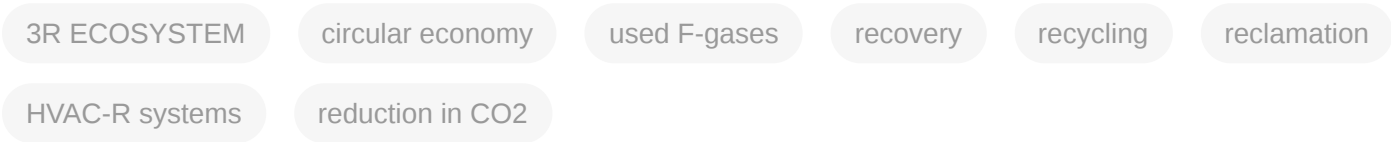# Recycling and Reuse ECOSYSTEM

Subjects: Engineering, Environmental

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Daikin Europe N.V. (DENV), Daikin Central Europe (DACE), the National Technical University of Athens (NTUA) and the Society for Materials and Energy Applications (MAT4NRG GmbH) are the four partners of the consortium behind the Retradeables project that receives EU funding. The key objective of the ongoing project is to realise the first circular economy ecosystem to strongly promote the efficient management of used gases, offering sustainability and accountability to the HVAC-R industry and reducing environmental pollution stemming from F-gas emissions. This is exactly the mission of the so-called "3R ECOSYSTEM" that is currently under development to bring total innovation to the HVAC-R industry, adding value to used refrigerants that will be treated as an asset instead of a waste to be destroyed.

3R ECOSYSTEM   circular economy   used F-gases   recovery   recycling   reclamation

HVAC-R systems   reduction in CO2

1. Innovative Aspects

The final version of the 3R ECOSYSTEM will consist of three main components: (i) a self-certification/self-declaration platform, (ii) the F-gas identification and recycling units (prototypes) and (iii) the "Retradeables" marketplace platform (**Figure 1**). This circular economy scheme is considered to incorporate all the necessary framework and tools to provide a sustainable market-wide solution for:
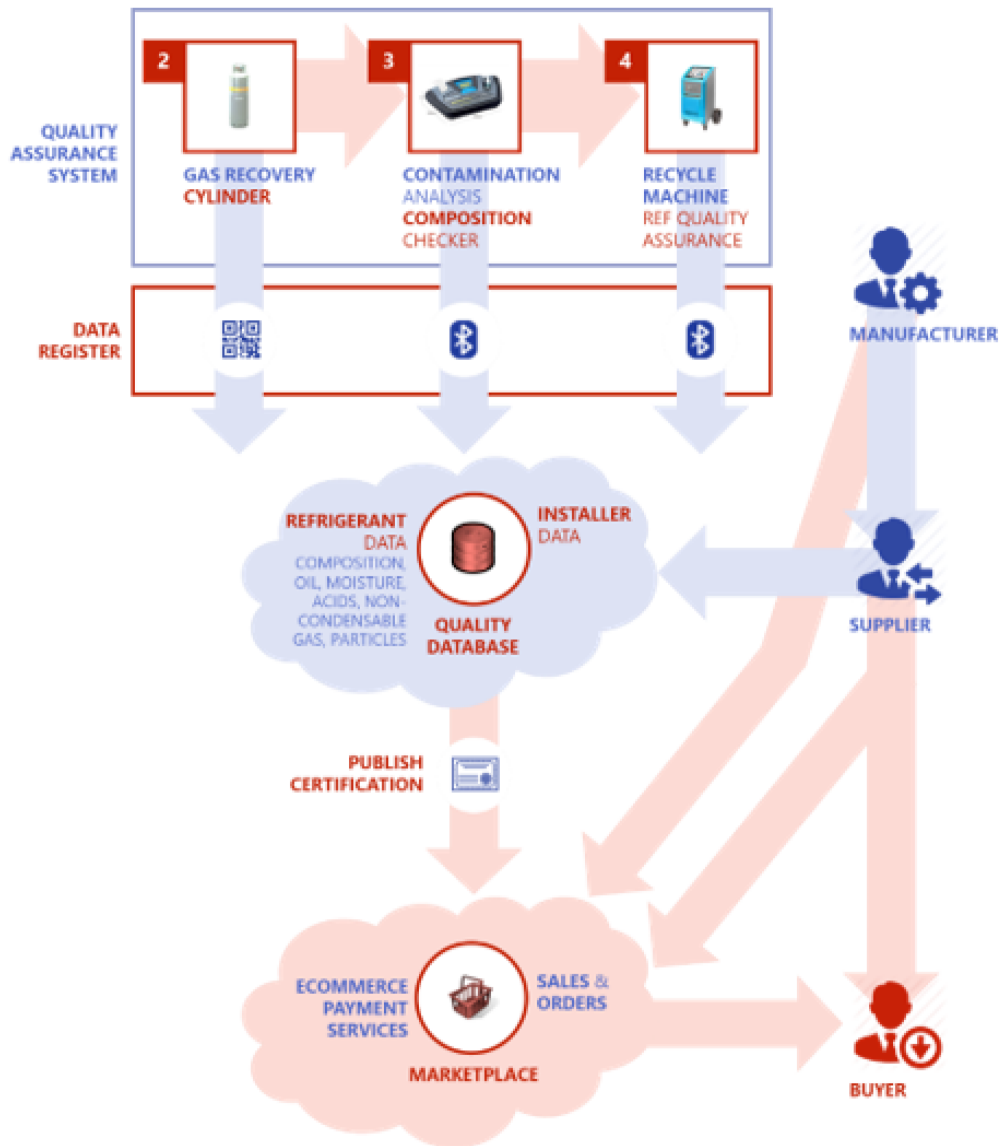
Figure 1. Overview of the "3R ECOSYSTEM" structure after the final implementation.

- The alternative management of used F-gases at the end-of-life of HVAC-R systems by enabling the recovery of all refrigerants in the installed base. The two possible options are then either reuse through recycling/reclamation or appropriate disposal (if reuse is not possible). For this purpose, three F-gas quality grades have been specified [1]:

  ○ A-grade refrigerants that can be recycled via a recycling machine and reused.

  ○ B-grade refrigerants that must be reclaimed in a distillation factory.

  ○ C-grade refrigerants that are contaminated to such an extent that they require destruction by certified means.

- The establishment of an online high-end marketplace to connect the relevant parties interested in trading their own recovered F-gases. The transparency and traceability of the transaction (price included) is regarded as an absolutely innovative aspect, as there is currently no fixed price index for recycled/reclaimed F-gases. Indeed, the Retradeables marketplace is intended to act like the stock market. This means that demand and supply are analysed and average prices for traded F-gases are displayed to all participants.

The very basic operating principles and other critical aspects of each of the three components of the 3R ECOSYSTEM are outlined below.

2. Self-Certification/Self-Declaration Platform

The self-certification/self-declaration platform will serve as a powerful tool to redefine the recent classification of existing refrigerants as "hazardous waste" by involving stakeholders (mainly installers) to implement the proposed methodology and input all necessary data on the recovery process in real time and on site. This approach will lead to a smoother transition towards a more easily regulated F-gas market driven by the HFC phase-down and create a value proposition for recovered F-gases. In particular, there are two possible practices for the evaluation of the F-gas quality grade (A/B/C grade):

- Self-assessment: making use of the HVAC-R unit's logbook. This is the current practice applied by F-gas technicians (self-declaration schemes).

- Measurement: making use of the HVAC-R unit's logbook in combination with the initial analysis results of the portable composition analyser. This is the intended practice (self-declaration and self-certification schemes).

Overall, the integrated self-declaration and self-certification schemes are expected to play a critical role in establishing a reliable and efficient HVAC-R circular economy by operating an accurate database and eliminating low-quality recycled refrigerants from the market.

Database Design and Development

Given that easy access to the self-certification/self-declaration platform is a key factor, the definition and categorisation of all individual parameters considered as data entries have already been defined. These are related to the client, the HVAC-R unit, the extraction location and date, as well as the F-gas quantity and quality (A/B/C grade). The structure and architecture of the platform also includes filtering, constraints, mandatory fields and other features to further improve the user experience, as well as facilitate administrator supervision.

The administrator of the database will be a third party. All necessary tables have been provided to ensure the traceability of all F-gas quantities during the recovery, composition analysis, data logging and reuse activities [2]. In addition, a separate index value will be assigned to each registered user. This index value will be regularly updated

based on a wide range of quantitative and qualitative criteria, such as accuracy on the F-gas quality statement, uploading (or not) of composition analysis results and on-time delivery.

Finally, field installers (technicians) will be responsible for printing QR codes and placing them on both the installed HVAC-R unit and the recovery bottle(s)/cylinder(s) to be used. This can be justified by the fact that the relevant data will be inserted into the database via scanning the individual QR codes with a smartphone camera. A QR code scanner application has already been developed for this purpose.

3. F-Gas Identification and Recycling Units

The F-gas identification and recycling units (prototypes) under development have been designed to serve as a total solution by combining a portable refrigerant composition analyser with a recovery and recycling unit, both applicable in pure HFCs, such as R32 or R134a, and HFC blends, such as R410A, R407C and R404A. Thanks to the prototypes, F-gas stakeholders (mainly installers) will be able to determine the composition of the recovered F-gas, categorise it by quality and also remove oil and moisture from it, all in real time and on site. The two key components of the prototypes are briefly described below:

- Portable refrigerant composition analyser: Devices of this type are currently commercially available from various manufacturers for determining the purity of recovered F-gases in the HVAC-R market. However, laboratory testing is being conducted under the Retradeables project with the ultimate goal of producing a similar product but with more advanced operating characteristics to provide more detailed F-gas composition analysis data, including oil and moisture contamination rates. Consequently, two different approaches will be utilised in combination: one incorporating existing state-of-the-art measurement devices (classic composition analysers) and the other one based on time series analysis of specific thermodynamic parameters (advanced product under development).

- Recovery and recycling unit: Such a unit is now marketable from DENV, one of the key partners involved in the Retradeables project. It is easy to use and can be connected directly or via a recovery pump to the installed HVAC-R equipment. After connecting the cylinder(s), the F-gas recovery and recycling process is automatic. The advantageous feature of this device is the maximisation of the recovered F-gas quality through the three-step recycling mode applied to remove the majority of impurities [3]:

  - Oil separation and electrostatic filtering.

  - Filter drier to remove moisture.

  - Liquid separation via evaporation.

All in all, the use of the prototype in the field is expected to have a very positive impact on installers, as the relevant process flow will be significantly simplified over the current practice, while the corresponding outcomes will also

appear much more upgraded and accurate. During the last stage of the development of the prototype unit, the recovery and recycling machine will be coupled with Internet of Things (IoT) equipment as an extra feature to enable automatic data upload to the operating database [4][5]. Once the prototype is equipped with the detachable IoT device under development, the final implementation will be tested in the lab and in the field to verify proper data flow. The F-gas identification and recycling IoT unit is then supposed to come onto the European HVAC-R market for sale.

Intercomparison Tests, Validity of Measurements and Performance of the Equipment

Balancing accuracy and precision with the main cost factors (e.g., equipment costs, labour costs, equipment/analyst maintenance) is considered of paramount importance to produce reliable and affordable results. Under this assumption, MAT4NRG GmbH is currently conducting a series of intercomparison tests between the selected analyser and the AHRI 700 Standard Reference Method [6] with respect to all target categories of sampled F-gases and each critical measured substance (oil, moisture, solids, etc.). The findings from this task are needed to confirm the validity of the measurements of the proposed portable analyser [7]. The performance of the recovery and recycling unit in removing oil and moisture will also be verified by measuring the oil and moisture content before and after removal. Final testing will take place when the prototypes are ready for use to determine whether their overall performance is satisfactory enough.

4. Retradeables Marketplace Platform

The Retradeables platform is actually the first European online marketplace to support the reliable trading of used F-gases between the various HVAC-R stakeholders, powered by well-defined legal frameworks and secure payment methods. The supply side (sellers) is represented by installers/installation companies, service companies and partner networks that have access to refrigerant through small, medium or large installations. Likewise, the demand side (buyers) is represented by gas distributors/distribution companies and gas producers. Therefore, the former parties can benefit from an additional revenue and cost reduction stream, while the latter parties can increase the amount of recovered product they receive from the F-gas market, thus easing the pressure on their quota of virgin refrigerant.

Development of the Platform

The Retradeables marketplace was officially launched in May 2021, even before the start of the three demos (SK, HU, CZ) in July 2021. Moreover, it is now considered to be a fully operational platform where all local stakeholders can register online [8]. Built on state-of-the-art technology to provide best performance and ease of use, the Retradeables marketplace supports seamless process flows, including a number of functionalities as outlined below [9][10]:

- Registration with legal check (F-gas certificate).

- F-gas recovery data input (at the location of the customer).

- F-gas quality documentation before and after recycling/reclamation (at the location of the customer).

- F-gas stock management.

- Supply and demand management, including aggregation of average prices on the market.

- Selling of used F-gas (supply side).

- Buying of used F-gas (demand side).

- Transactions between installers/installation companies and distributor/distribution companies, including price offers and secure payment methods.

- Data processing and information generation that are currently not accessible, as there is no mechanism/platform to support the collection and configuration of data directly at the time of input.

From the general setup and architecture to the final solution, the Retradeables marketplace is based on the "Plan Do Check Act" cycle which is an iterative four-step management method used in business for the control and continuous improvement of processes and products. This indicates that the platform will be monitored on a regular basis throughout the demos in order to be appropriately customised and enriched with new features according to additional requirements arising from different users.

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