



ENOUGH

EUROPEAN FOOD CHAIN SUPPLY
TO REDUCE GHG EMISSIONS BY 2050

PROJECT ACRONYM	ENOUGH
PROJECT TITLE	European Food Chain Supply to reduce GHG emissions by 2050
PROJECT COORDINATOR	SINTEF OCEAN
PROJECT DURATION	2021-2025

D6.13

Report summarising proposals sent to the open call and the ongoing projects analysis

PROJECT NO: 101036588

TYPE OF ACTION: IA (INNOVATION ACTION)

CALL: H2020-LC-GD-2020-4



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036588

DOCUMENT INFORMATION

DELIVERABLE NO.	D6.13 Report summarising proposals sent to the open call and the ongoing projects analysis
DISSEMINATION LEVEL	Public
WORK PACKAGE	WP6
TASK	T6.8 Open Call
LEAD BENEFICIARY	SO
CONTRIBUTING BENEFICIARY(IES)	CNR, LSBU
DUE DATE OF DELIVERABLE	31.07.2025
ACTUAL SUBMISSION DATE	29.09.2025

DOCUMENT HISTORY

Version	DATE	CHANGE HISTORY	AUTHOR	BENEFICIARY
1.0	22.09.2025		Kristina N. Widell	SO

QUALITY ASSURANCE, STATUS OF DELIVERABLE

ACTION	PERFORMED BY	DATE
Reviewed	Hanne Dalsvåg (SO), Silvia Minetto (CNR), Robin Campbell (LSBU)	25.09.2025
Approved	Silvia Minetto (CNR)	25.09.2025
Uploaded to SyGMa	Kristina N. Widell (SO)	29.09.2025

TABLE OF CONTENTS

1	Task and deliverable description.....	5
2	Sectors and topics included in the demonstrators	5
3	Original demonstrators	7
4	Selected new demonstrators in 2022	10
5	Selected new demonstrators in 2023	11
6	Ongoing projects analysis.....	12

EXECUTIVE SUMMARY

This report provides an overview of the activities in the task Management for new demonstrators (task 6.8). The objective of this task was to describe and include new demonstrators in the project, ensuring that a larger part of the cold chain and more sectors are covered. Both the process for selecting and the selected new demonstrators were described in several confidential deliverables. This deliverable is public as is several others which are available on the [ENOUGH](#) website.

The original demonstrators that were included from the beginning were:

- D1. Advanced Integrated Control
- D2. Dairy Norway
- D3. Dairy Austria
- D4. Dairy UK
- D5. Energy-efficient Dynamic Controlled Atmosphere (DCA)
- D6. Climate Neutral Packaging
- D7. Fresh and Green Delivery
- D8. TES Last Mile Delivery
- D9. DSR and TES
- D10. Future Retail Display
- D11. Thermal Storage
- D12. Long-term Food Storage
- D13. Next-generation Household Refrigerator
- D14. Osnabrück4.0 HTHP

Four new demonstrators were approved in 2022 and included after an amendment to the grant agreement in September 2022:

- D15. Brine Freezing for Fish
- D16. Heat Reclaim in Cold Storage
- D17. Superchilling for Meat and Fish
- D18. Blast Freezing with CO₂

Another three demonstrators were included in the project in 2023 (amendment approved December 2023):

- D19. CO₂ Pressure Exchanger
- D20. CO₂ Plate Freezer
- D21. Food Loss and Waste Mapping

As part of ENOUGH, an analysis of ongoing projects was carried out to identify opportunities for new demonstrators. This approach enabled the consortium to build on existing initiatives, secure a diverse set of demonstrators across the cold chain, and create a strong foundation for follow-up projects. The work has not only supported the project's immediate goals but also positioned the consortium for long-term impact. Strategic impact of this work includes:

- Establishing a pipeline of new projects at national, European, and international levels
- Accelerating the uptake of innovative technologies and methods developed in ENOUGH
- Strengthening collaboration within the consortium and with external partners
- Enhancing visibility and credibility with funding bodies, industry, and policymakers
- Supporting the transition to sustainable and climate-neutral food systems by 2050

Deliverable 6.13

1 TASK AND DELIVERABLE DESCRIPTION

The overall objective of WP6 in ENOUGH is to demonstrate promising technologies and improve their performance in real-life situations. In the grant preparation phase, several demonstrators were identified. These considered the supply chain of four specific product categories (meat, fish, fruit & vegetables, dairy) and three cross-sector areas (transport, retail and domestic). Although these encompass a large sector of the food cold chain in Europe, we proposed to add additional demonstrators to cover both existing and new areas for the ENOUGH project.

To support this, several activities have now been completed:

- A review of ongoing projects with similar objectives to ENOUGH was conducted. This included projects involving ENOUGH partners, sister projects funded under the same call, and other related initiatives. The review identified several ongoing and completed projects working on similar topics, and helped inform the selection of new demonstrators.
- Two open calls for new demonstrators were carried out, targeting both the sectors already specified and additional areas not originally included.
- Alignment of new demonstrators with existing ones was undertaken to ensure optimal implementation and maximise impact.

All demonstrators selected through this process showed potential for reducing GHG emissions, and the technologies and methods involved are considered transferrable to other industries, companies, or sectors. The active involvement of industry partners has been essential throughout.

This report summarises the outcomes of the addition of new demonstrators. For more results from the different demonstrators, find reports and papers at the project website: <https://enough-emissions.eu/>

2 SECTORS AND TOPICS INCLUDED IN THE DEMONSTRATORS

At the beginning of the project, 14 demonstrators were included, they are listed in the executive summary, briefly described in section 3 and shown in Figure 1.

	Meat 	Fish 	Dairy 	Fruit & veg. 	Other
Processing 	D14		D2, D3, D4		D1
Transport 	D7, D8			D6	
Storage & Retail 	D9, D10, D11			D5	
Domestic 	D12, D13				

Figure 1. Placement of the first 14 demonstrators within the food value chain (processing, transport, storage & retail, domestic) and their distribution across different sectors (meat, fish, dairy, fruit&veg, other).

The procedure we used when selecting new demonstrators involved defining clear objectives for the demonstrators, applying selection criteria that supported the project’s overall goals, and ensuring good coverage of relevant products and sectors. We prioritised technologies that had not been previously demonstrated and required participation from at least one partner to promote integration and knowledge sharing. All WP6 task leaders took part in the assessment group, and the process included clear rules for proposal calls, collaboration with WP11 for ongoing project analysis, awarding criteria, and documentation requirements for applicants. Adding new demonstrators required an amendment to the project, including an updated description of the new demonstrators and corresponding changes in the budget.

After the first call for demonstrators and consequent amendment (September 2022), 4 more demonstrators were added (Figure 2), mainly covering fish (D15, D18) and meat processing (D17), which were underrepresented before. Heat reclaim (D16) was also applied to large storage facilities, being a technology that can be easily transferred to other sectors such as processing of all products.

	Meat 	Fish 	Dairy 	Fruit & veg. 	Other
Processing 	D14	D15, D18	D2, D3, D4		D1
Transport 	D7, D8			D6	
Storage & Retail 	D9, D10, D11, D16			D5	
Domestic 	D17	D12, D13			

Figure 2. Updated overview of the demonstrators’ placement within the food value chain and sectors, including the four newly added demonstrators.

During the 3rd call (31st January 2023) the team mainly concentrated on other products and sectors: D21 is addressing food loss and waste, which is relevant for all sectors and products; An additional retail demonstrator was also foreseen, which widens the offer of energy efficient and NWF (natural working fluids) based solutions for the sector. This is especially relevant as retail is now acting as a

leading sector in long-term sustainable NWF solutions for the food sector. After the second amendment (in 2023), three more demonstrators (D19-21) were added, shown in Figure 3.

	Meat 	Fish 	Dairy 	Fruit & veg. 	Other
Processing 	D14	D15, D18, D20	D2, D3, D4		D1 D21
Transport 	D7, D8			D6	
Storage & Retail 	D9, D10, D11, D16, D19			D5	
Domestic 	D17	D12, D13			

Figure 3. Updated overview of the demonstrators' placement within the food value chain and sectors, including the three newly added demonstrators.

At present, fruit and vegetable processing appears to be underrepresented. However, processing for these products—primarily chilling—is largely associated with storage, which is where it is reflected in the graphics. Technologies demonstrated in other cases (D14, D18) are also readily transferable to fruit and vegetable processing.

3 ORIGINAL DEMONSTRATORS

3.1 DEMO 1 – Advanced Integrated Control (All Sectors)

Demo 1 served as a collaborative platform where researchers from the various demonstrators came together to explore and experiment with new possibilities for holistic and systemic value creation, going beyond their individual breakthroughs. Demonstrators 3 (“HTHP Dairy Austria”), 5 (“Energy-efficient dynamic controlled atmosphere (DCA)”), and 11 (“Thermal storage unit for refrigeration cycle”) participated to provide concrete examples and contribute to a feasibility study. In addition, Demo 1 functioned as the testing ground for the technological and business framework developed within WP5 (Smart Data Systems – SDS). - Università Politecnica delle Marche led the work, involving PREMA, TU Graz, KU Leuven, and others.

3.2 DEMO 2 – Energy smart dairy Norway

This demonstrator mapped and optimised the CO₂-based thermal energy system at the Norwegian dairy Rørosmeieriet to reduce specific energy consumption by ~36% and assess cold thermal energy storage for increased flexibility and robustness. SINTEF Ocean, NTNU, and Rørosmeieriet monitored energy flows in key heating and cooling devices to enhance energy efficiency. They also investigated advantages with thermal storage solutions to support load shifting and significantly reduce peak power demand.

3.3 DEMO 3 – HTHP Integration in an Austrian Dairy

TU Graz, EQUANS, and the Austrian dairy Ennstal Milch demonstrated a high-temperature heat pump (HTHP) as a heat source for the cleaning-in-place (CIP) system, using waste heat. They also explored supplying additional dairy processing steps with the HTHP, replacing steam with more efficient hot water systems. Operational strategies were developed based on measurements and simulations.

3.4 DEMO 4 – Thermal integration at a yoghurt dairy in UK

Demo 4 has delivered a new chilled water system at yoghurt producer Yeo Valley's Blagdon site. The ammonia chiller replaces HFC chillers. The rejected heat from the chiller is used to preheat milk prior to pasteurisation, reducing natural gas use. The rejected heat is stored in a 40m³ tank allowing for future expansion to the rejected heat use. Yeo Valley and London South Bank University (LSBU) have worked together in this demonstrator.

3.5 DEMO 5 – Energy-efficient Dynamic Controlled Atmosphere (Fruit & Vegetables)

Demo 5 demonstrated an energy-efficient Dynamic Controlled Atmosphere (DCA) technology for long-term storage of Conference pears. By continuously adjusting oxygen levels in commercial cold rooms, DCA minimised fruit respiration and ripening, helping to maintain quality and reduce food losses. Compared to conventional ultra-low oxygen storage, DCA resulted in lower energy use for cooling while preserving fruit quality more effectively. KU Leuven, VCBT, and Optiflux collaborated in this demonstrator.

3.6 DEMO 6 – Climate Neutral Packaging (Fruit & Vegetables)

Demo 6 tested climate-neutral packaging for soft fruits, using bio-sourced materials to extend shelf life and reduce carbon footprint. While sustainable packaging helps cut plastic waste, it can sometimes increase fruit losses for highly perishable produce. The demonstration evaluated different packaging options for blueberries and strawberries, assessing their impact on shelf life and fruit quality. KU Leuven, VCBT and INRAE collaborated in this demonstrator.

3.7 DEMO 7 – Fresh and Green Delivery (Transport)

Demo 7, "Fresh and Green Delivery," aimed to reduce the carbon footprint of refrigerated road transport by integrating a CO₂-based cooling unit and rooftop solar panels into a medium-sized delivery van for fresh food. Using natural refrigerants eliminated emissions associated with synthetic alternatives, while advanced components and a specially developed ejector improved system efficiency and reduced energy use. The addition of photovoltaic panels further decreased primary energy consumption by supplying electricity during daytime deliveries. Involved in this demonstrator were CNR and ENEX.

3.8 DEMO 8 – TES Last Mile Delivery (Transport)

This demonstrator addressed the growing need for efficient, temperature-controlled urban deliveries of perishable goods by demonstrating the use of thermal energy storage (TES) inside insulated boxes for frozen products. The TES, based on a eutectic solution cooled by a stationary propane unit, maintained the required temperature for over 12 hours without an active refrigeration system on the vehicle. This approach reduced greenhouse gas emissions, local pollution, and noise, while allowing flexible use of non-specialised vehicles for last-mile delivery. The system was tested with ambient temperatures up to 30°C, consistently keeping the internal temperature below -20°C and helping to preserve product quality throughout transport. CNR led the activities in this demonstrator.

3.9 DEMO 9 – Thermal energy store (TES) and Demand Side Response (DSR) in supermarkets (Storage & Retail)

Demo 9 focused on optimising Demand Side Response (DSR) in a UK concept store, where supermarkets are incentivised to reduce electricity use during peak periods to lower grid CO₂ intensity. The demonstration tested a thermal energy storage (TES) system. By cooling water overnight and using it during peak times, the system improved efficiency and enabled practical retrofit to existing equipment, accelerating CO₂ emission reductions in supermarket refrigeration. LSBU led this demonstrator, with City contributing.

3.10 DEMO 10 – Future Retail Display (Storage & Retail)

This demonstrator focused on optimising an advanced refrigerated display cabinet using best available technologies, such as doors, short air curtains, proximity sensors, and reflective packaging. Traditional open-front cabinets rely on fan-driven air curtains to maintain product temperatures, but these can allow warm air to enter, especially as the air curtain length increases. By implementing short air curtains and other innovations, like overfed evaporator, the demonstrator aimed to reduce energy consumption and improve temperature control. LSBU led this demonstrator.

3.11 DEMO 11 – Thermal storage unit for refrigeration cycle (Storage & Retail)

Demo 11 combined two thermal energy storage technologies for refrigeration: the integrated Thermosiphon Thermal Accumulator (TTA) and a centralised Cold Thermal Energy Storage (CTES) unit. The TTA was tested under various operating conditions and consistently maintained product temperatures within regulatory limits, even during compressor shutdowns. The centralised CTES, using water as the phase change material, supported both food cooling and air conditioning with CO₂ as the working fluid. This approach enables significant load shifting, reduces the need for installed cooling capacity, and lowers capital costs. By connecting multiple supermarket cabinets to the CTES, food safety during power outages is improved, helping to reduce food waste and maintain cooling with minimal energy demand from emergency power sources. INRAE led this demonstrator.

3.12 DEMO 12 – Long-term Food Storage (Domestic)

This demo implemented vacuum-freezing in small-scale freeze-dryers. This modification reduced both freeze-drying time and energy demand, offering a more affordable solution for the long-term storage

of highly nutritious foods such as seasonal fruits and vegetables compared to standard market freezers. Involved partners were Silesian University of Technology and FrostX.

3.13 DEMO 13 – Next-generation Household Refrigerator (Domestic)

introduced innovative technologies and components to household refrigerators, including natural refrigerant blends (R290/R600a), an electronic expansion valve, a new defrost cycle, and advanced thermal insulation. These improvements significantly increased the refrigerator's efficiency, achieving an A energy class and up to 12% energy savings compared to the reference device. INRAE, LSBU and Arçelik (now named BEKO) participated in this demo.

3.14 DEMO 14 – 150°C ACHP for steam production

150 °C ACHP for Steam Production focused on utilising an absorption-compression high-temperature heat pump (ACHP) to generate hot water and steam for meat processing. The system enables surplus heat recovery, replaces fossil fuel boilers, and significantly reduces energy consumption. Lead: NTNU, participants: SINTEF Ocean.

4 SELECTED NEW DEMONSTRATORS IN 2022

The first call for new demonstrators had a deadline of 31st January 2022 and 5 suggestions were discussed in the initial phase, with WP6 leader Silvia Minetto and Task 6.8 leader and coordinator Kristina N. Widell.

4.1 DEMO 15 – Brine Freezing for Fish (Fish Sector)

This demonstration analysed the effect of using brine freezing for fish. Brine freezing of a single pelagic fish resulted in a freezing time from 4°C to -17°C within one hour. Partial brine freezing of pelagic fish showed the potential to reduce the industrial freezing time of 20 kg blocks by 50%, along with a 14% reduction in energy consumption. Similarly, brine freezing of whole salmon indicated the possibility of halving the freezing time. The partners involved in this demonstration were SINTEF Ocean, NTNU, and MMC First Process.

4.2 DEMO 16 – Refrigerated store heat advanced recovery (Storage and Retail)

Demo 16 addressed the significant quantities of waste heat generated by cold stores (both chilled and frozen) during refrigeration. While some heat is occasionally reclaimed for underfloor heating, most is not utilised, despite substantial on-site heating needs for offices, dehumidification, hot water, and other processes. A UK assessment found that large cold stores could provide over 400 MW of recoverable heat, much of it at usable temperatures. Currently, these heating demands are typically met with gas or electricity, even though around 40% of a cold store's energy use is for non-refrigeration purposes, with at least half related to heating. This demonstrator highlights the untapped potential for waste heat recovery in cold storage facilities. LSBU, City and STAR Refrigeration were involved in this demonstrator.

4.3 DEMO 17 – Superchilling for Meat and Fish (Meat Sector)

Superchilling is a promising method to reduce food waste and its environmental impact by extending product shelf life. By maintaining meat products just below their freezing point in a carefully controlled compartment at $-2^{\circ}\text{C} \pm 0.2^{\circ}\text{C}$ within a domestic refrigerator, superchilling offers a significant improvement in shelf life over traditional refrigeration. This demonstrator is led by INRAE, with ARÇELİK and LSBU as partners.

4.4 DEMO 18 – Blast Freezing with CO₂ (Fish Sector)

The blast freezer demonstrator showed that the technology using 100% use of natural refrigerants achieved a low evaporation temperature down to -50°C , which can improve food quality and reduce process time. Control technology demonstrated technical application limits close to the triple point, resulting in an improvement of energy efficiency of about 15% compared to single-stage HFC/HFO units. Partners that were involved in this demonstrator were CNR and ENEX.

5 SELECTED NEW DEMONSTRATORS IN 2023

The second call for new demonstrators had a deadline 31st January 2023 and 9 suggestions were discussed in the initial phase, with WP6 leader Silvia Minetto and Task 6.8 leader and coordinator Kristina N. Widell. Three out of nine were then advised to submit a proposal and an overview is provided in **Error! Reference source not found.** and the following sections. The drivers for the selection were the feasibility of implementation within the project's timeline, the potential for reducing GHG emissions, and a realistic budget. All the three demonstrators were approved and added to the project in the 2023 amendment (approved December 2023). With a total of 21 demonstrators, we have now satisfied the goal of 20 demonstrators planned for the project.

5.1 DEMO 19 – CO₂ Pressure Exchanger for Retail (Storage and Retail)

Demo 19 explored the use of a pressure exchanger (PX) to recover expansion work and improve the efficiency of vapour compression refrigeration systems using natural refrigerant CO₂ (R744) in retail applications. The goal was to advance the technology from TRL 6 to TRL 8. While pressure exchangers are commonly used in desalination with water, adapting them for closed-loop CO₂ refrigeration presents challenges, such as managing pressure losses and ensuring correct flow direction. This demonstrator aimed to address these challenges and demonstrate the potential performance benefits for food and beverage refrigeration equipment, documenting 15% average COP for the system with respect to baseline. EPTA led this demonstrator.

5.2 DEMO 20 – CO₂ Plate Freezer (Fish Sector)

The plate freezer demonstrator showed that the system exhibited significantly lower specific energy consumption compared to the baseline case operating at -40°C using a CO₂-NH₃ cascade system. It achieved reduction a 59% in energy consumption (kWh/kg) at -50°C compared to the baseline case. By decreasing the evaporation temperature from -36°C to -50°C , the freezing time was reduced by 43.2%. The demonstrator was led by NTNU and SINTEF Ocean contributed.

5.3 DEMO 21 – Food Loss and Waste Mapping (Dairy Sector – FLW Norway)

Demo 21 focused on designing and testing a conceptual digital tool for mapping food loss and waste (FLW), aiming to collect detailed data on waste categories, volumes, and underlying causes. The tool prioritised automation and digitalisation to minimise additional work for users. Developed in collaboration with the Municipality of Trondheim, REEN Control, and led by SINTEF Ocean, the project also supported the identification and implementation of FLW reduction measures.

6 ONGOING PROJECTS ANALYSIS

At the start of ENOUGH, it was essential to analyse ongoing initiatives to identify opportunities for new demonstrators. By leveraging the networks and contacts of the project partners, we were able to meet this goal successfully. The result was not only a sufficient number of demonstrators but also strong diversity across the value chain — covering the entire cold chain from farmgate to fork. This broad scope has been critical to ensuring that ENOUGH demonstrators reflect the real-world variety of food production, processing, transport, and consumption.

Added value of linking to ongoing projects:

- Enabled faster identification of relevant demonstrators without starting from scratch
- Ensured synergies with existing initiatives and avoided duplication of effort
- Strengthened partnerships by building on already established trust and collaboration

Lessons learned:

- Early engagement with partners' networks is key to securing a broad variety of demonstrators, to be able to finalise the results and innovations on time
- Flexibility in scope allowed us to include both small-scale pilots and larger industrial demonstrators
- A structured mapping process makes identification of demonstrators efficient

For a project like ENOUGH, it is equally important to secure continuity beyond its lifetime. The technologies, methods, and impacts developed must be carried forward through follow-up projects that allow scaling, refinement, and adaptation to new contexts. To this end, we have applied for several new projects, in some cases led by a single partner and in others involving multiple members of the consortium. These applications reflect different levels of ambition: some are focused on national implementation, others target broader European priorities, and still others explore international cooperation in new markets.

This forward-looking approach demonstrates the sustainability of ENOUGH's results. It shows that the project not only delivered during its active period but also created a platform for continued innovation, collaboration, and policy impact.

Strategic impact of this work:

- Positioned the consortium as a leading actor in sustainable food systems and cold chains in Europe
- Created a pipeline of projects to scale up ENOUGH's technologies and methods nationally, regionally, and globally
- Enhanced visibility and credibility towards funding bodies, industry, and policymakers

Below is a list of projects we have started on, building on ENOUGH's outcomes:

Title	start	end	financed by	coordinator	partners
Supershield	2023	2027	French National Research Agency	INRAE	French University partners
Sustainable Dairy	2025	2027	UKRI	LSBU	Yeo Valley LSBU
Energy efficiency in chicory root storage	2025	2029	VLAIO (Flemish government)	Practical Research Centre	KU Leuven & VCBT
Iceslurry @ RM	2025	2026	Regional research fund Norway	SINTEF Ocean	RM, Skala, SINTEF NTNU
CONNECT	2021	2023	Norwegian research council	SINTEF Ocean	
IPN REFRESHING	2025	2027	Norwegian research council	SINTEF	SINTEF, MMC, IceFresh, Hofseth+
COOLHEATDC	2025	2028	CETP2024	AIT	AIT, SINTEF Energy, SUT, Schneider Electric, Green Mountain, ATM
HybriGrowth	2024	2026	Norwegian research council	SINTEF Energy	Viken greenhouse

Below is a list of proposals we have sent, building on ENOUGH's outcomes:

Title	submitted	project start	financed by	coordinator	partners
Adapt food	2025	Q1 2026	FutureFoods (EU co-financed)	SINTEF Ocean	SINTEF, CNR, RISE, Fraunhofer, FH Joanneum
KSP Mat2050	2025	Q4 2025	RCN (Norwegian research council)	SINTEF Ocean	SINTEF, NTNU + Norwegian industry stakeholders
Africa Fresh	2025	TBD	UN CCAC	IIR	IIR, SINTEF, LSBU + African partner

We are also aware of additional projects and proposals within the consortium that are not currently included in this list. Furthermore, an extensive list of relevant projects was compiled at the beginning of the project, but it is not presented here.



enough-emissions.eu

Disclaimer: This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036588.

The sole responsibility for the content of this paper lies with the authors.

It does not necessarily reflect the opinion of the European Commission (EC).

The EC is not responsible for any use that may be made of the information it contains.

© ENOUGH. All rights reserved.

Any duplication or use of objects such as diagrams in other electronic or printed publications is not permitted without the author's agreement.