to avoid the embodied carbon associated with manufacturing new systems. Importantly, these programs also address key environmental risks, such as refrigerant leakage, through more frequent servicing and responsible equipment management.

In addition to physical renewal, the integration of digital solutions is proving transformative. AI-driven analytics pilots are enabling remote monitoring and diagnostics on thousands of connected units, with predictive maintenance capabilities expected to be standard on all new products. Remote connectivity not only identifies issues before failures occur thereby reducing unexpected downtime and site visits but also optimizes energy efficiency, translating into measurable carbon savings. As building service teams adopt these technologies, the sector moves toward a more sustainable, productive, and resilient operational environment.

Circular business offerings extend beyond maintenance to include equipment sharing and rental programs. Rather than replacing aging customer assets, OEMs repurchase, refurbish, and reintegrate equipment into their rental fleets, giving machinery a new lease on life while eliminating the need for new product manufacturing and the accompanying carbon emissions. This asset sharing model provides customers with scalable access to vital HVAC and cold storage systems, minimizes both capital costs and carbon footprint, and maximizes resource utilization. The inclusion of battery-powered cold chain solutions further underscores the move toward renewable energy integration in critical logistics applications.

Collectively, these proactive service, maintenance, and circular resource-sharing initiatives accelerate the HVAC industry's progress toward ambitious sustainability targets, such as substantial reductions in embodied carbon and gigaton-scale greenhouse gas savings for customers. By making energy efficiency and lifecycle maintenance fundamental to their business models, OEMs are rapidly advancing the pace of decarbonization. These practices not only drive operational and economic benefits but also position the HVAC sector as a leader in translating circularity principles into real-world, scalable sustainability solutions.

Key benefits include financial savings that offer a cost-effective alternative to expensive emergency repairs or replacements; improved energy efficiency leads to reduced operating costs; reliable operation due to proactive, planned renewals that prevent unexpected failures, minimize downtime, and avoid replacement part delays during peak periods and environmental compliance. Replacing all refrigerant seals and gaskets reduces the risk of refrigerant leaks and supports environmental protection. This service program is best for chillers with heavy usage, frequent starts/stops, installations sensitive to downtime, customers with limited capital for new equipment, and those focused on environmental stewardship.

One example from a representative OEM, Trane Technologies®, is R'Newal® Service Program which is a comprehensive maintenance and renewal solution tailored for Series R chiller models (RTAA, RTAC, RTUA, RTWA, RTWD). It aims to restore compressor performance and reliability, extend equipment lifespan, and offer peace of mind with a new factory warranty. Trane evaluates the unit's needs based on its operational history and arranges the renewal process to minimize disruptions. The program is flexible, fitting both proactive maintenance and post-failure

restoration. Equipment is not taken offline until a replacement compressor is available. The service program includes inspection of heat exchangers (evaporator and condenser tubes), wear-sensitive parts, and testing for corrosion or material damage; faulty parts are replaced, and new serial numbers issued for tracking. The chiller is run-tested, and samples are sent for analysis. The R'Newal® Service Program addresses the most common causes of performance decline to extend the life of our customers' chillers. It reduces unplanned downtime and renews reliability through the repair of worn components. The technicians inspect critical components, identify wear or damage, install genuine parts, improve chiller efficiency, and refresh worn name plates and serial numbers for legibility. The program helps maximize equipment efficiency, extends lifespan, and aligns with OEM's commitment to circularity and sustainability.

4. Reuse, Redistribute: Decarbonization for Refrigerated Transport

Transportation and logistics represent a significant frontier for decarbonization within the transport HVAC sector, particularly through the application of circularity principles to refrigerated transport assets. The transport HVAC OEMs are advancing a circular business model that keeps equipment and key components in productive use for extended periods[4]. By designing products to be easily repaired, repurposed, and reused, OEMs can dramatically reduce waste, lower the environmental impact, and support broader objectives in supply chain decarbonization, all while enabling cost-effective growth.

A notable illustration of circularity in transport decarbonization is the Certified Pre-Owned (CPO) program that a representative OEM Thermo King® has for refrigerated transport. This initiative not only prolongs the life of critical cold chain infrastructure but also aligns economic and environmental objectives. Under this program, previously used refrigeration units undergo targeted refurbishment and component replacement at certified dealer locations. Each unit is rigorously inspected and renewed to meet reliability and performance standards, with participants earning certification and an extended warranty for the reconditioned equipment. Such practices allow units to be redeployed by fleet operators or sold to new owners, ensuring valuable assets stay on the road rather than entering the waste stream. Since inception, nearly 150 trailer refrigeration units have been recertified, extending their service life from approximately seven to over ten years. This practice defers the need for new manufacturing which is associated with substantial greenhouse gas emissions and reduces the capital expenditures required of customers.

Beyond direct carbon reductions, the CPO program addresses a key industry challenge: the mismatch between the operational lifespans of refrigeration units and the trailers on which they're mounted. By extending equipment lifecycles, OEMs synchronize these timeframes, maximizing asset utility for fleet managers and giving them tangible tools for managing tightening emissions regulations. Dealers benefit from offering solutions that deliver measurable progress toward sustainability while differentiating themselves in a marketplace increasingly focused on environmental impact. This strategy not only translates ambitious climate commitments into practical, trackable outcomes—such as embodied carbon reductions and progress toward industry "gigaton" emission reduction targets—but also becomes a compelling market proposition.

Circularity-driven programs like the CPO initiative exemplify how environmental stewardship and business value creation can dovetail. These actions reduce resource extraction, cut manufacturing- and operational-related emissions, and showcase leading-edge decarbonization technology. By focusing on the pillars of reuse and redistribution, OEMs set a benchmark for the entire refrigerated transport sector and reinforce their pledge to deliver on decarbonization targets, including significant embodied carbon reduction and a cumulative goal of removing one billion metric tons of customer carbon emissions by 2030.

In summary, the implementation of circularity principles in refrigerated transport offers a proven model for decarbonizing supply chains and generating customer value. Initiatives like the CPO program demonstrate scalability, measurable outcomes, and adaptability to regulatory and market demands. Through strategic equipment life extension and targeted refurbishment, HVAC OEMs are leading a transformative shift for their industry translating sustainability commitments into real-world impact and illustrating the broader potential for circularity across commercial transportation and beyond.

5. Remanufacture, Repair:

Remanufacturing is a thorough industrial process that restores a previously sold, used, or non-functional product or component to a like-new condition in terms of both quality and performance[5]. This process includes several steps: disassembly, cleaning, inspection, testing, repair, reassembly, finishing, and verification. In comparison to other

processes like repair or refurbishment, remanufacturing is distinguished by its comprehensive approach to returning a used product or component to a quality and performance perspective similar to its original functional specifications.

Remanufacturing supports circularity principles through efficient reuse of materials and components, which minimizes waste, reduces energy consumption, and lowers carbon emissions. Research indicates that remanufacturing requires only a fraction of the energy needed for new manufacturing, with energy savings ranging from 70% to 95% compared to producing new products or components[6]. Remanufacturing also enhances supply chain resilience by creating a local or regional infrastructure for parts and materials. This reduces lead times and increases product availability. Additionally, it minimizes equipment downtime and supports customers throughout the equipment's service life, ultimately lowering their total cost of ownership. Remanufacturing can also unlock new revenue streams through product differentiation and market expansion.

Although remanufacturing has been established for many decades, particularly in the automotive, electronics, and heavy industrial equipment sectors, it is still emerging in the HVAC industry. Currently, only select HVAC components, such as screw and reciprocating compressors and certain chiller motors, are being remanufactured, mainly for commercial applications. There are opportunities to expand remanufacturing to a wider range of parts and applications, including other types of compressors and motors, as well as electronic components like drives and controllers.

The HVAC industry faces several challenges that must be addressed to stimulate growth in remanufacturing. In North America, policy incentives for remanufacturing, particularly for HVAC components, are minimal. The remanufacturing infrastructure is fragmented and disconnected, and there is a limited ecosystem of specialized expertise and suppliers for remanufacturing of HVAC parts. Although local repair shops and refurbishment providers may exist for specific activities like motor rewinding or control board repair, this infrastructure is inconsistent, logistically challenging, and not widespread.

Additionally, technical complexities arise from components that are not designed for remanufacturing, such as hermetically sealed compressors or electronic boards with conformal coatings. To address design challenges, the REMADE Institute, Trane Technologies and others have collaborated on the development of a software plug in that incorporates design for remanufacturing considerations in the product design process and is seamlessly integrated with existing CAD software packages commonly used in industry7.

Remanufacturing represents a robust and sustainable approach to restoring used or non-functional products to like-new condition, offering significant environmental and economic benefits. While technical, logistical and policy challenges exist, they can be solved through greater collaboration and innovation within the HVAC industry, ultimately leading to greater sustainability, reduced costs, and improved product longevity.

6. Recycle:

In recent years, circularity has emerged as a transformative principle for sustainable industrial operations, offering significant opportunities for decarbonization, economic resilience, and operational innovation. A representative HVAC OEM, Trane Technologies' facility in Galway, Ireland provides a compelling case study on how circularity can be implemented to achieve zero waste to landfill at an industrial scale. Traditionally, most manufacturing waste ends its lifecycle in landfills, contributing to land degradation and air pollution. However, the circular approach views all materials as valuable resources, prompting a shift in waste management paradigms and practices.

At the Galway site, which manufactures over 100 cold chain refrigeration units daily, historic landfill waste exceeded 20 tons per year a decade ago. In 2014, a cross-functional team set an ambitious target: transform the facility into the first zero-waste-to-landfill site for the organization. The plant's unique position between residential neighborhoods necessitated a community-focused approach to waste minimization. A thorough evaluation of every waste stream led to the separation and collection of plastics, metals, cardboard, timber, and other components at employee workstations. Equally critical to success was collaboration with regional partners, who introduced innovative recycling alternatives tailored to the specific waste outputs of the facility.

Transparency was central to the waste management system, with every material tracked, weighed, and its final destination recorded. Sustainability reporting and regular audits ensure persistent improvement and compliance with zero-waste objectives. The reverse logistics ecosystem enabled metals to be reclaimed and processed locally, timber to be converted into garden mulch, and paper products to be recycled into new packaging. In cases where

recycling was not viable, residual materials were repurposed for energy generation at cement manufacturers, ensuring nothing was sent to landfill.

Further progress was realized through supply chain collaboration. HVAC OEM expanded its circularity ethos beyond factory operations, working with suppliers across several countries to reconceptualize packaging and shipping practices. The adoption of reusable crates and corrugated boxes replaced single-use pallets and packaging, establishing a sustainable reverse-logistics supply chain where packaging materials continuously circulate between factory and suppliers.

The outcomes of this initiative are remarkable: landfill waste at the Galway site dropped from an average of 230 tons per year (2002–2012) to virtually zero since 2015, maintaining ten consecutive years of zero landfill waste. This transition delivered significant value both to the business and its customers, with returnable metal pallets eliminating disposal and landfill taxes, and reduced packaging costs yielding supplier discounts. Additionally, the environmental benefits are pronounced—such decarbonization efforts advance both internal carbon neutrality goals and those of customers.

The success of the Galway facility illustrates that zero-waste manufacturing is achievable when systems, data integrity, and organizational culture align. It underscores how sustainability-centered behavior can drive operational results and deliver tangible business and environmental value. This model of circularity not only demonstrates leadership within the HVAC industry but also provides a scalable blueprint for other sectors and facilities seeking to advance toward zero waste and carbon-neutral operations. As HVAC OEM pursues its 2030 sustainability commitments, the company continues to design and deploy circular systems that support the transition to a decarbonized economy.

Policy measures

Policy measures such as tax breaks, subsidies, and low-interest loans can significantly motivate manufacturers to adopt sustainable practices.

Extended Producer Responsibility (EPR): EPR is a policy approach that assigns producers responsibility for the end-of-life management of their products. This may include financial and/or operational responsibilities, depending on the specific scheme. The legal basis for EPR schemes is set out in Articles 8 and 8a of Directive 2008/98/EC (Waste Framework Directive). Additional regulations establish EPR obligations for specific product categories, such as Packaging and Packaging Waste Directive (PPWD)8, Batteries and Waste Batteries Regulation9, and Waste Electrical and Electronic Equipment(WEEE)10 Directive. The upcoming Circular Economy Act (expected in Q3 2026) will revise EPR schemes with the aim of simplifying, digitalizing, and expanding them in a targeted manner.

Taxation: The Circular Economy Act will also introduce measures related to taxation, notably ensuring that reused products and their recycled content are not subject to double Value-Added-Tax (VAT), and introducing fiscal incentives to reduce landfilling. As taxation remains primarily a Member State competence, EU directives generally require Member States to promote product recovery and reuse without prescribing specific instruments. However, reduced VAT rates and tax deductions are listed in Commission working documents as potential policy tools to support these objectives.

Public Procurement: Public procurement plays a key role in ensuring that public funds are used efficiently, transparently, and in line with Europe's strategic goals, boosting competitiveness, resilience, and economic security. The European Commission has developed voluntary Green Public Procurement (GPP)[11] criteria for several product groups. The upcoming Industrial Decarbonization Accelerator Act (expected 10th December 2025) will introduce resilience and sustainability criteria to promote clean European supply chains in energy-intensive sectors. These criteria—covering aspects such as clean production, circularity, resilience, and cybersecurity—aim to strengthen demand for EU-made clean products, build on the experience of the Net Zero Industry Act, and promote innovation and high EU environmental and social standards, ensuring a level playing field. For strategic technologies (e.g. wind and solar), more detailed procurement criteria will be established through secondary legislation. In addition, the EU is revising the Public Procurement Directives (expected Q2 2026) to mainstream the use of non-price criteria across all procurement processes.

Subsidies: To enhance the effectiveness of state aid in supporting clean energy, industrial decarbonization, and clean technologies, the EU Commission adopted the Clean Industrial Deal State Aid Framework (CISAF) in June 2025. CISAF applies as of 25th June 2025 and remains in force until 31st December 2030. CISAF allows Member States to establish aid schemes supporting circular economy investments such as activities related to preparing for re-use, recycling, and other resource efficiency measures.

Loans: The InvestEU Programme, funded through the EU and EIB budgets, supports the green and sustainable transition, notably via its Sustainability Guarantee Product. Between December 2022 and September 2024, approximately €80 million in investments were directed towards circular economy, waste prevention, and recycling initiatives.

Conclusions:

The discussions and insights shared in "Embracing Circular Economy: Innovative Approaches and Business Models in the HVAC Industry" exemplify the momentum building within our sector to adopt and scale circular economy strategies. As demonstrated by industry leaders such as Trane Technologies, the integration of circularity principles—spanning sustainable design, material selection, maintenance, reuse, remanufacturing, and recycling—is already delivering measurable benefits: waste reduction, lower carbon emissions, resource conservation, cost efficiencies, and new business growth.

Case studies from the HVAC industry validate that practical innovations, such as upcycling plastics and using recycled alloys, are not only achievable but replicable at scale. Maintenance programs and asset-sharing models extend equipment lifecycles and cut emissions, while certified refurbishment initiatives synchronize value creation for fleet managers, manufacturers, and the environment. The transition to zero waste operations—and the robust measurement of key performance indicators—is transforming internal culture and setting exemplary benchmarks for advanced sustainability practices.

Yet, we are reminded that the success of circularity depends on collaborative ecosystems, enabling policy frameworks, innovative technologies, and a shared commitment from every stakeholder in the value chain. Policy instruments, such as extended producer responsibility (EPR), targeted subsidies, fiscal incentives, and green public procurement, are accelerating the adoption of circular models and fostering resilient supply chains.

This paper highlights that the journey to a sustainable, circular HVAC industry is both a business and societal imperative. It requires cross-functional collaboration, continual investment, and engagement from OEMs, suppliers, regulators, and customers alike. By championing circularity, the HVAC industry is uniquely positioned to deliver on bold sustainability goals—such as drastic reductions in embodied carbon by 2030—while fostering operational excellence, innovation, and long-term value creation.

References:

1. “Circular Design and Repurposing Plastics.” *Trane Technologies Blog,* Trane Technologies, https://www.tranetechnologies.com/en/index/blog/sustainability-leadership/circular-design-and-repurposing-plastics.html

2. “Material Selection for Supply Chain Decarbonization.” *Trane Technologies Blog,* Trane Technologies, https://www.tranetechnologies.com/en/index/blog/sustainability-leadership/material-selection-for-supply-chain-decarbonization.html.

3. “Maintain, Prolong, Share: A Circular Blueprint for Decarbonization.” *Trane Technologies Blog,* Trane Technologies, https://www.tranetechnologies.com/en/index/blog/sustainability-leadership/maintain-prolong-share-a-circular-blueprint-for-decarbonization.html.

4. “Circularity and Decarbonization for Refrigerated Transport.” *Trane Technologies Blog*, Trane Technologies, https://www.tranetechnologies.com/en/index/blog/sustainability-leadership/circularity-decarbonization-for-refrigerated-transport.html.

5. Reman Standard. https://remanstandard.us/.

6. Center for Sustainable Systems, University of Michigan. (2022). Bound factsheets 2022 https://css.umich.edu/sites/default/files/2022-09/Bound_Factsheets_2022.pdf

7. "Development of a Novel Design for Remanufacturing Software Plugin for CAD." *REMADE Projects*, REMADE Institute, https://remadeinstitute.org/remade-projects/development-of-a-novel-design-for-remanufacturing-software-plugin-for-cad/.

8. European Parliament and Council of the European Union. (1994). Directive 94/62/EC of 20 December 1994 on packaging and packaging waste (Consolidated version, July 4, 2018). EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A01994L0062-20180704

9. European Union. (2023). Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries. EUR-Lex. https://eur-lex.europa.eu/eli/reg/2023/1542/oj

10. European Parliament and Council of the European Union. (2012). Directive 2012/19/EU of 4 July 2012 on waste electrical and electronic equipment (WEEE) (Consolidated version, April 8, 2024). EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02012L0019-20240408

11. European Commission. CIRCABC group library: CIRCABC, https://circabc.europa.eu/ui/group/44278090-3fae-4515-bcc2-44fd57c1d0d1/library/f69e60f9-9dc6-4345-aa18-b9a4b6dfdbf0?p=1&n=10&sort=modified_DESC.

About the Author(s)

Swathy Ramaswamy is the Circularity Program Manager at Trane Supply, where she is focused on designing and implementing remanufacturing, reuse, and recycling programs for the aftermarket business. She has experience working at the intersection of sustainability, supply chain, product, and engineering in the Built Environment and Information and Communication Technology (ICT) sectors. Swathy holds a master's degree in industrial engineering from the Georgia Institute of Technology.

Cal Krause is an Embodied Carbon Specialist at Trane Technologies. He works on strategies to reduce embodied carbon in Trane Technologies products. He holds a B.S. degree in Industrial and Operations Engineering from The University of Michigan.

Tiffany Waymer is a Metallurgist at Trane Technologies. She supports new technology introduction, product development, and quality and reliability initiatives. Tiffany holds M.S. and B.S. degrees in Materials Engineering from Purdue University, West Lafayette, IN.

Richard Jameson is a Sr. Engineering Manager and Principal Engineer within the Materials and Chemistry Network of Excellence team at Trane Technologies, he is based out of Tyler, TX USA. He leads a team focused on new technology development with a strategic focus on projects aimed at reducing embodied carbon in Trane Technologies products. He holds bachelor's degree in Plastics Engineering from Ferris State University, and master's in business administration from Regis University.

Jenelle Shapiro is Sustainability and Circularity Leader at Trane Technologies. She holds a bachelor's degree in architecture, a Minor in Business Administration, and a Master's in Sustainability Management. Mrs. Shapiro is recognized as an expert in green design and construction, decarbonization risk management, circularity innovation, and Scope 3 greenhouse gas supplier emission reductions.

Shannon Sajdak is Product Sustainability Leader at Trane Technologies. She holds a bachelor's degree in Environmental Science and a Masters in Environmental Management. She has leveraged her expertise in product-level carbon footprints previously in the food industry and now in the building and transport HVAC-R space. She leads Trane's product sustainability program, including life cycle assessments and environmental product declarations as well as design for sustainability and circularity.

Presenter: **Dr. Debajyoti Maitra** received Ph.D. in metallurgical engineering from University of Nevada, Las Vegas. He has worked as Product and Application Development Engineer focused on alloy development, managed metallurgical lab and led new product innovation team. In his current role at Trane technologies, he leads corporate projects related to new technology development with a focus on materials for HVAC and refrigeration systems.