

Advancing Refrigerant Circularity with RefNEXT: Digital Traceability, Leak Monitoring, and Policy Influence

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Abstract

To establish a circular economy for refrigerants used in refrigeration and air-conditioning systems, a digital management platform, “RefNEXT (Refrigerant + NEXT),” has been developed and implemented. RefNEXT integrates six key processes: recovery, collection, processing, reclamation or destruction, reuse and refilling. Through its implementation in Japan and its presentation to policymakers and industry stakeholders in Southeast Asia, three key values of RefNEXT have been identified. First, RefNEXT enhances traceability. By integrating data from all stakeholders—including equipment manufacturers, contractors and equipment owners—it enables real-time visibility of refrigerant inventory and distribution pathways. This is particularly beneficial in countries such as Indonesia and Vietnam, where such measures are increasingly being mandated. Second, RefNEXT facilitates leak-rate monitoring. By identifying discrepancies in multiple data entry processes, RefNEXT detects refrigerant leakage, thereby supporting compliance with logbook regulations mandated in Japan and Europe. It also has the potential to contribute to similar regulatory frameworks in Southeast Asia. Third, RefNEXT influences refrigerant policies. While destruction has traditionally been the primary method for handling used refrigerants, increasing traceability and verification capabilities have led to policy developments toward supporting refrigerant reclamation. Additionally, carbon credit methodologies are evolving to include not only destruction but also reclamation as a viable option. This study examines how RefNEXT contributes to advancing a circular economy for refrigerants and supports the development of sustainable refrigerant management policies. Future implementation efforts will focus on adapting RefNEXT to regional regulatory frameworks.

Key words: carbon credit, circular economy, digital management, leak detection, policy reform, RefNEXT (refrigerant management platform), refrigerant traceability

1. Introduction

As of 2023, GenbaNEXT developed and provided a digital management platform, “RefNEXT (Refrigerant + NEXT),” to establish a circular society for refrigerants used in refrigeration and air conditioning systems. This initiative is driven by our conviction that digital management and traceability are essential for achieving a circular economy for refrigerants. Furthermore, since 2022, GenbaNEXT has collaborated with Daikin Industries, Ltd., a global leader in the industry, to promote the introduction of digital refrigerant management in Japan. This domestic initiative has laid the foundation for new insights through demonstration projects in various Southeast Asian countries.

The transition to a circular economy is essential for reducing resource consumption and minimizing environmental impacts, making it a pressing global issue. In particular, refrigerants are potent greenhouse gases, necessitating urgent measures. Hydrofluorocarbons (HFCs), commonly used as replacements for earlier refrigerants, have zero ozone depletion potential but exhibit global warming potentials (GWP) hundreds to thousands of times that of CO₂ (IPCC, 2007). Consequently, the Kigali Amendment to the Montreal Protocol (UNEP, 2016) mandates the phased reduction of HFCs. While it does not explicitly regulate the recovery, destruction, or reuse of refrigerants, such measures have been increasingly adopted by national policies to support compliance and environmental goals. Although HFCs

have attracted recent regulatory focus, earlier generations of refrigerants—chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs)—are still in use, particularly in developing countries. These legacy refrigerants continue to contribute substantially to global warming. In fact, according to the WMO Greenhouse Gas Bulletin No. 20 (WMO, 2024), the radiative forcing from CFCs and HCFCs in 2023 exceeded that of HFCs.

Effective refrigerant lifecycle performance remains low, however. For instance, Japan's refrigerant reclamation rate is only about 12% (METI, 2021). This issue is not limited to recovery inefficiencies but extends to a lack of comprehensive lifecycle management from production and importation to reuse and destruction. In Southeast Asia, countries such as Indonesia and Vietnam are strengthening their refrigerant inventory management in response to international regulations but continue to face implementation challenges.

This study examines how the introduction of the RefNEXT digital management platform impacts the circular economy of refrigerants. Using case studies from Japan and Southeast Asia, we evaluate its potential contribution.

- Section 2 of this paper discusses the current situation and challenges in Japan.
- Section 3 introduces the core functionalities of RefNEXT and outlines initial implementation examples in Japan. While detailed empirical case studies are forthcoming, this section focuses on the system's structure and early-stage applications.
- Section 4 explores the platform's impact on traceability, leak detection, and policy influence.
- Section 5 summarizes the study's significance and outlines future directions.

2. Challenges in Fluorocarbon Management in Japan

In Japan, the handling of refrigerant recovery, reuse and destruction is regulated under the Fluorocarbons Emission Restraining Law. This law was enacted to prevent the release of ozone-depleting substances and greenhouse gases that contribute to climate change. Specifically, it mandates proper gas management across all processes, including the manufacturing, sale, use and disposal of equipment that utilizes certain refrigerants. Additionally, it stipulates guidelines for the reuse and destruction of recovered refrigerants, with businesses and operators subject to reporting obligations. Within this framework, the Ministry of the Environment (MOE) monitors refrigerant recovery rates nationwide.

The refrigerant lifecycle consists of six key processes: filling, recovery, collection (transportation), processing, reclamation or destruction, and reuse (commercialization) (Table 1). In this study, “recovery” refers to the extraction of refrigerants from equipment

Table 1 Key stakeholders in the refrigerant circulation process. (prepared by the authors)

Process	Main Role	Main Stakeholders
Filling	Injecting refrigerants into air conditioning equipment, etc.	Type 1 Fluorocarbon filling and recovery operators
Recovery	Recovering refrigerants from air conditioning equipment into dedicated refrigerant containers	Type 1 Fluorocarbon filling and recovery operators
Collection (transportation)	Transporting recovered refrigerant containers	Transport operators
Processing	Analyzing recovered refrigerants, consolidating them into large cylinders, and transferring them to reclamation or destruction operators	Processing operators (Article 49 of the Ministry Ordinance)
Reclamation or destruction	Conducting refrigerant reclamation or destruction	Reclamation operators, fluorocarbon destruction operators
Commercialization (reuse)	Selling regenerated refrigerants for reuse	Refrigerant manufacturers

Note 1: “Type 1 Fluorocarbon Filling and Recovery Operators” refers to professionals licensed under Japan's Fluorocarbon Emissions Control Act to perform regulated refrigerant filling and recovery, specifically from commercial equipment, which is managed under a distinct regulatory category.

Note 2: Reclaimed refrigerants are sold directly by licensed reclamation operators, who are also responsible for reporting the amount of reclamation to the government, in accordance with Japanese regulations.

into small cylinders, while “collection” involves the transportation and transfer to larger cylinders. “Processing” is used instead of “analysis” for terminological consistency, but it encompasses component analysis and classification for either reclamation or destruction. “Reclamation” is defined as the removal of impurities to restore the refrigerants to a reusable condition. These definitions align with current practices in Japan and Southeast Asia, and are used consistently throughout this manuscript. As of FY2019, the refrigerant recovery rate at the time of equipment disposal stood at approximately 38% (MOE, 2020), indicating a low level of compliance and efficiency. To address this issue, the MOE implemented a legal revision on April 1, 2020, strengthening mandatory recovery obligations for equipment owners and introducing penalties for failure to transfer recovered gas to authorized collectors. Additionally, enforcement measures by local governments were enhanced to improve compliance. As a result, by FY2022, the refrigerant recovery rate had increased to approximately 44% (MOE, 2024b).

Despite these measures, full recovery has yet to be achieved, necessitating further improvements. Key challenges include insufficient on-site leak management and difficulty in selecting appropriate recovery operators. In response, additional measures have been introduced, such as prohibiting the collection of equipment by waste and recycling businesses if proper refrigerant recovery is not verified. Furthermore, the development of alternative substances for refrigerants and stricter leak prevention measures for commercial refrigeration and air

conditioning systems are being promoted to reduce emissions.

3. Overview of RefNEXT Functions and Preliminary Implementation Examples

In Japan, the legal system governing fluorocarbon management is divided into three sectors: home appliances, automobiles and commercial equipment. RefNEXT was initially developed for use in the commercial equipment sector, where large quantities of refrigerants are handled and lifecycle traceability is institutionally required. While the current implementation is focused on this category, the system architecture is designed for flexibility, allowing for potential future expansion to home appliances and automotive applications. As noted earlier, Japan's refrigerant reclamation rate remains low. This reflects broader global challenges in achieving effective refrigerant lifecycle management. This section of the paper explores how RefNEXT addresses these challenges by enhancing traceability and stakeholder integration across the value chain. To address these issues, we developed the RefNEXT (Fig. 1) digital management platform to enhance traceability and optimize the recovery process. While Japan's Fluorocarbon Emissions Control Act mandates the recording and reporting of refrigerant transfers at each stage, these processes have largely remained paper-based and fragmented. RefNEXT addresses this gap by offering an integrated, digital platform that enhances traceability, reduces the reporting burden, and enables real-time data aggregation across stakeholders.

3.1 Enhanced Traceability

RefNEXT integrates key processes across the refrigerant lifecycle, such as filling, operation and maintenance (e.g., leak estimation based on process discrepancies), recovery, collection, processing, reclamation or destruction, reuse and refilling, into a

single digital management system. Traditionally, equipment manufacturers, contractors and equipment owners managed data separately, complicating efforts to track refrigerant locations and verify proper recovery or reuse.

With the implementation of RefNEXT in Japan, data from all stakeholders will be consolidated and instantly visualized. This improves transparency regarding refrigerant location and movement, reducing the risk of illegal disposal or improper treatment. Additionally, countries considering refrigerant inventory obligations, such as Indonesia and Vietnam, may leverage this framework to strengthen their regulatory measures.

3.2 Leak Rate Monitoring

RefNEXT enables quantitative tracking of refrigerant leakage, which directly impacts greenhouse gas emissions (Fig. 2, which shows the CFP (Carbon Footprint) associated with equipment manufacturers). By comparing data inputs from manufacturers, contractors and maintenance teams, potential leaks can be identified early (Fig. 3). In Japan, the Fluorocarbon Emissions Control Act requires equipment owners to keep annual records of refrigerant filling and recovery, and mandates that significant leakage be reported based on the difference between the two. RefNEXT's digital recording of annual refrigerant filling and recovery is designed to align with this mechanism. This alignment enables equipment owners to meet reporting requirements and monitor leak rates more efficiently.

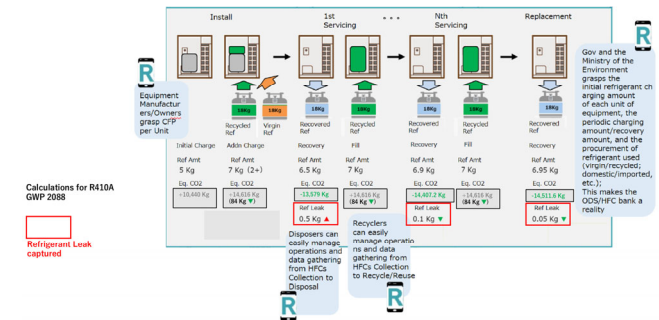


Fig. 2 Estimating refrigerant leakage via the filling–recovery gap. (prepared by the authors)

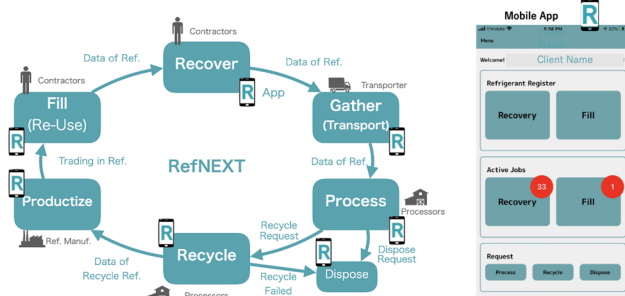


Fig. 1 Overview of RefNEXT. (prepared by the authors)

RefNEXT offers three key values:

1. Enhanced Traceability
2. Leak Rate Monitoring
3. Influence on Refrigerant Policies

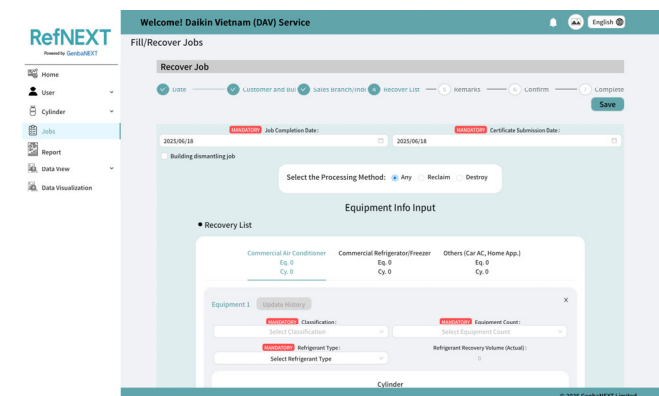


Fig. 3 RefNEXT Stakeholder input interface. (prepared by the authors)

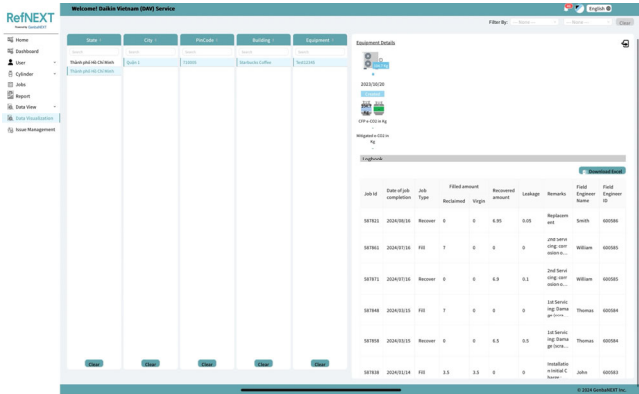


Fig. 4 Automated logbook for compliance, generation function (prepared by the authors)

Currently, logbooks for refrigerant management are mandatory in Japan and Europe, requiring detailed records of leakage volumes. Similar regulations are likely to be introduced in Southeast Asia, where RefNEXT could serve as a key compliance tool (Fig. 4).

4. Results and Discussion

4.1 Enhancement of Traceability

With the introduction of RefNEXT, traceability of refrigerant gases in Japan has improved significantly, reducing the risks of illegal emissions and improper disposal. As of FY2022, the refrigerant recovery rate at the time of disposal in Japan has reached 44% (MOE, 2024b), an increase from FY2019 (38%) (MOE, 2020). This improvement is primarily attributed to stricter legal enforcement and increased awareness among stakeholders. While still limited in scope, the early adoption of digital management platforms such as RefNEXT is also expected to contribute to further improvements in transparency and operational efficiency.

Full-scale refrigerant recovery has yet to be achieved, however, and further improvements are necessary. To achieve higher recovery rates, it is crucial to identify who is properly engaged in recovery efforts and who is not, ensuring transparency in the actual recovery process. The expansion of digital management platforms like RefNEXT is essential in achieving this goal.

In Indonesia and Vietnam, the governments are in the process of mandating refrigerant inventory reporting, but the actual management systems remain underdeveloped. In particular, Indonesia consumed approximately 16.6 million tons of CO₂-equivalent HFCs in 2019, highlighting the need for proper management (UNDP, 2021). Implementing systems like RefNEXT could enable accurate inventory tracking in these countries.

4.2 Leak Rate Monitoring

RefNEXT has facilitated the monitoring of discrepancies in refrigerant charging and recovery data at the equipment level, enabling the estimation of potential

leakage within specific operations. Separately, based on national reporting under the Fluorocarbon Emissions Control Act, Japan’s total refrigerant leakage in FY2021 was estimated to be 2.34 million tons of CO₂-equivalent (MOE, 2024a). While RefNEXT does not contribute directly to national-scale estimations, its alignment with the statutory methodology enhances local-level leak detection and compliance. While installation defects, pipeline degradation and operational inefficiencies are among the contributing factors, their specific impacts require further investigation. Continuous monitoring and documentation of leaks can help promote proper installation management and reinforce leakage prevention measures.

Logbook management has already been mandated in both Europe and Japan, and RefNEXT functions as a tool that meets these regulatory requirements. In the future, similar leak detection mandates may be introduced in Southeast Asia, where RefNEXT’s framework could provide significant support.

4.3 Policy Impact on Refrigerants

As discussed previously, RefNEXT may influence refrigerant policies by enabling lifecycle tracking and verification. As of 2024, Vietnam is advancing legislation to enhance HFC lifecycle management (CCAC, 2024), and policies recognizing refrigerant reclamation are gradually being adopted. Although RefNEXT has not directly driven these regulatory changes, its presence reinforces ongoing policy discussions.

While RefNEXT does not directly improve the reclamation rate, it enables end-to-end traceability of recovered refrigerants. This transparency allows stakeholders—including regulators and reclamation operators—to identify unprocessed recovered refrigerants and promote their entry into the reclamation process. In this way, RefNEXT contributes indirectly to improving reclamation outcomes by supporting better decision-making and operational intervention.

Additionally, carbon credit methodologies are evolving to include refrigerant reclamation alongside destruction, increasing the market value of reclaimed refrigerants. For instance, the ACR564 Tradewater HFC Reclamation project in the United States (Fig. 5) recovers and reuses HFCs to curb the demand for virgin HFC production and mitigate greenhouse gas emissions. Figure 5 provides an illustrative overview of such a project, rather than presenting quantitative evaluation results.

BBB	ACR564 Tradewater HFC Reclamation
B	ACR629 Hudson Tech HFC Reclamation Project Champaign 2020
B	ACR648 Hudson Tech HFC Reclamation Project 2020 - Georgia

Fig. 5 Example of a carbon credit project related to refrigerant reclamation. (BeZero Carbon Ltd., 2024)

Thus, fluorinated gases are not merely waste; with rigorous management, they can be utilized as “recyclable resources.”

This shift has the potential to shape a new regulatory framework for environmental policies, particularly those supporting refrigerant reclamation, lifecycle tracking and carbon credit certification. For example, Vietnam is currently institutionalizing HFC lifecycle management, and carbon credit methodologies such as the ACR564 project now recognize reclamation as a viable emission reduction strategy. RefNEXT’s digital traceability enables verification mechanisms essential for such policy evolution.

While some carbon credit methodologies, such as South Korea’s scheme, allow credits for refrigerant reclamation, international consensus on this practice remains limited. Under the Paris Agreement, reclamation is often criticized for lacking “permanence,” as reclaimed refrigerants may eventually be emitted. Methodological discussions are still evolving, and currently, Japan does not recognize reclamation as an eligible reduction activity for carbon credits. Regardless of these debates, RefNEXT can contribute significantly by enhancing MRV (measurement, reporting and verification) processes and enabling data-driven lifecycle management. Moreover, by preventing leaks and reducing refrigerant losses, RefNEXT also benefits equipment owners through decreased refrigerant consumption.

5. Conclusions

This study has examined the role of RefNEXT in realizing a circular society for refrigerant gases, demonstrating its effectiveness from three perspectives: enhancing traceability, monitoring leak rates and influencing policies.

First, enhanced traceability in Japan has led to improved visibility of refrigerant stocks and distribution routes, reducing the risks of illegal emissions and improper disposal. In particular, the adoption of digital management platforms has proven effective in identifying who is properly engaged in recovery efforts and who is not, ensuring a transparent recovery process. Implementing similar systems in Indonesia and Vietnam could enable more accurate inventory management.

Second, leak rate monitoring has been confirmed as a valuable tool for promoting proper installation management and strengthening leakage prevention measures. In Japan, the estimated refrigerant leakage in FY2021 was 2.34 million tons of CO₂-equivalent (MOE, 2024a), with installation defects and pipeline degradation identified as contributing factors. Leveraging systems like RefNEXT for continuous monitoring can facilitate early leak detection and appropriate countermeasures. Logbook management is already mandatory in both Japan and Europe, and similar regulations on leak detection may be

introduced in Southeast Asia in the future.

Third, regarding policy impact, Vietnam is advancing legislation to strengthen HFC lifecycle management, gradually adopting policies that recognize refrigerant reclamation. Additionally, carbon credit methodologies are evolving to include reclamation alongside destruction, altering the market value of refrigerant gases. This indicates that refrigerants are no longer merely considered waste but can be utilized as “recyclable resources” through proper management, potentially reshaping environmental regulatory frameworks. The widespread adoption of RefNEXT could accelerate this policy shift.

Future Perspectives

While this study has analyzed RefNEXT’s impact on the circular economy for refrigerant gases, several key issues remain for future investigation, including regulatory adaptation, system scalability and cost-effectiveness analysis.

1. Pilot implementation in Southeast Asia: As of now, RefNEXT has been implemented only in Japan. Further testing and adaptation in Southeast Asian countries are required to align with local regulations and industry structures.
2. Measuring the impact on recovery rates: Further empirical studies are needed to quantify the extent to which RefNEXT contributes to improving refrigerant recovery rates.
3. Real-time leak detection: Current leak monitoring relies primarily on data discrepancies during charging and recovery. The potential application of IoT technology for real-time leakage monitoring should be explored.

Effective refrigerant management and circulation will play a crucial role in achieving environmental sustainability. Through the continued development and widespread adoption of RefNEXT, further optimization of refrigerant management is expected.

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With a background in engineering and technology management, he is developing businesses integrating on-site operations with digital technologies. He emphasizes open innovation and co-creation with major air conditioning manufacturers.



Ashish BUSI

Ashish Busi is the founder of GenbaNEXT and a key motivator behind the development and global expansion of the digital management platform “RefNEXT” for refrigerant management and circular economy. He graduated from the Indian Institute of Technology (IIT) and has extensive

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Dr. Shirasaka is a professor and Dean of the Keio University Graduate School of System Design and Management (SDM).

He earned his Master’s degree in Aerospace Engineering from the University of Tokyo. During his tenure at Mitsubishi Electric Corporation, he contributed to multiple space development projects, including the Engineering Test Satellite VII (ETS-VII) and the H-II Transfer Vehicle (HTV) for the International Space Station. His contributions to the HTV “Kounotori” project, from initial design to its first mission, earned him numerous awards. As a program manager for Japan’s ImPACT program, he led the development of a small Synthetic Aperture Radar (SAR) satellite. Since 2004, he has taught Systems Engineering at Keio University, becoming a professor in 2017 and Dean of SDM in 2023.

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