ENOUGH

EUROPEAN FOOD CHAIN SUPPLY TO REDUCE GHG EMISSIONS BY 2050

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Introduction to the ENOUGH project

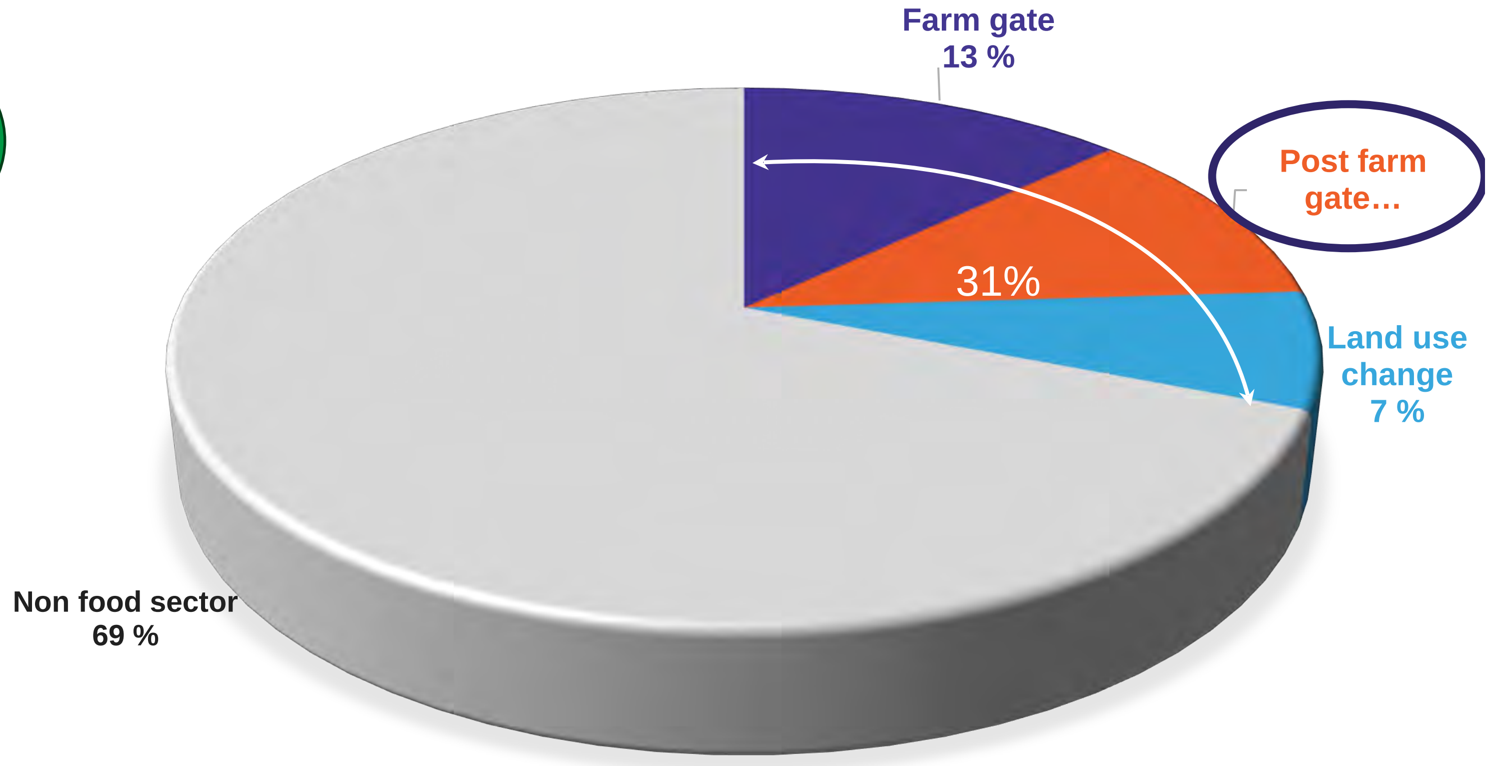
Hanne Dalsvåg

SINTEF Ocean

Demonstrator webinar
December 2023
Teams

ENOUGH: Decarbonising the food sector

1/3 of total GHG emissions related to food systems

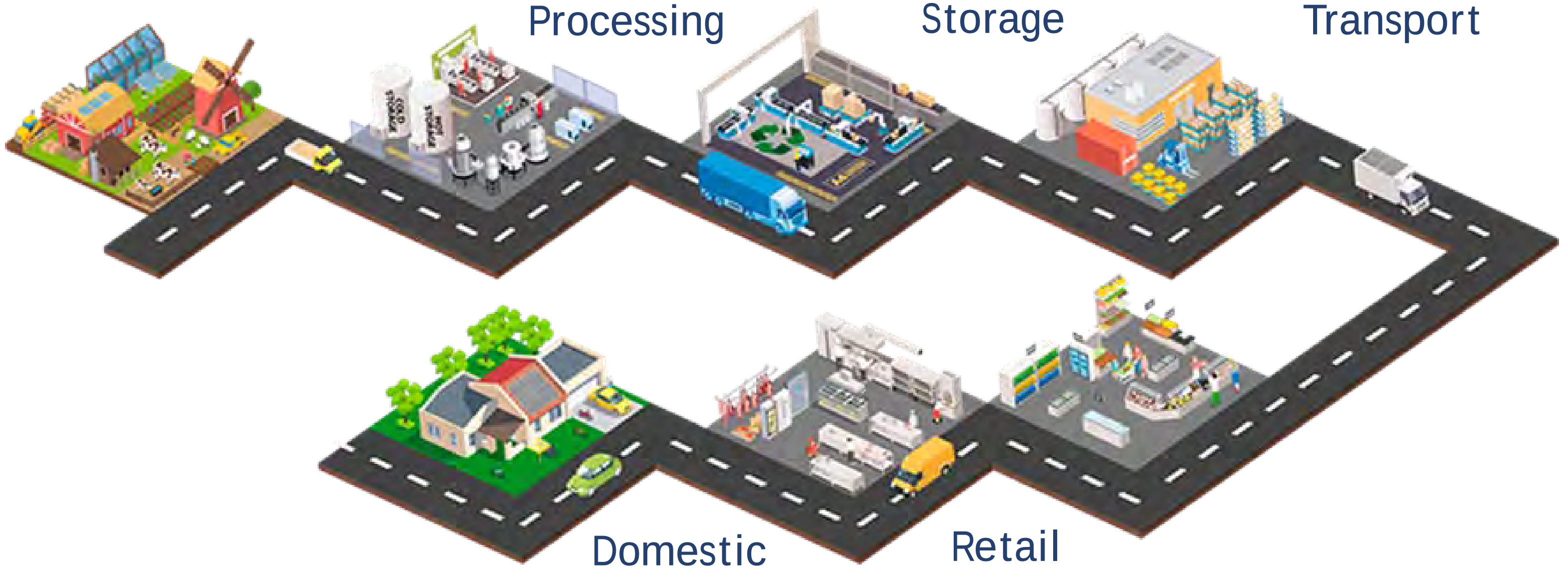


ENOUGH: Decarbonising the food sector

1/3 of total GHG emissions related to food systems

- Funded by the EU
- 4 year project within the EU Green Deal

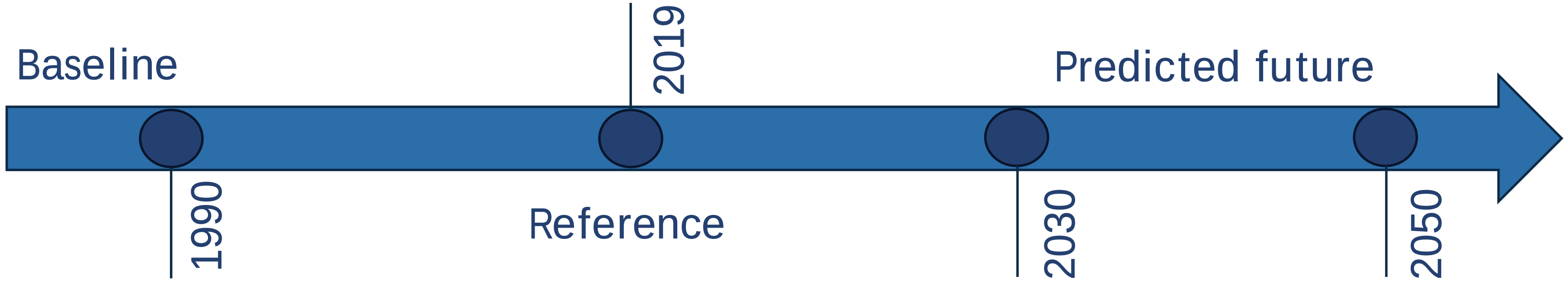
Goal: Reduce greenhouse gas emissions from the food supply chain
Aiming for a 55% reduction by 2030 and climate neutrality by 2050



Mapping and predicting GHG emissions

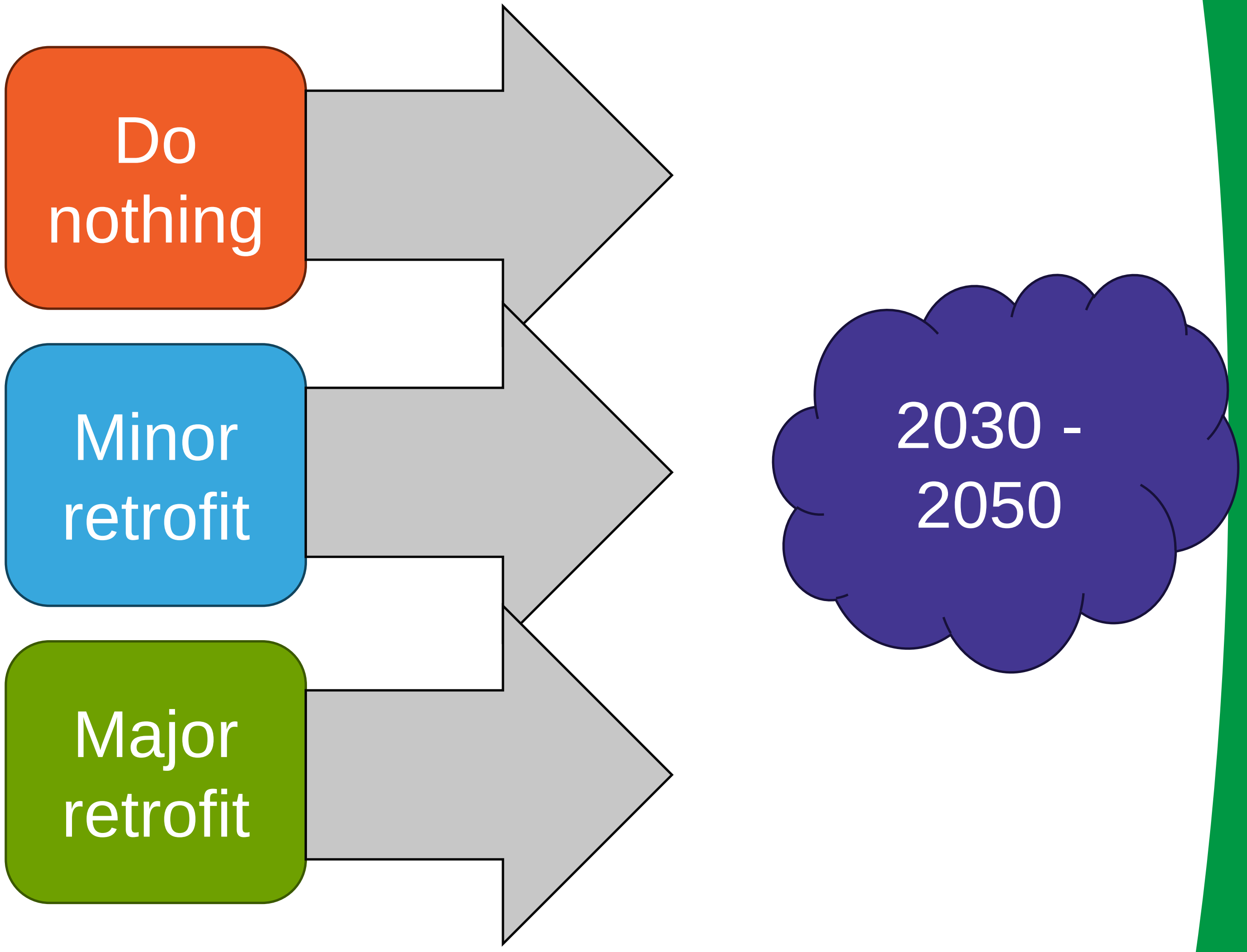
- Information available in data inventories – difficult to compare
- Models to quantify and calculate emissions in 1990, 2019, 2030, 2050
- Identify the sectors and technologies responsible for the majority of emissions
- Impact of future scenarios

We need to standardize data collection and availability



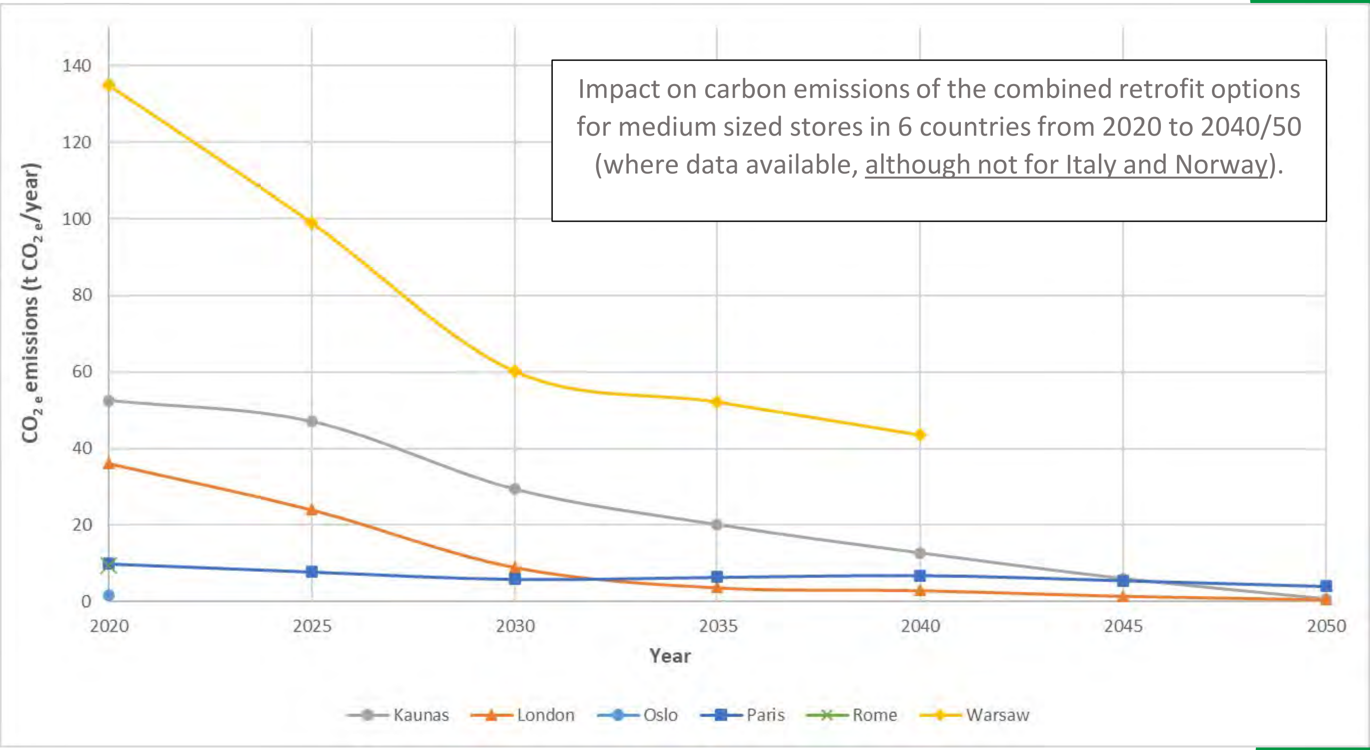
Technology roadmaps

- What is a roadmap?
- Technology reviews
- Modelling



Example: retail roadmap

- Review of 95 technologies
- 2 typical supermarket stores modelled
- 6 countries
  - Varied climatic conditions and grid carbon conversion factors
- Predicted energy savings from 55-94% and carbon emission reduction of 61-97%.



- Change to natural refrigerants
- Put doors on cabinets
- Energy efficient equipment

Calculation tools and smart data system

- Environmental impact of food chain is complex.
  - Calculation tools and smart data systems for decision making and evaluation
  - Should also be easily accessible for all
- ENOUGH tool evaluates emissions from food supply chain – identify the most critical point
- Combines quality and sustainability aspects at the same time

Only 3 steps

Select a product

Six main product categories have been considered: fruits, ready to eat meal, meat, fish, vegetable and milk products

Build the chain

Select every step, personalize them or just start with the reference chain for a first simulation

Simulate

Evaluate the evolution of quality, the energy consumption, compare your custom chain with the reference chain

Non-technological aspects

- Impact that non-technical issues have on energy consumption and emissions for food chain, including:
  - Financial requirements and business models
  - Public perception, social and behavioural barriers
  - Build upon the technological roadmaps
- Policy measures that concern the food value chain:
  - Food standards, industry and consumer initiatives
  - Policy measures and alternative road maps of policy actions
  - Policy recommendations and strategy advice for governments on how to reach zero emissions by 2050

At the core of the ENOUGH project is the demonstration of promising technologies to provide food companies tools, knowlede and evidence to reduce emission and improve energy efficiency

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 101036588

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THANK YOU !

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WP6 objectives

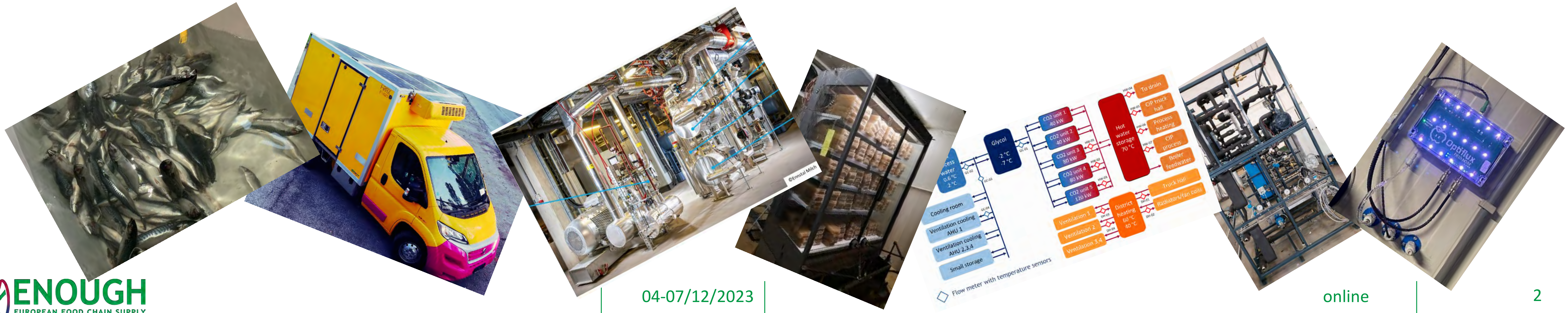
“Demonstrate **promising** **technologies** and **improve** their performance in **real-life situations”**

Relevant and viable TRL5-7 decarbonisation technologies

Real-life

Adapt, integrate, Improve

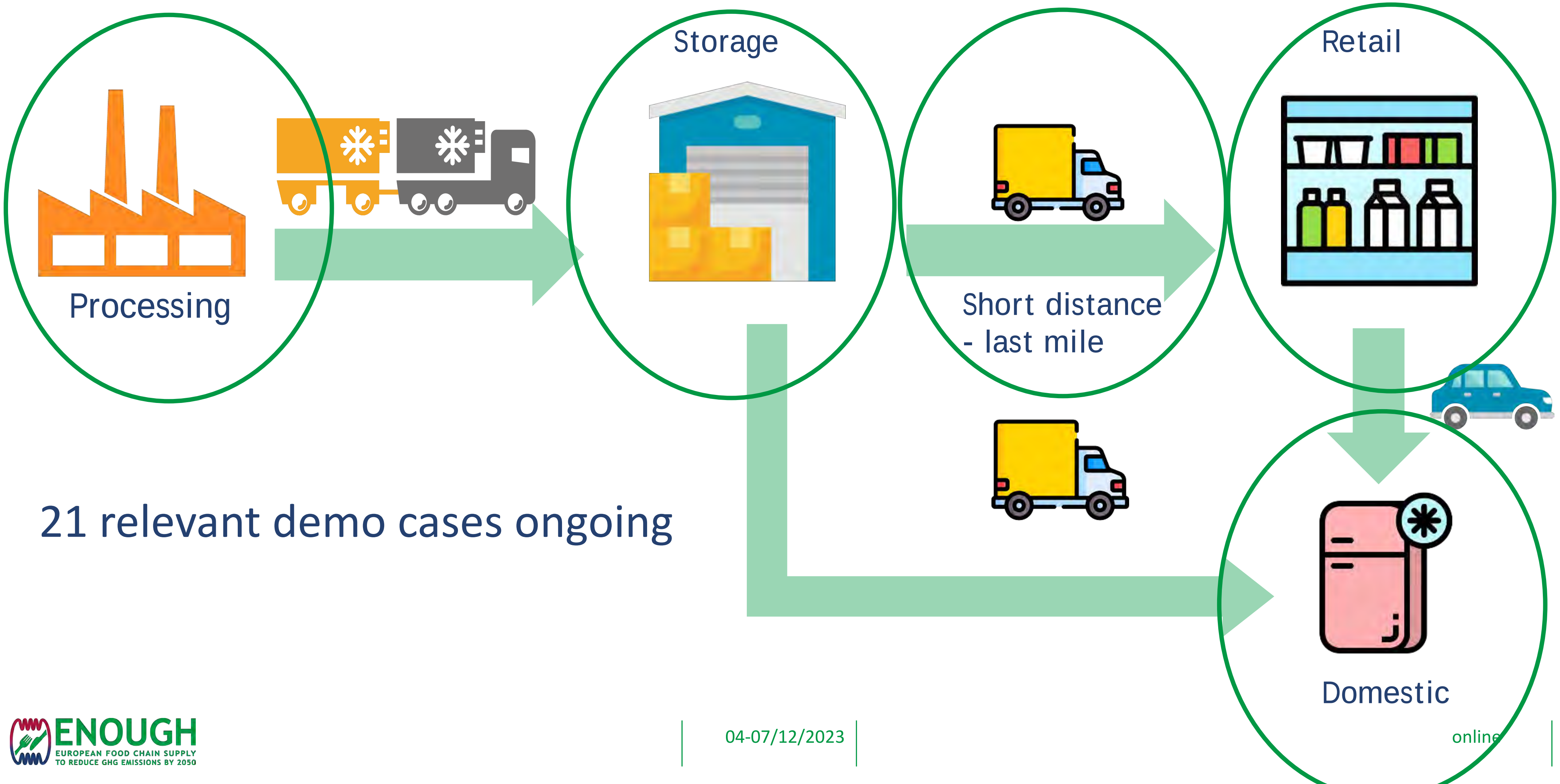
Measure



WP6 structure – product/process approach

	Meat	Fish	Dairy	Fruit&Veg	Other
Processing					
Transport					
Storage&Retail					
Domestic					
Other					

Food chain and demonstrators



21 relevant demo cases ongoing

WP6 Core strategies for GHG reduction

1. INTEGRATE AND OPTIMIZE ENERGY FLOWS
2. INCREASE ENERGY EFFICIENCY
3. REPLACE FOSSIL FUELS AND INCREASE RENEWABLES

HOW?

- **Heat Recovery** and **Thermal Energy Storage** (CTES and TES)
- Temperature level upgrade by **High Temperature Heat Pump** (HTHP)
- **Demand Side Response** (DSR)- integration with the grid, electrification
- **Efficient** components

WP6 Core strategies for GHG reduction

1. USE NATURAL WORKING FLUIDS and MATERIALS

HOW?

- Only **natural refrigerants** (carbon dioxide, ammonia and hydrocarbons) in all refrigeration and heat pump systems
- Sustainable packaging for sensitive products storage and transportation

WP6 Core strategies for GHG reduction

1. IMPROVE PROCESSING AND PRESERVATION CONDITIONS

2. REDUCE FOOD WASTE

HOW?

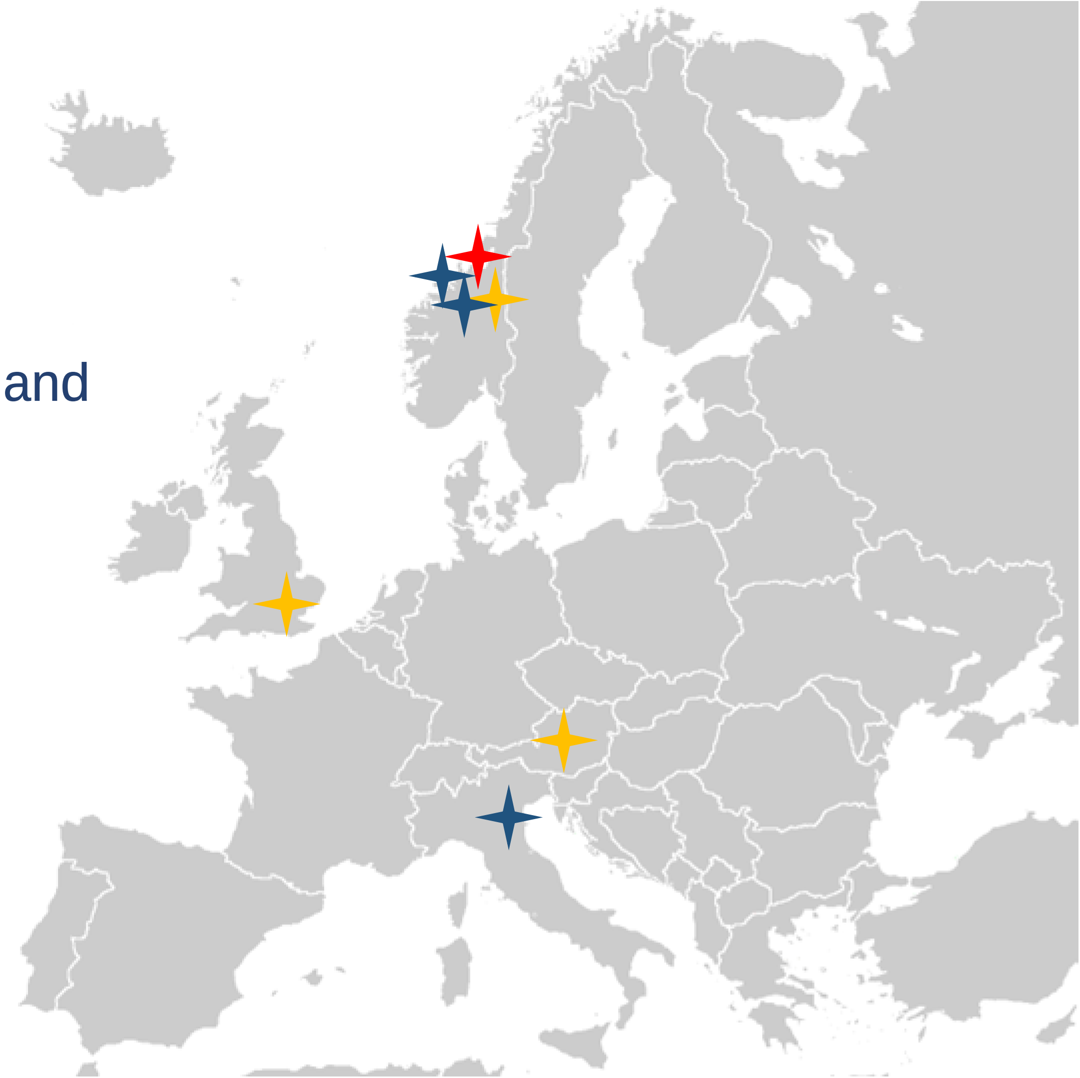
- Adopt **improved** freezing techniques to maintain **quality** and prolong **shelf life**
- Promote innovative **preservation** techniques
- Utilize proper tools to **manage** and **monitor** the supply chain and **reduce food waste**

Demonstrators - Processing

3 Dairy
Heat Recovery, HTHP
TES and CTES
Natural Working Fluids (CO_2 and Ammonia)

3 Fish
Natural Working Fluids (CO_2)
Improved processing (Brine freezing, plate freezing and blast freezing)
Improved efficiency

1 Meat
HTHP
Natural Working Fluids (NH_3-H_2O)
No fossil fuels - Improved efficiency



Demonstrators – Transport

2 Short distance, Last mile –
Mixed products
Electrification of
refrigeration unit
Renewables (PV)
Use of NWF (CO_2 and HC)
TES

1 Transport – Fruit
Sustainable materials
(Carbon neutral packaging)
Improved preservation

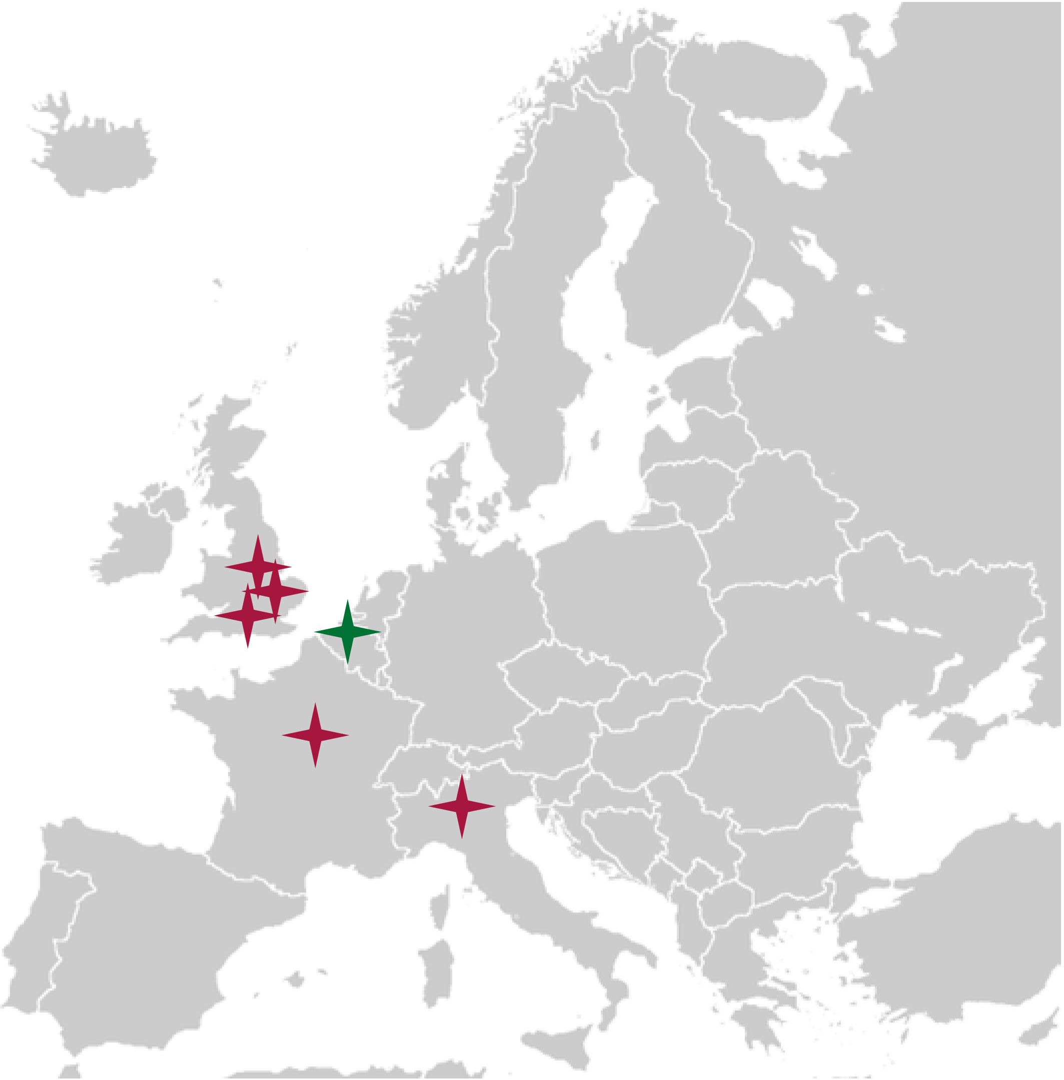
Demonstrators – Storage and retail

1 Storage – Mixed products
Heat Recovery

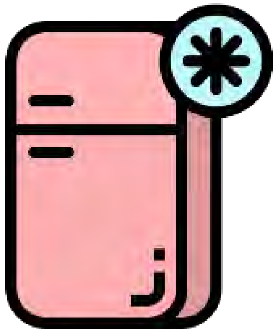
1 Storage – Fruit
Dynamically Controlled Atmosphere
Better efficiency
Natural Working Fluids

2 Retail – Mixed Product
DSR and TES (cabinet and system level)
Natural Working Fluids (CO_2)

2 Retail – Mixed Product
Energy Efficient Components (Cabinet and Refrigerating Unit level)
Natural Working Fluids (CO_2)

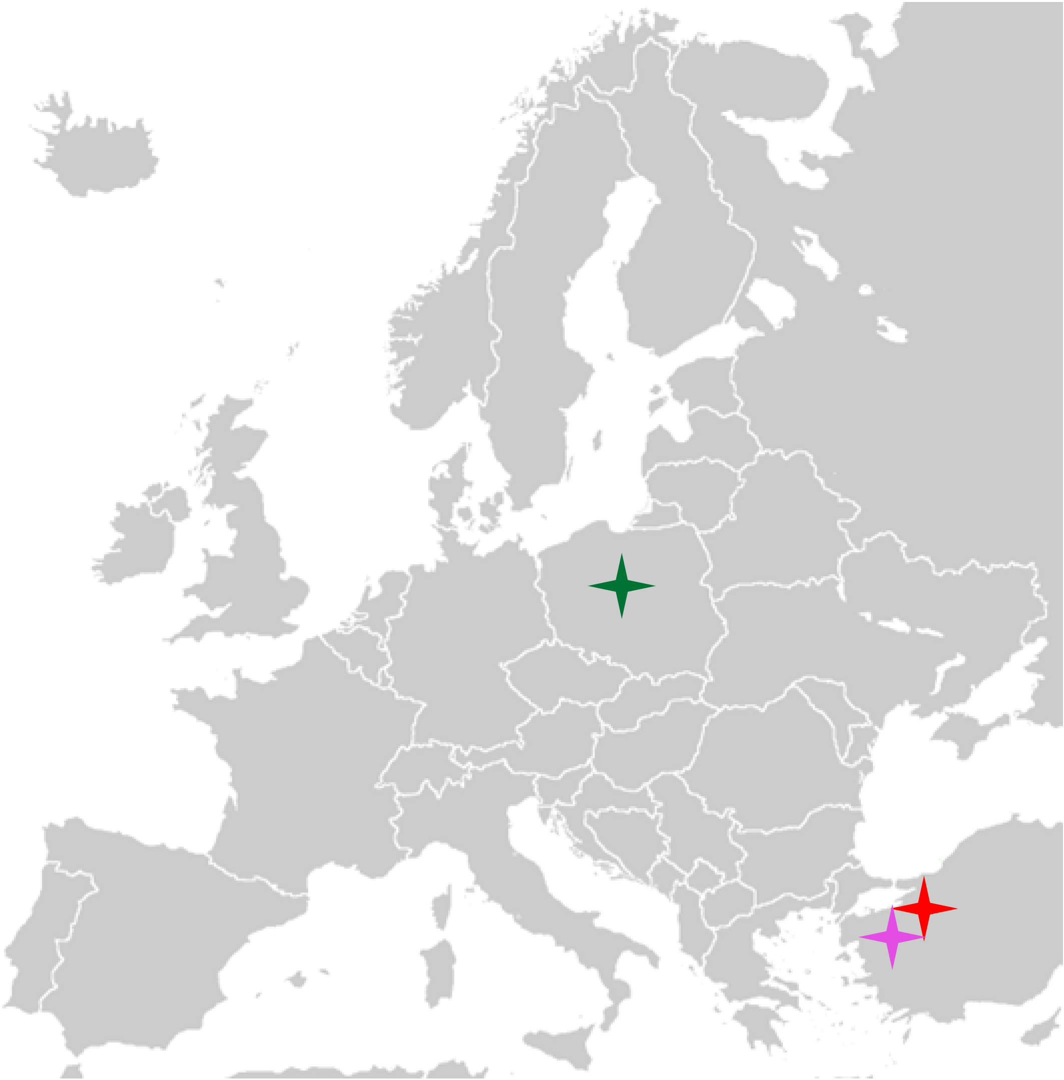


Demonstrators – Domestic



2 Domestic Preservation–
Meat and Fruit&Veg
Improved preservation
(superchilling and freeze
drying)
Use of NWF (HC)
TES

1 Domestic refrigerator –
mixed products
Energy efficiency
Natural Working Fluid (HC)

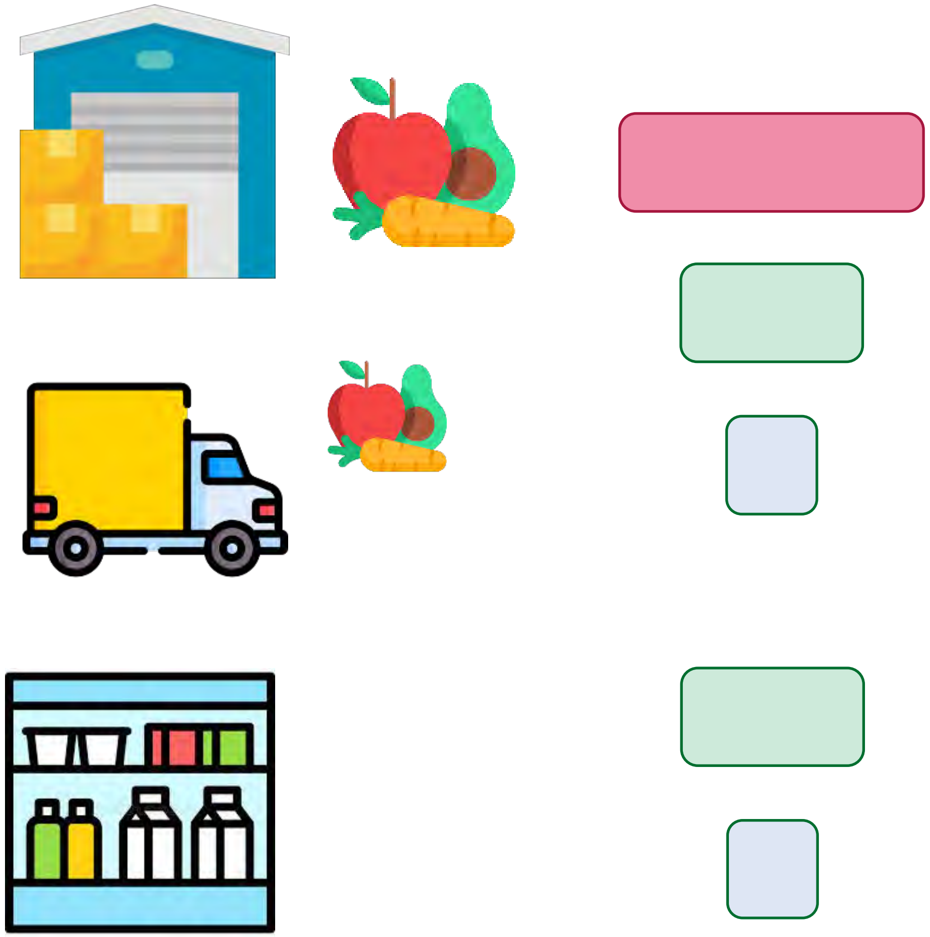


Demonstrators – Miscellaneous

1 Supply chain management and control – Mixed products

1 Food Waste Management – Mixed products

How to improve the sustainability of the food chain?– 7th December Webinar



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Energy efficient brine freezing

Eirik Starheim Svendsen
Researcher at SINTEF Ocean

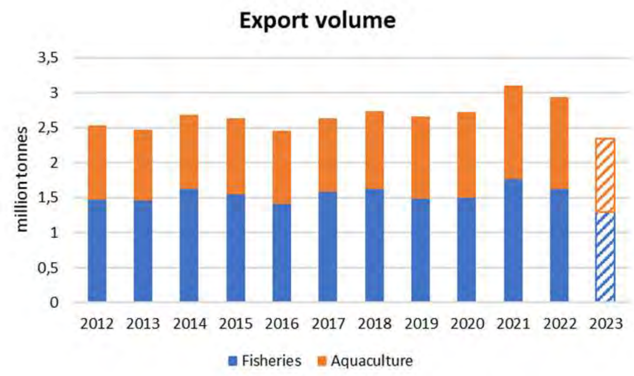
Advancements in freezing techcnology for a sustainable food chain
04.12.2023
Webinar

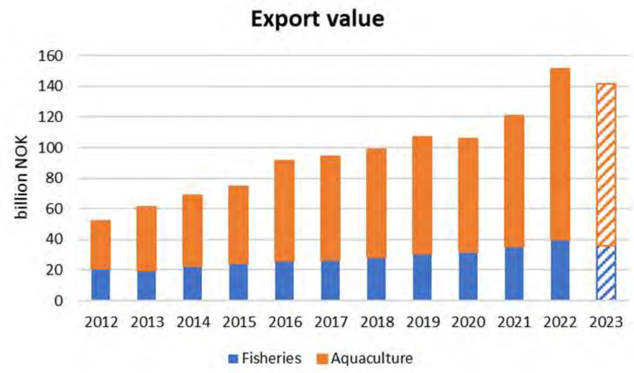
Outline of presentation

- Freezing of seafood
- About the demonstrator
- 1) Brine freezing of mackerel
  - Idea
  - Results from trials so far
- 2) Brine freezing of salmon
  - Idea
  - Results from trials on salmon portions and whole salmon
- Further work

FISHERIES AND AQUACULTURE – IMPORTANT FOR NORWAY AND EU
SECONDARY TITLE HERE

- Norway is the second largest exporter of seafood in the world (behind China)
- EU is the largest market and receive about 60% of seafood exports (Poland, Denmark, France, Netherlands, Spain, Italy, Portugal ++)
- Fisheries and aquaculture production contribute greatly to GHG emissions: 1.55-1.85 million tonnes for 2021



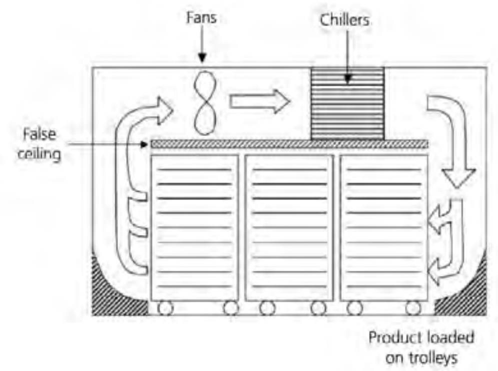


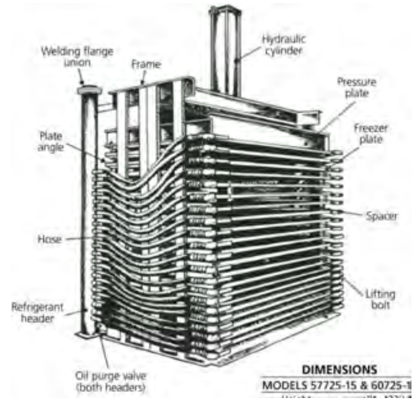
Sources:
'Fisheries and trade in seafood', 2018, Government.no
'Key export figures', 2023, Norwegian Seafood Council
'*Kartlegging av utslipp fra fiskeri og havbruk i Norge*', 2022, Stakeholder AS

Freezing of seafood

A short background

- There are three basic methods for freezing:
  - **Air blast freezers:** cool air flows around the foodstuff, removing the heat
  - **Plate freezing:** foodstuff are in direct contact with plates which are internally cooled by a cold refrigerant
  - **Immersion freezing:** foodstuff are immersed or sprayed with a liquid refrigerant (e.g., a brine)
- Choice of freezer system is dependent on a balance between freezing rate, preserving quality and costs
- Brine freezing was one of the first methods used for commercial freezing of fish in Norway (1930’s), but practice declined due to challenges with brine spillage and corrosion and uptake of new technologies
- Brine refers to solutions containing salts, mainly NaCl or $CaCl_2$, whose eutectic points are -21 °C and -55 °C





Principal sketches of freezers. Top: air blast tunnel. Bottom: Horizontal plate freezer. Images from ‘*Planning for Seafood Freezing*’, Kolbe & Kramer (2007)

Benefits of brine freezing

- The rate of heat transfer between food and surrounding medium is governed by:

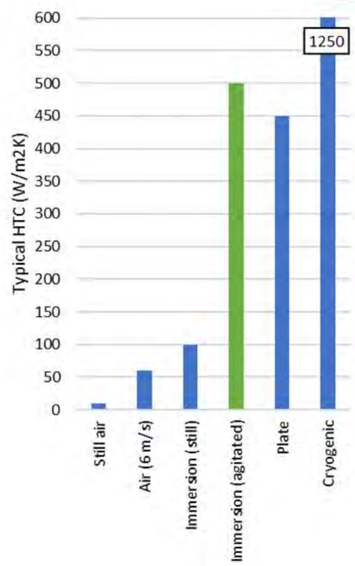
$$Q = h \cdot A \cdot \Delta T$$

$A = food\ surface\ area\ (m2)$

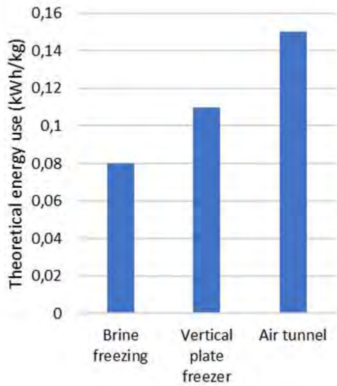
$\Delta T = temperature\ difference\ surface\ and\ medium$

$h = heat\ transfer\ coefficient{:}\ depends\ on\ food\ shape\ and\ brine\ properties$

- For immersion freezing, the heat transfer coefficient is relatively high compared to air-blast (and comparable with plate freezing) -> **large** $\boldsymbol{h}$
- Brine temperature is typically higher compared to plate freezer temperatures -> **less compressor work**
  - **Brine freezing is very energy efficient**

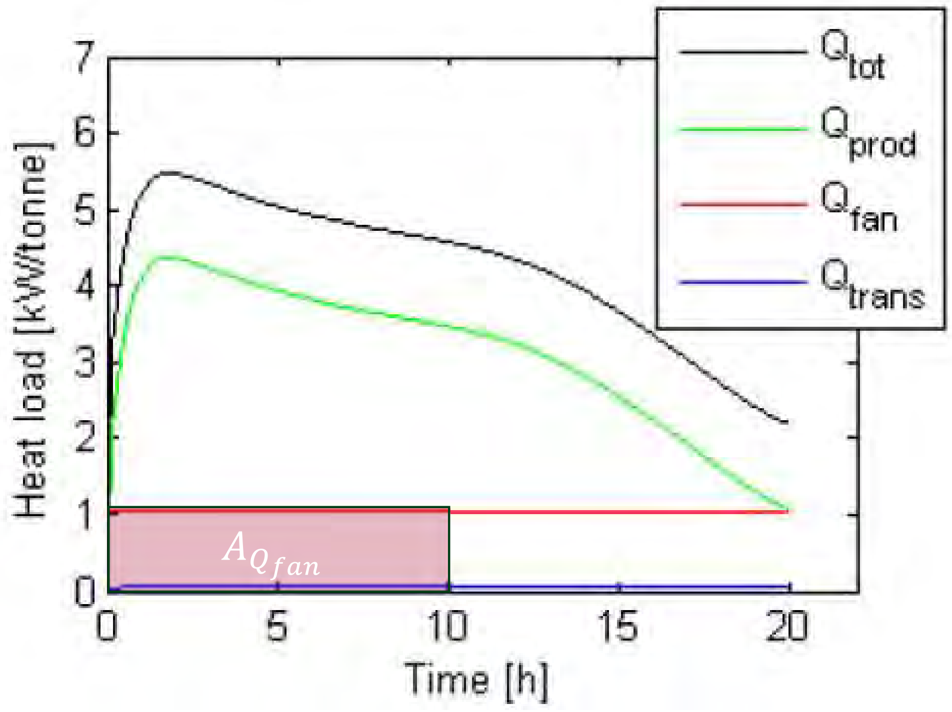


Figures from *'Chilling and Freezing of Foods'*, James & James (2014)



Figures from *'Lakefrysning av hvitfisk'*, Møreforskning (2022)

Energy calculations for freezer tunnel



Simulated heatload (Q) for a batch freezing tunnel (Widell et al. (2012): *The effect of reduced air fan speed on freezing time and energy consumption in a freezing tunnel.*)

Impact on energy use of air tunnel if we remove 10 hours of initial holding time

$$A_{Q_{fan}} = 1\,\frac{kW}{tonne} \cdot\ 100\ tonnes \cdot\ 10\ hours = 1000\ kWh$$

- Assuming a COP of 2 → 500 kWh of compressor work is saved
- Approx. 1000 kWh of fan work is also saved

- **1500 kWh savings in electric energy input per batch**

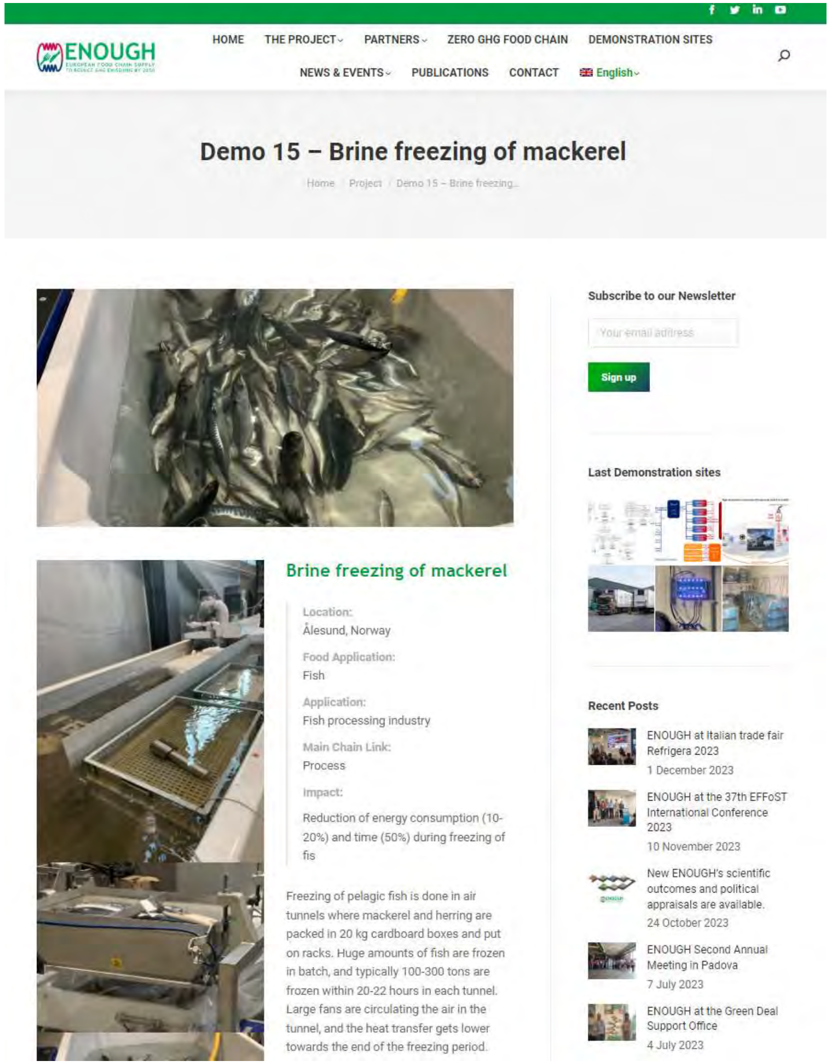
Demo 15 – Brine freezing

Partners involved:

- **MMC First Process** (NO): Manufacturer and provider of system solution for handling, processing and cooling to the seafood industry
- **SINTEF Ocean** (NO): Conducts research and innovation related to ocean space, including seafood processing

The demo (equipment) is located at MMC’s premises in **Ålesund, Norway.**

The demonstrator is exploring **different concepts for different seafood products**, where the main purpose is to (partially) replace current freezing methods with the more energy efficient brine freezing method.



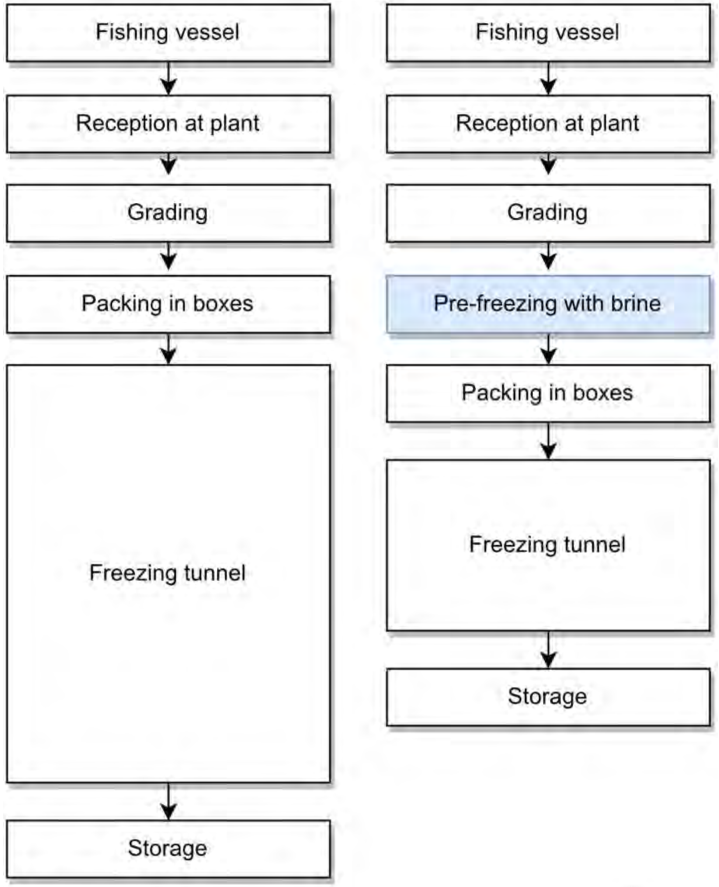
Demo 15 - Brine freezing of mackerel - Enough (enough-emissions.eu)

1) Two-stage freezing of mackerel

- Freezing of pelagic fish is typically done in air tunnels. The fish is packed in 20 kg cardboard boxes, put on racks and put into tunnels with capacity of ~100 tonnes/batch.
- Air tunnels, while able to handle large amounts of fish, are heavy consumers of energy and requires long freezing times (18-22 hours)
  - Requires substantial amount of energy to drive air fans
  - Air fans also add heat to the total heat load which must be removed; heat load from product accounts for only 50-80%
- By pre-freezing mackerel in a brine freezer, time spent in the tunnel freezer is less and the overall process is thus more energy efficient

Expected impact: Reduction of energy consumption (10-20%) and time (50%) during freezing of mackerel

Conventional chain | Chain w/brine freezing

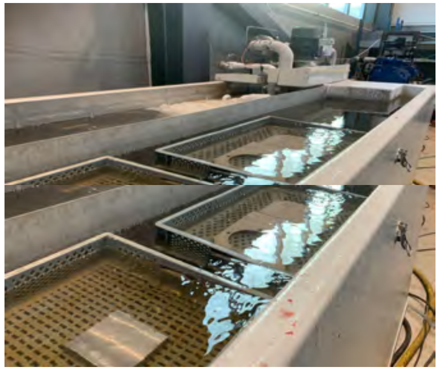


Trial 1: Pre-freezing of mackerel

Purpose of the first trial was to locate the 'sweet spot' between extracting as much heat as possible from the product, while maintaining a mackerel that is elastic enough so that 20 kg of product can be placed in boxes

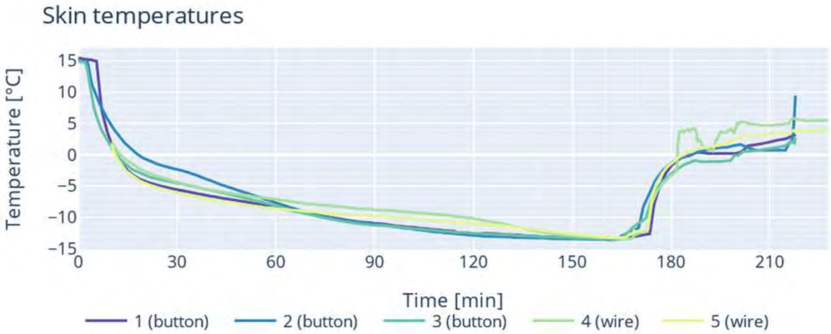
Method

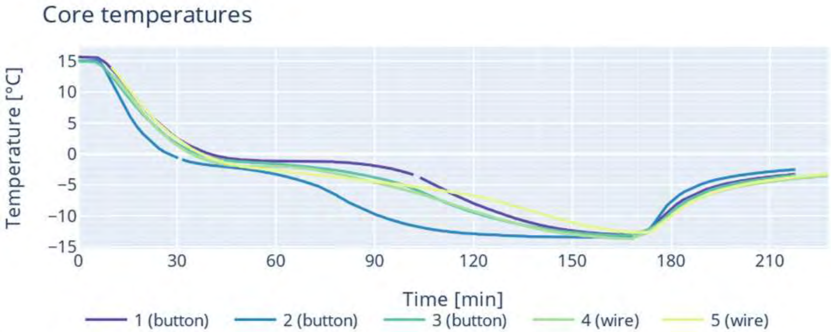
- 50 kg of mackerel
- 5 of the mackerels were instrumented with temperature sensors (either iButtons (3) or thermowires (2)): skin, core and core of tail
- Frozen in test rig at MMC, brine (NaCl) at -14 °C, mackerel placed in perforated boxes
- Subsequently thawed in fresh water at 9.5 °C

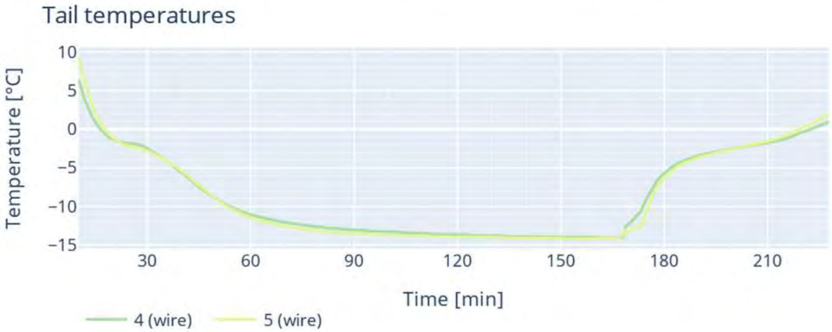


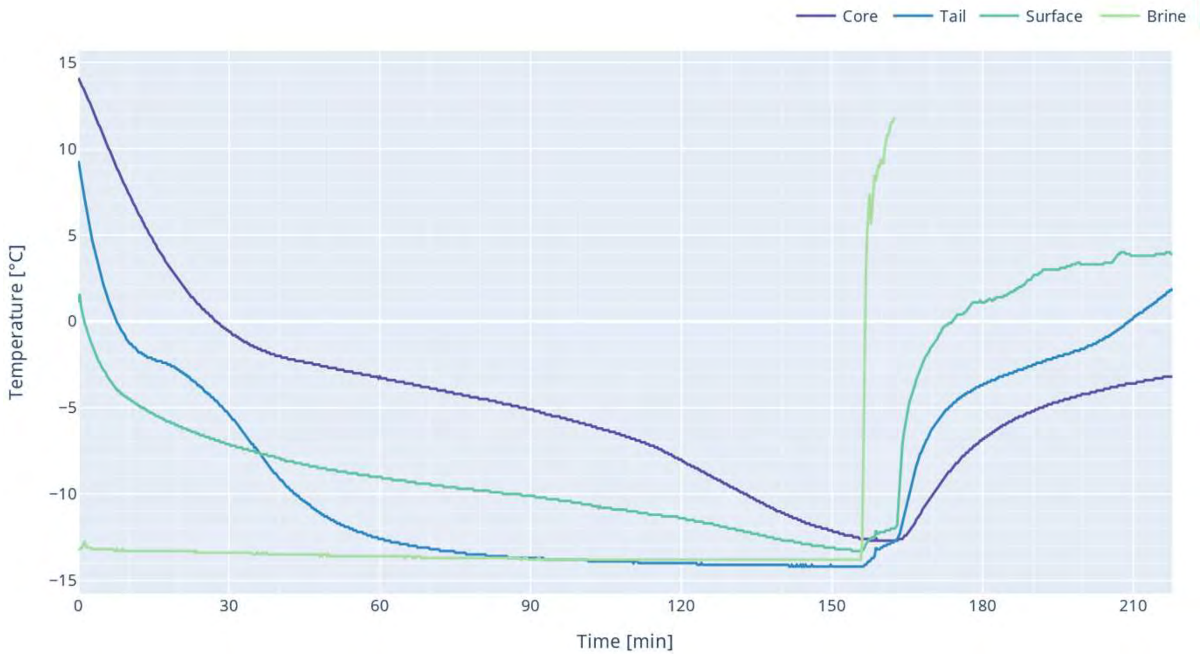
1) Two-stage freezing of mackerel

Trial 1: Results





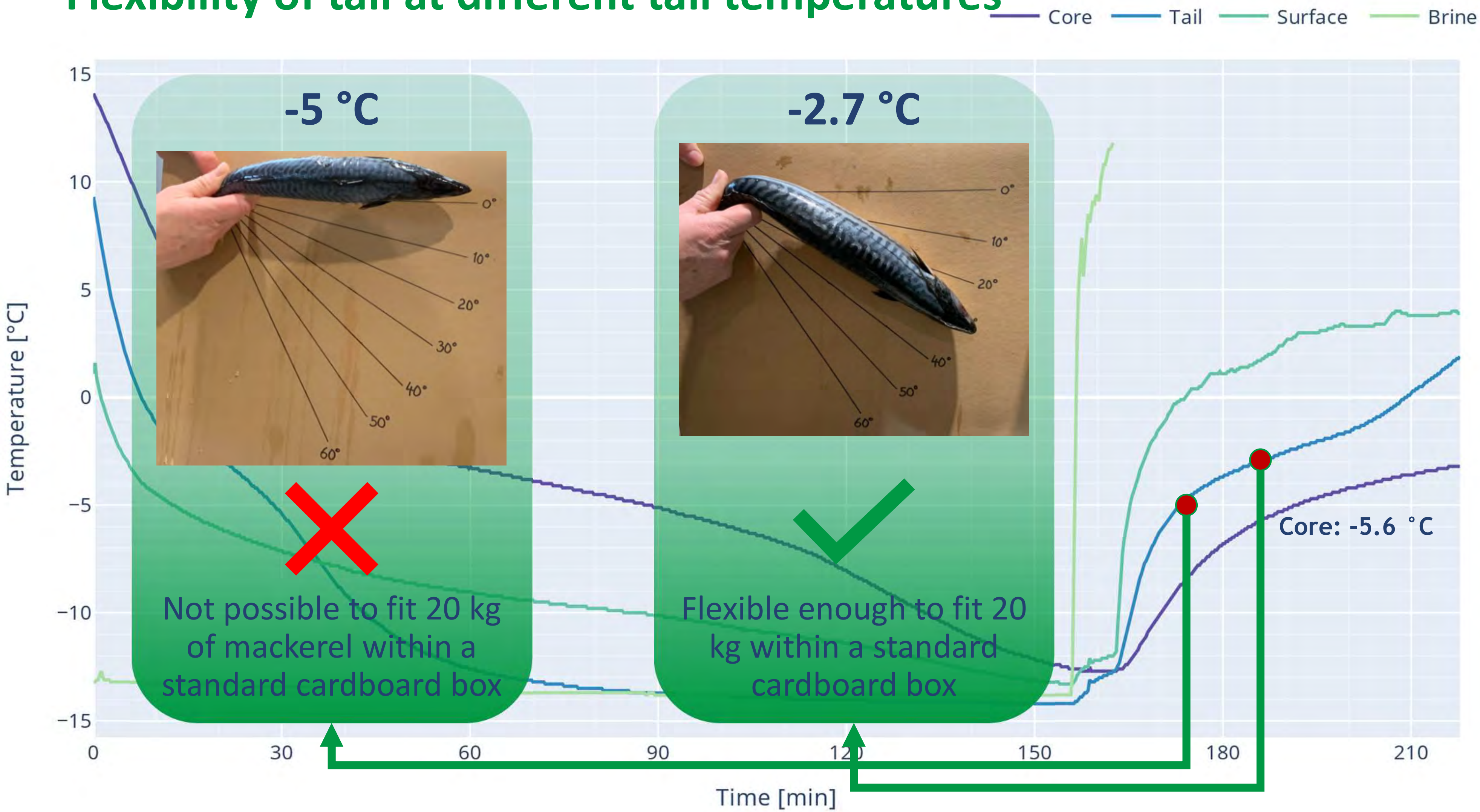




- 120-160 min to reach -14 °C in core, 80-90 min for tail
- Rate of ice formation in tail quite rapid, compared to both core and skin

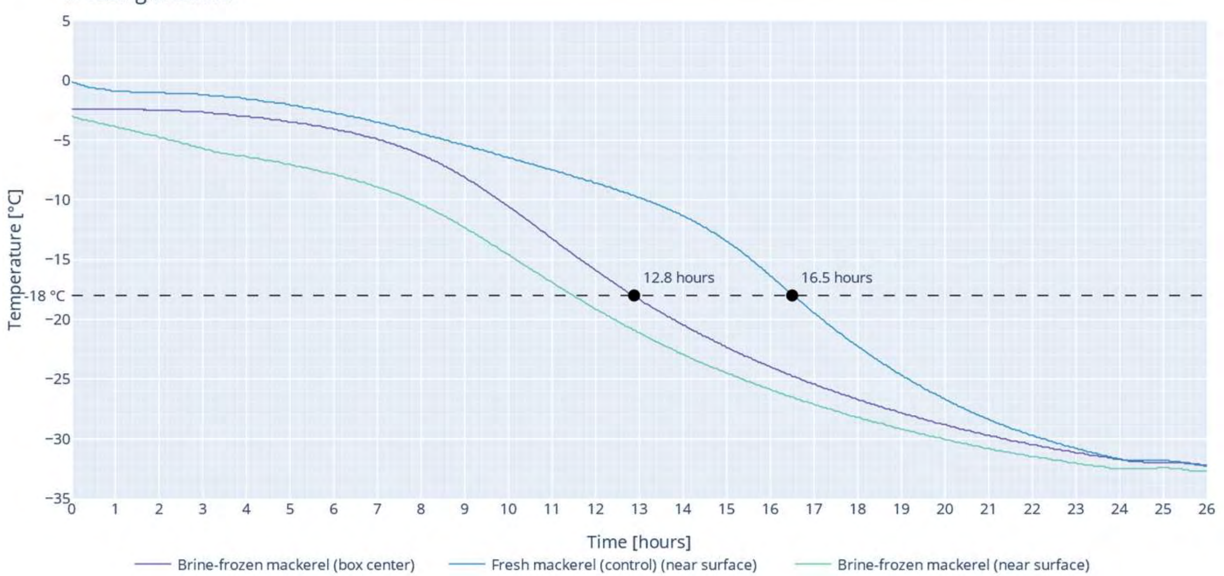
1) Two-stage freezing of mackerel

Flexibility of tail at different tail temperatures



Trial 2: pre-freezing + tunnel freezing

- **Target**: -2.7 degC in tail, -5 degC in core.
- **Next trial**: pre-freeze, thaw tail, pack in boxes and complete freezing in tunnel. Due to logistic challenges, there was a 3-hour hold between packing and tunnel, resulting in core temperature increase from -4.7 to -2.8 degC



Flexibility where tail -2.7 and core -5 degC

- Graph shows results from 2 boxes; 1 pre-frozen in brine and 1 fresh (control)
- Time to reach -18 °C:
  - 13 hours for pre-frozen (core)
  - 16.5 hours for fresh (near surface)

2) Brine freezing of salmon

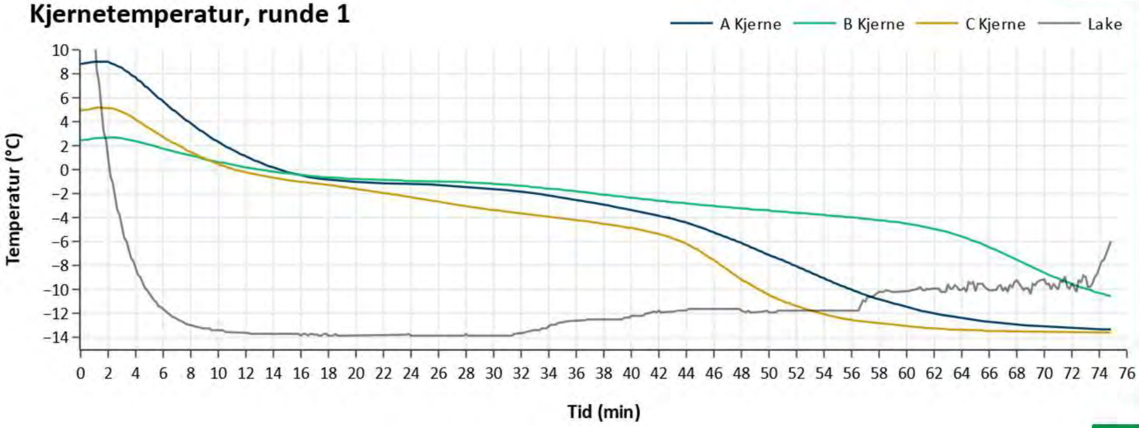
- Trials have also been carried out on freezing of salmon
- Conventional methods for freezing of salmon include cryogenic and tunnels (whole products) and IQF/spiral freezers (fillets, portions).
- **First trial**: freezing of vacuumpacked salmon portions in NaCl brine at -14 °C
- **Second trial**: freezing of whole salmon (vacuumpacked and non-packed) in NaCl brine at -14 °C
- ***Third trial****: freezing of whole salmon (vacuumpaked and non-packed) in $CaCl_2$ brine at -35 °C*

Trial 1: Salmon portions

- **Purpose**: investigate freezing rate for product and impact on sensoric quality attributes
- **Method:** 6 portions (roughly 300gr, 30 mm thickness) was made from fresh salmon fillets, instrumented with iButton loggers (core and skin) and vacuum packed.
- Portions were fixed in perforated boxes, and immersed in circulating NaCl-brine holding ~-14 degC
- After 60-75 min holding time, portions were put to thaw in room temperature

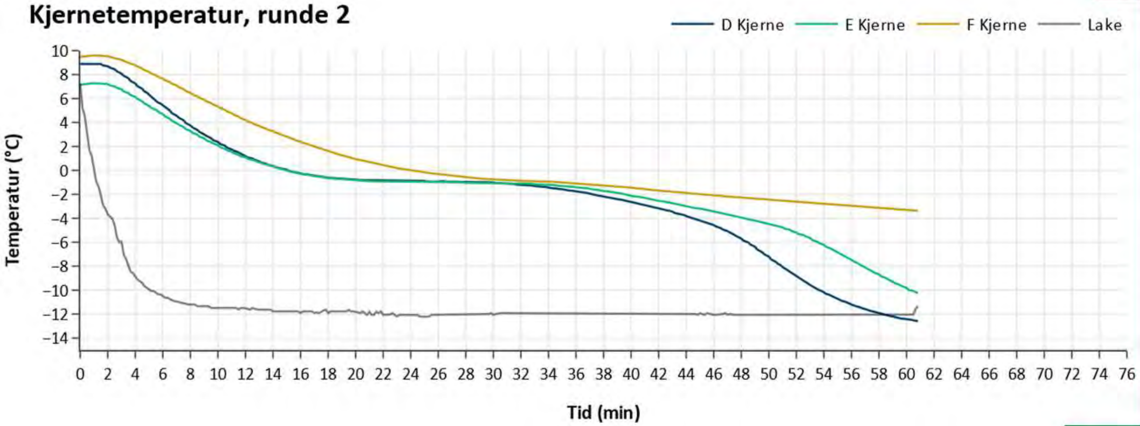
Trial 1: Salmon portions

- **Freezing rate:** Took approx 45-60 minutes to freeze down to -5 degC (one can assume that abt 70% of freezeable water is converted to ice at this point)



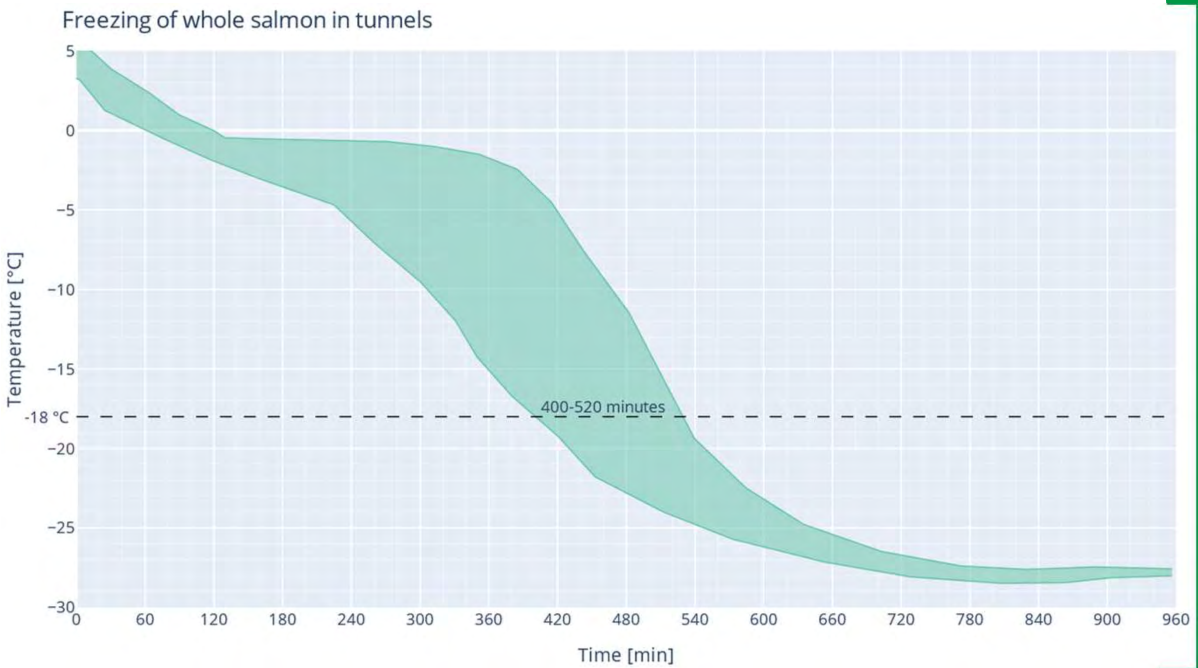
Before

After



Trial 2: Whole salmon

- Whole salmon is typically single frozen in air tunnels.
- Pre-freezing with brine could unlock the same benefits as for the mackerel case.
- Freezing in $CaCl_2$ could replace the entire freezing process



Typical freezing times for single frozen salmon in tunnel (gutted)

Trial 2: Whole salmon in NaCl (-14 °C)

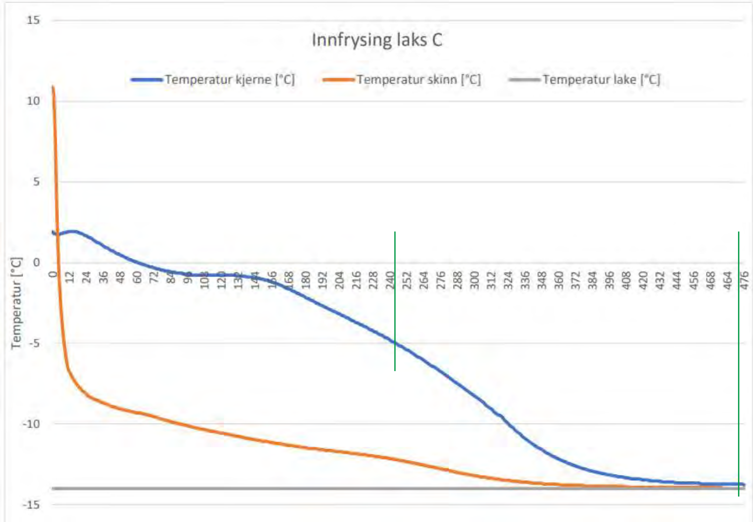
- 4 salmon, of which 2 (C and D) were vacuumpacked, were frozen in brine over night
- Temperature (skin and core) was registered with iButtons and thermowire
- Temperature curves for un-packed salmon corrupted (salmon A and B)

Trial 2: Whole salmon

- Freezing rates: **Brine** **Air tunnel**
  - -5°C: 172 – 242 min 230 – 420 min
  - -14°C: 432 – 470 min 350 – 512 min

Freezing rates	**Brine**	**Air tunnel**
-5°C:	172 – 242 min	230 – 420 min
-14°C:	432 – 470 min	350 – 512 min

- Before and after freezing - unpacked



Trial 2: Whole salmon

Vacuumpacked salmon: Before

After

After 5 hour thawing in room temperature

Conclusions so far and further work

- Trials show that brine freezing can be employed for some seafood products with potential benefits on the freezing time and energy savings, but:
  - Energy use for brine freezing part remains to be measured/evaluated
    - Theoretical potential is large, but one need to consider the entire chain
  - Not suitable for all products:
    - One must consider barrier for salt uptake (dependent on species)
    - Evaluation of relevant quality parameters should be conducted
- Industry is very traditional, requires effort to push uptake of ‘new’ technology
  - Concepts must be proven in larger scale
- The brine rig itself must be optimised

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Ultra-low temperature blast freezing

Muhammad Mubashir Ahsan

Department of Industrial Engineering
University of Padova, Italy

ITC

enex
INNOVATION AS ENERGY

ENOUGH webinar , 04/12/2023

Challenges & Objectives

- Challenges:
  - The food processing industry is one of the largest consumers of energy in the manufacturing sector.
  - Freezing food products often involves use of synthetic fluids (such as HFCs and HFOs) based refrigeration units, which can have adverse environmental impacts.
  - The quality of frozen products strongly depends on the time required for freezing.
- Objectives
  - Development of a refrigeration unit with high efficiency, that guarantees significant energy savings.
  - Use of natural refrigerants with zero or negligible environmental impact.
  - Designing a system capable of operating at extremely low evaporation temperatures, and reducing the time required for freezing.

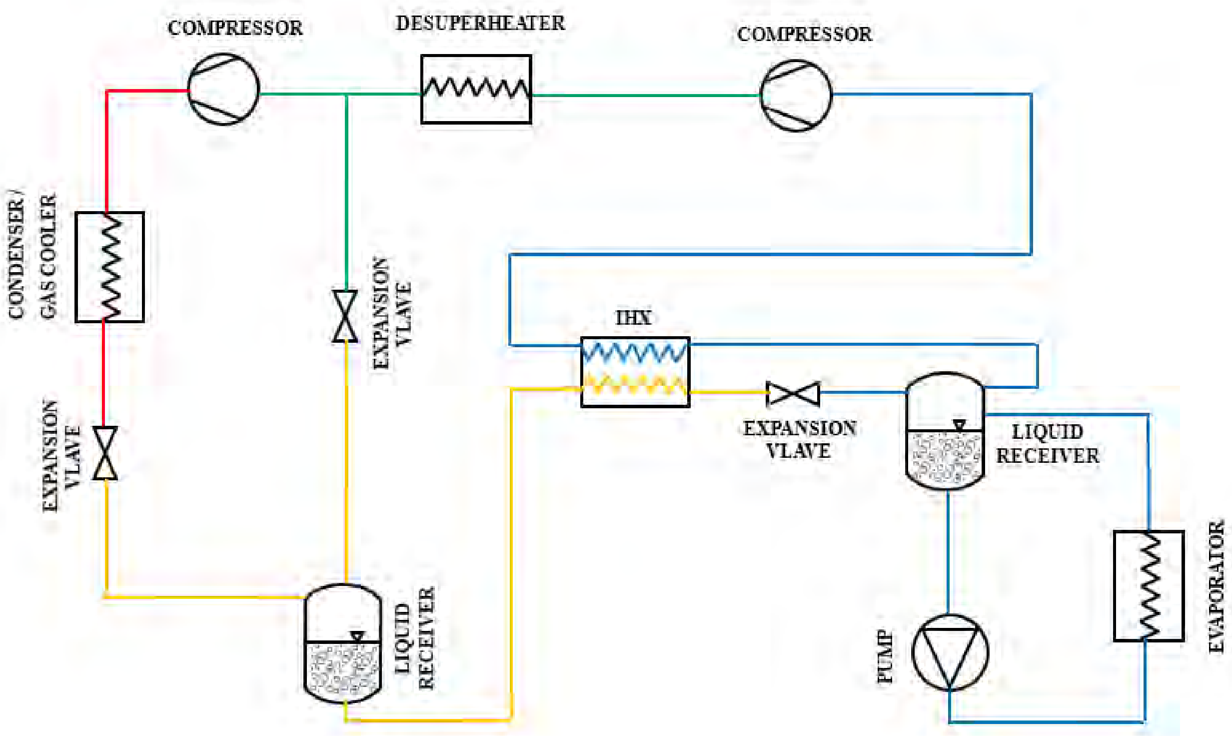
Blast freezer – Application

Blast freezer:

- Vapor compression refrigeration system.
- Usually employed in freezing tunnels, conveyors, spirals, and similar applications.
- Blast freezing is achieved by exposing the product to extremely low temperatures (-40°C to -30°C) to reduce the freezing time.
- The way the ice crystals interacts with the food products is affected by the freezing time.

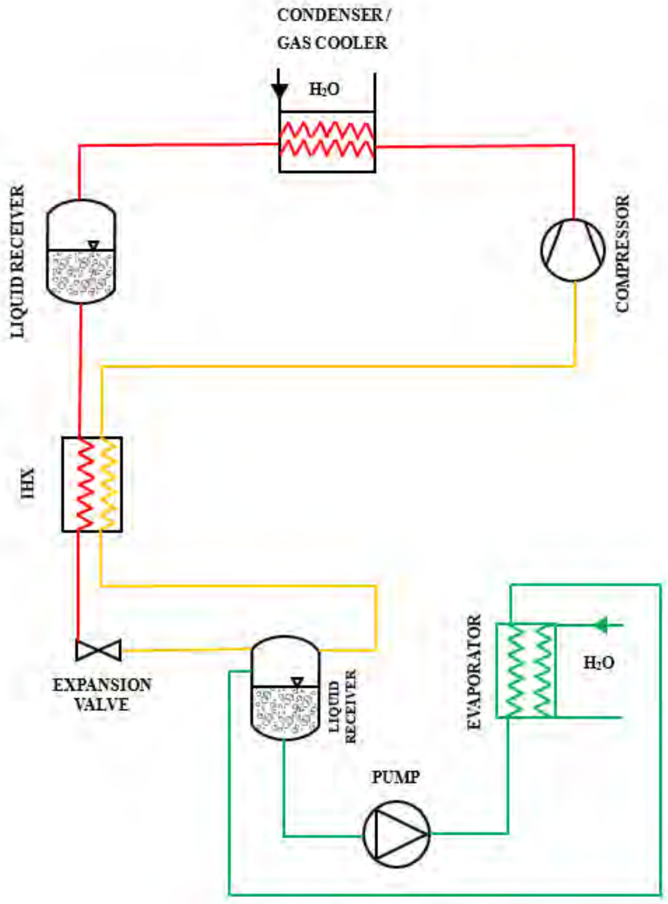
Blast freezer – Schematic diagram

- Vapor compression refrigeration unit
- Refrigerant used: R744 (CO2).
- Two-stage dual compression system with intercooler.
- Flooded evaporator with pumped R744.
- Subcritical or transcritical cycle depending on the ambient temperature.



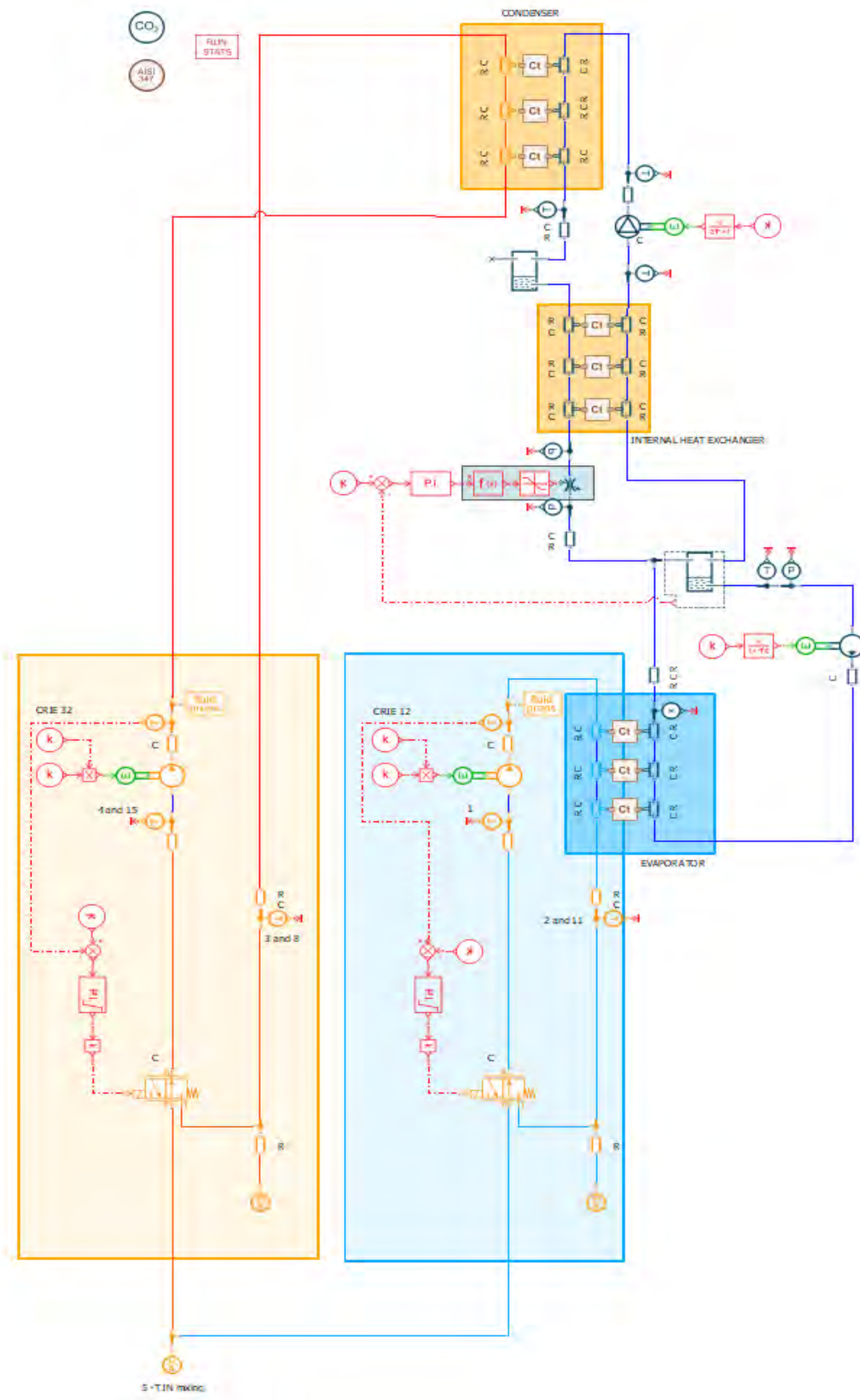
Demonstrator prototype: Single stage water to water unit

- System has been simplified to a water-to-water unit to perform the first performance and functional tests of the LT circuit.
- Plate condenser and evaporator with secondary water/glycol mixture.
- Experimental tests to evaluate system performance over long periods of operation: oil management in the low pressure liquid receiver.



Numerical model of single stage water to water demonstrator prototype

- Based on the actual demonstrator unit, an equivalent numerical model of the unit has been developed by using Simcenter Amesim.
- Numerical model is used to:
  - Map the performance of the actual unit under different operating conditions.
  - Diagnosing problems in case of errors or unexpected behavior observed during experimental tests.
  - Optimize the system operating parameters.
  - Evaluate the performance of the system in operating conditions that are difficult to test experimentally.



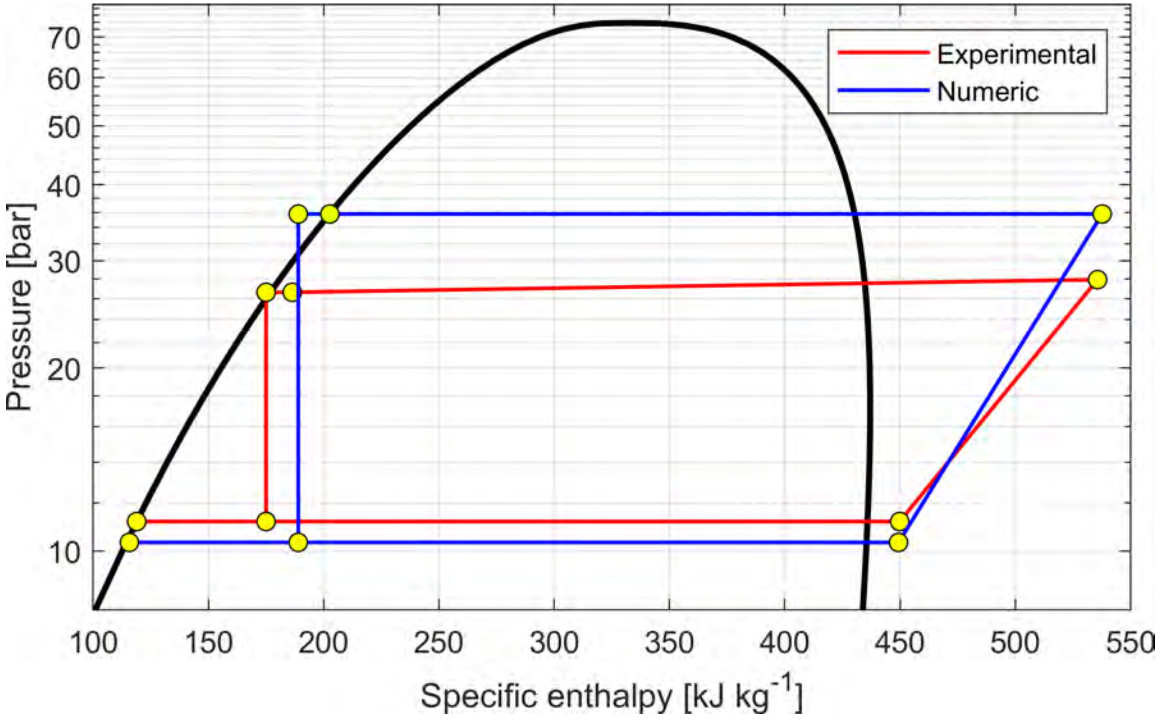
Experimental results

- Endurance tests with continuous operation for several hours to verify the correct operation of the oil management system in the low-pressure receiver.
- Experimental results have shown that the system is able to operate continuously for several hours without any major issue.
- Different experimental tests have been performed at different evaporation temperatures to evaluate the unit performance under different conditions.
- Numerical model is currently being validated against experimental results at all these experimental conditions.

	Cond. 1	Cond. 2	Cond. 3	Cond. 4
T_{evap} [°C]	-31.99	-33.57	-38.76	-42.94
p_{evap} [bar]	13.35	12.64	10.51	9.00
$T_{wat-gly,evap,IN}$ [°C]	-20.76	-23.40	-28.81	-32.72
$T_{wat-gly,evap,OUT}$ [°C]	-27.07	-29.06	-34.43	-38.50
p_{cond} [bar]	28.26	28.12	27.45	26.75
$T_{wat-gly,cond,IN}$ [°C]	-12.70	-12.51	-12.55	-12.59
$T_{wat-gly,cond,OUT}$ [°C]	-7.40	-7.32	-8.04	-8.69

Comparison of experimental and numerical results

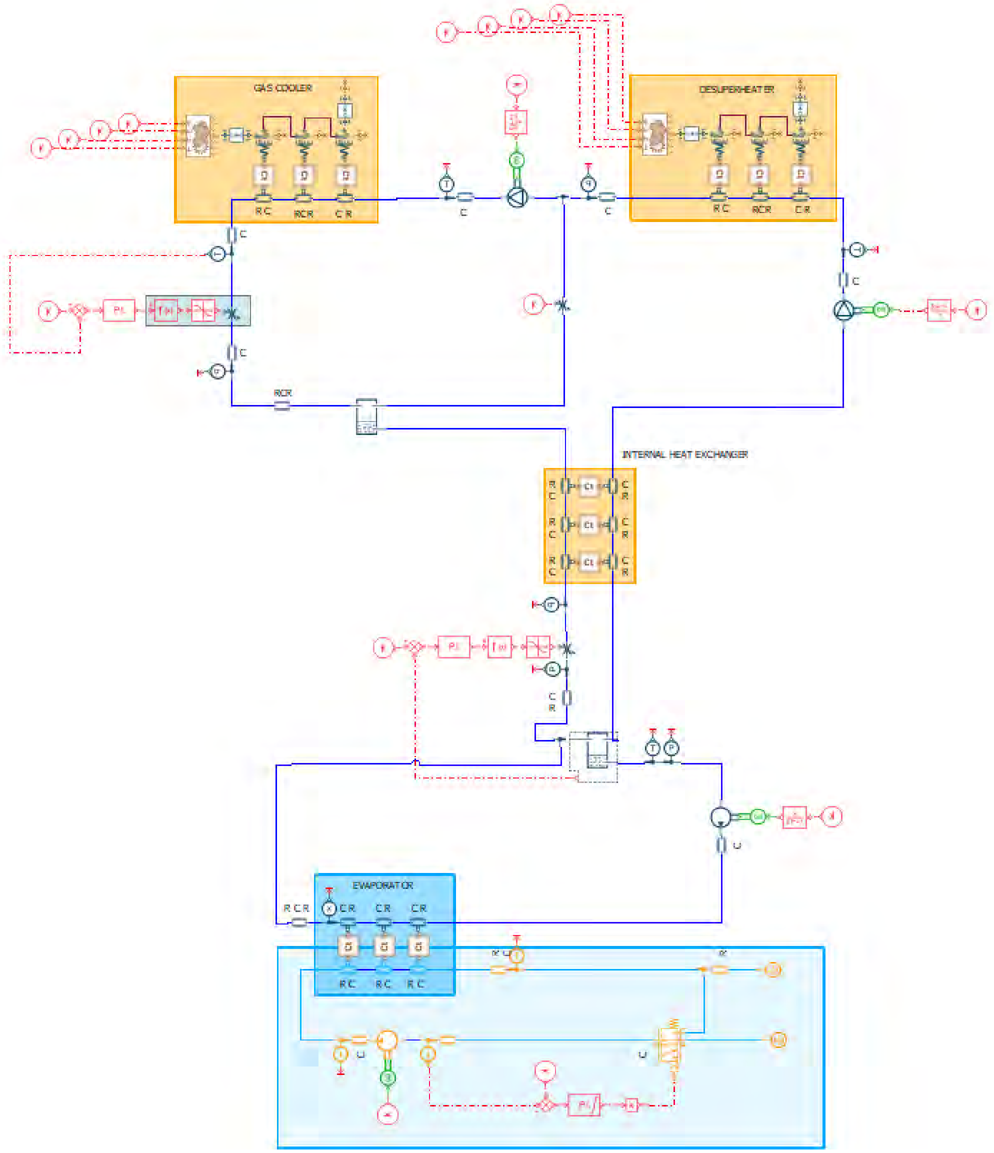
- The comparison between experimental results and numerical results highlights that:
  - The evaporation pressure is similar (EXP: 11.2 bar, NUM: 10.3 bar).
  - The condensing pressure is not accurately reproduced in the numerical model (EXP: 27.9 bar, NUM: 35.8 bar).
  - The temperatures of the secondary fluid are almost identical.
- In particular, the result highlight (verifications and experimental investigations in progress):
  - Experimental performance of the compressor (experimental discharge temperature is much higher than the nominal data given in the manufacturer's catalogue).
  - Presence of significant pressure drops during condensation in the experimental case.



	Experimental	Numeric
$T_{wat-gly,cond,IN}$ [°C]	-12.08	-12.09
$T_{wat-gly,cond,OUT}$ [°C]	-6.97	-6.94
$T_{wat-gly,evap,IN}$ [°C]	-27.76	-27.80
$T_{wat-gly,evap,OUT}$ [°C]	-32.60	-32.71

Numerical model of two stage compression air to air unit system.

- Numerical model of the standard application two-stage refrigeration unit.
- The results of the numerical model of the two-stage system will be used for:
  - Final sizing of the components including finned heat exchangers.
  - Preliminary evaluation of the system's performance for actual installation and field tests of final application.
  - Optimization of operating and control parameters.



Future Work

- Design and sizing of two stage compression air to air unit according to the final application.
- Preliminary evaluation of the system's performance for installation and field tests.
- Commissioning and installation of an actual unit on the field.
- Performance monitoring of the actual unit on the field after installation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 101036588

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EUROPEAN FOOD CHAIN SUPPLY TO REDUCE GHG EMISSIONS BY 2050

THANK YOU !

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TO REDUCE GHG EMISSIONS BY 2050

Freeze-drying for a long-term food storage

Michal Palacz

Silesian University of Technology, Gliwice, Poland

ENOUGH webinar: Advancements in freezing technology for a sustainable food chain
04/12/2023

WHY FREEZE-DRYING?

- High nutritional quality of freeze-dried foods
- Significant mass reduction of the food products
- Very effective water removal – up to 99%
- Suitable for long-term storage at ambient conditions

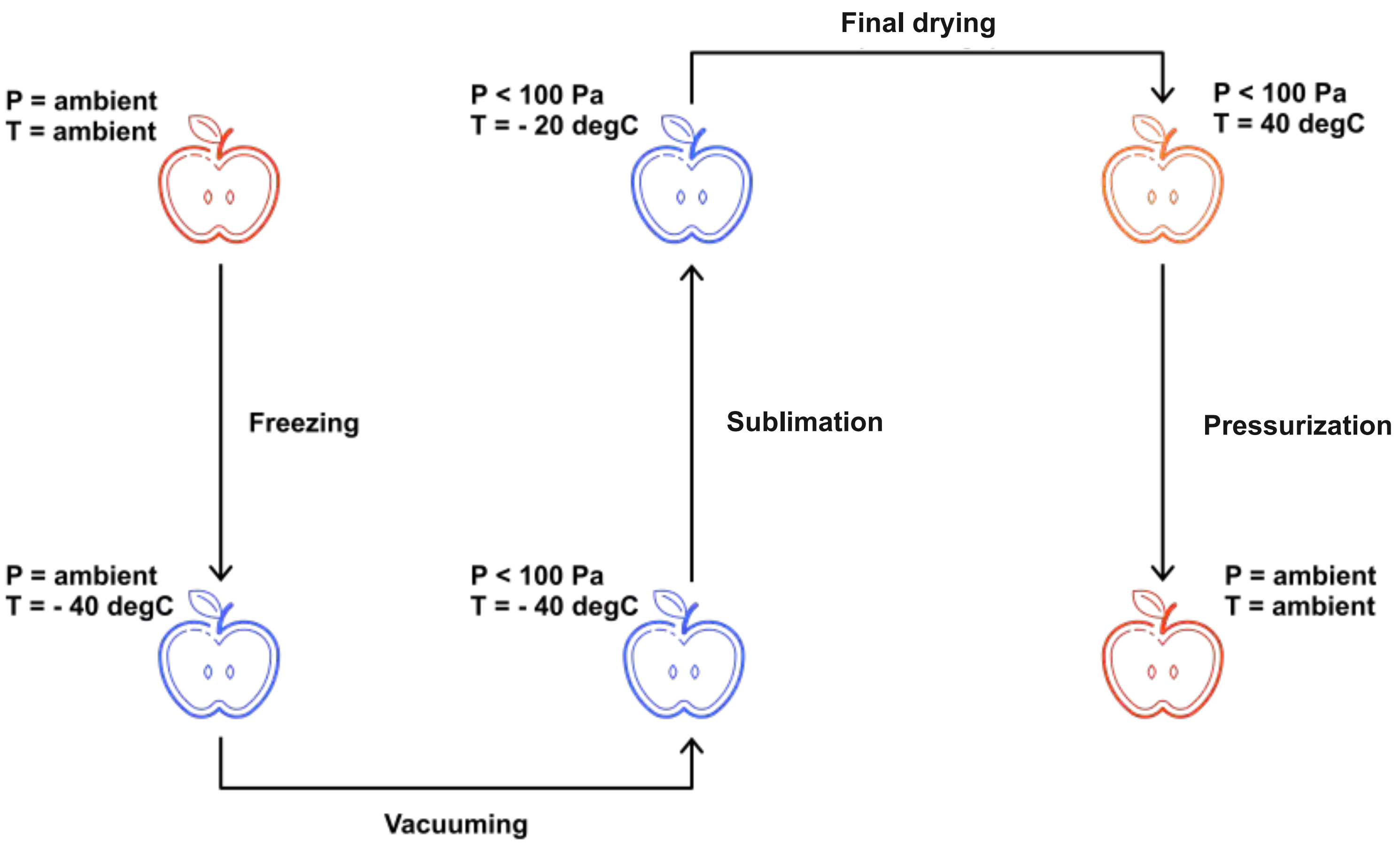
Challenges:

- Energy consumption
- Time of the process

Freeze-dried vegetables and fruits

IMPROVED FD ENERGY EFFICIENCY AND ACCESSIBILITY = GHG EMISSION AND FOOD WASTE REDUCTION

FREEZE-DRYING PROCESS



Stages of freeze-drying:

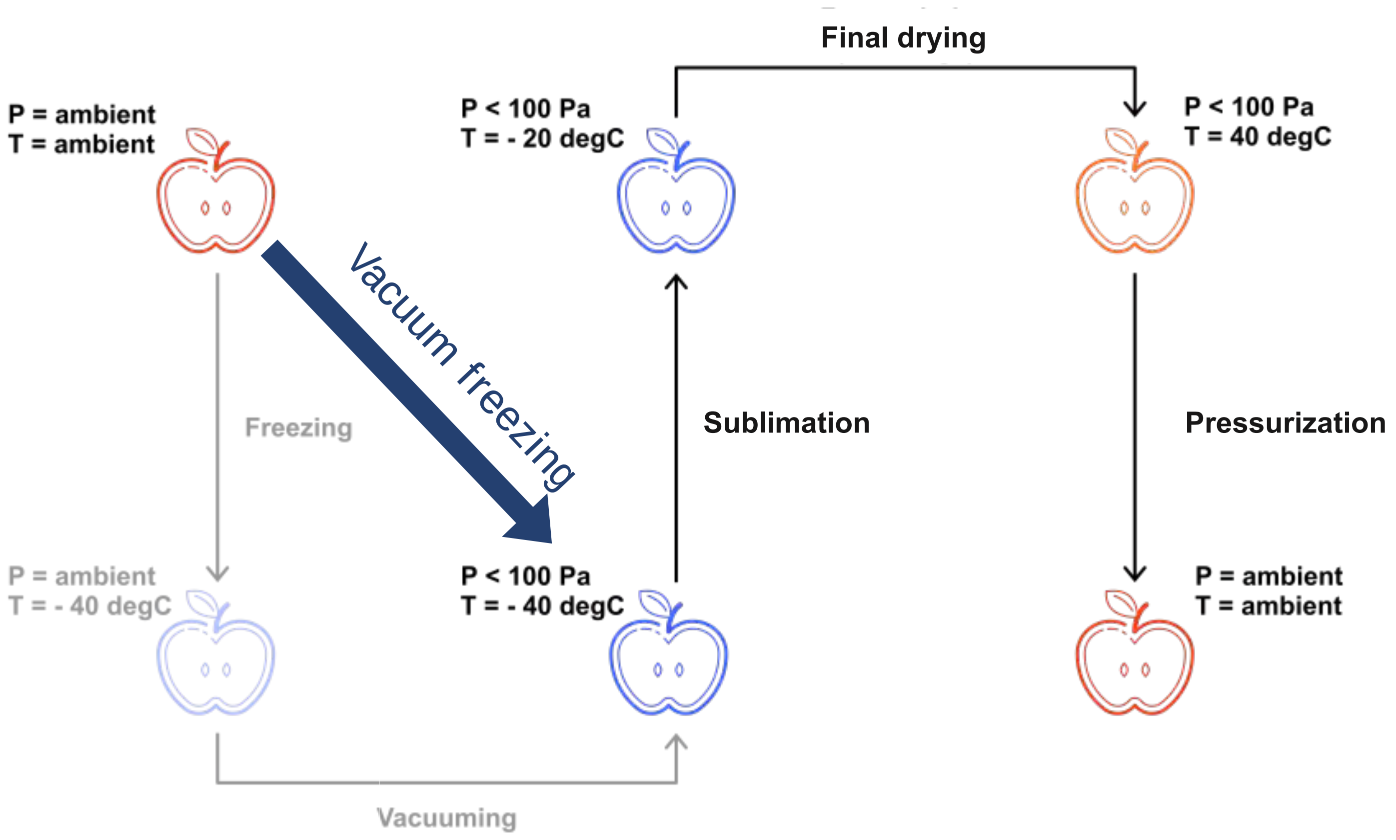
1. Freezing of fresh foods
2. Vacuuming
3. Sublimation
4. Final drying
5. Pressurization

IMPROVEMENTS IN FREEZE-DRYING TECHNOLOGY

- Refrigeration system based on the natural refrigerant
- Reduction of freezing time (e.g. application of Vacuum Freezing)
- Modification of the heating system (e.g. Microwave heating system)
- Scale down for domestic applications

IMPROVEMENT OF FREEZING PROCESS IN DOMESTIC FREEZE-DRYER

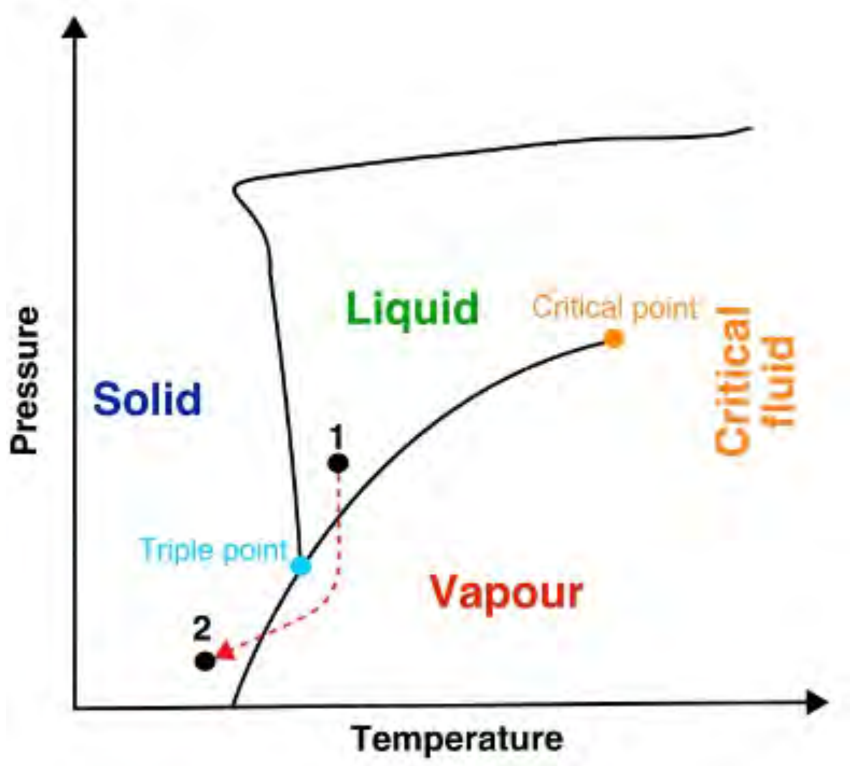
Application of the vacuum freezing at the first stage of freeze-drying process



- Reduction of freezing time
- Reduction of sublimation time

VACUUM FREEZING PROCESS

- Relatively new freezing technology
- Suitable for food products with high water content
- Heat removed due to the water evaporation
- Guarantees rapid freezing process
- Can be implemented in the domestic scale freeze-dryers



ENOUGH DOMESTIC SCALE FREEZE-DRYER

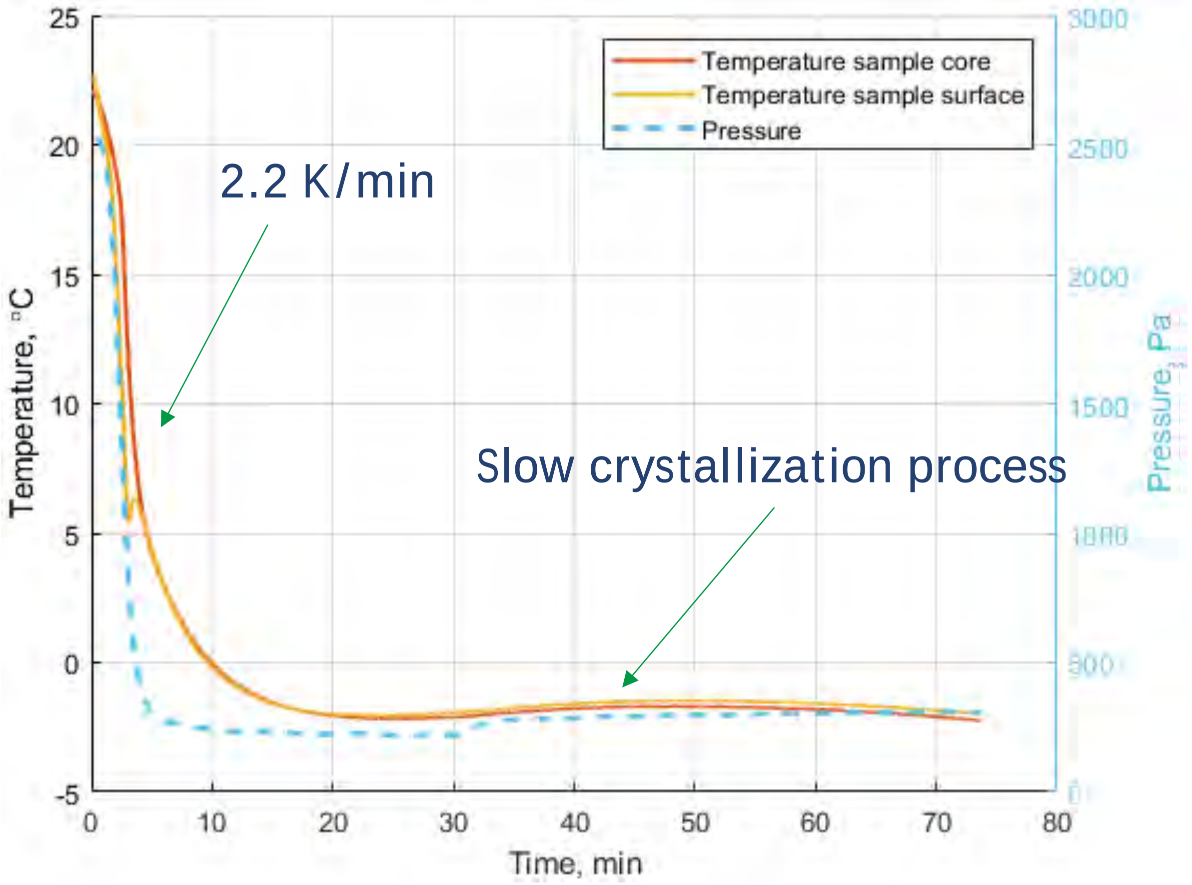
- "All-in-one" device (freezing & freeze-drying conducted in the single vacuum chamber)
- Compact design suitable for household applications
- Designed for up to 10 kg of fresh product
- Equipped with R290 refrigeration system
- Vacuum freezing implemented

ENOUGH Freeze-dryer manufactured by FrostX, Gliwice, Poland

RESULTS

- Vacuum freezing of potato slices

Frozen



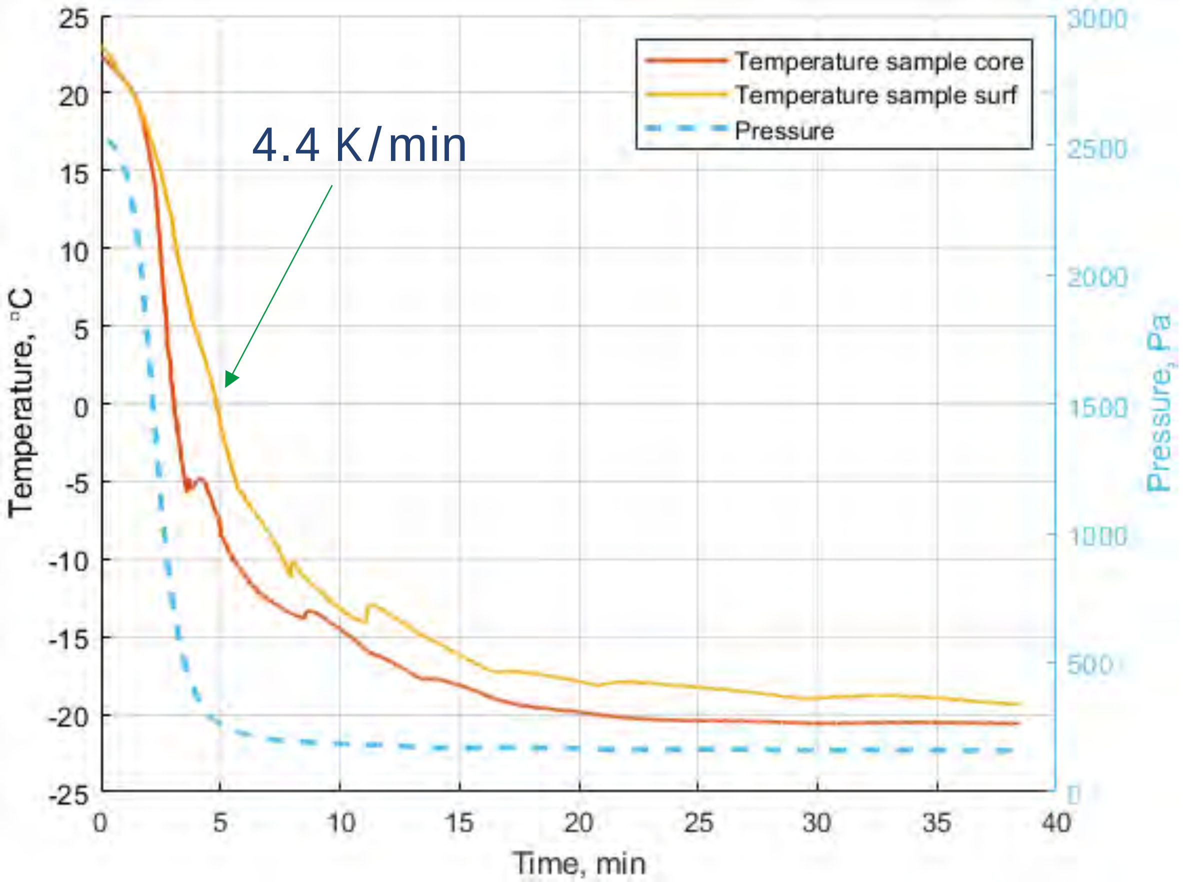
Temperature and pressure profiles for potato slices vacuum freezing

RESULTS

- Vacuum freezing of raspberries

During the process

Frozen



Temperature and pressure profiles for vacuum freezing of raspberries

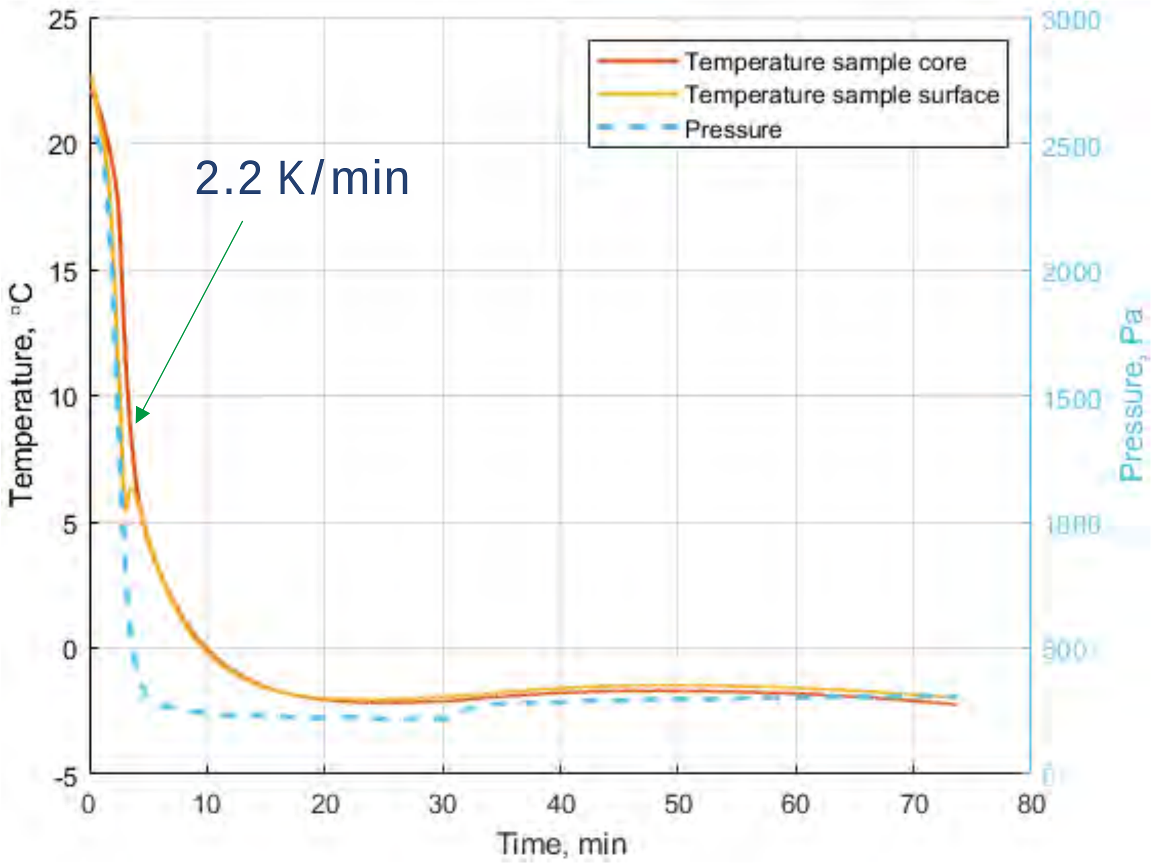
RESULTS

- Freezing rate for various food products

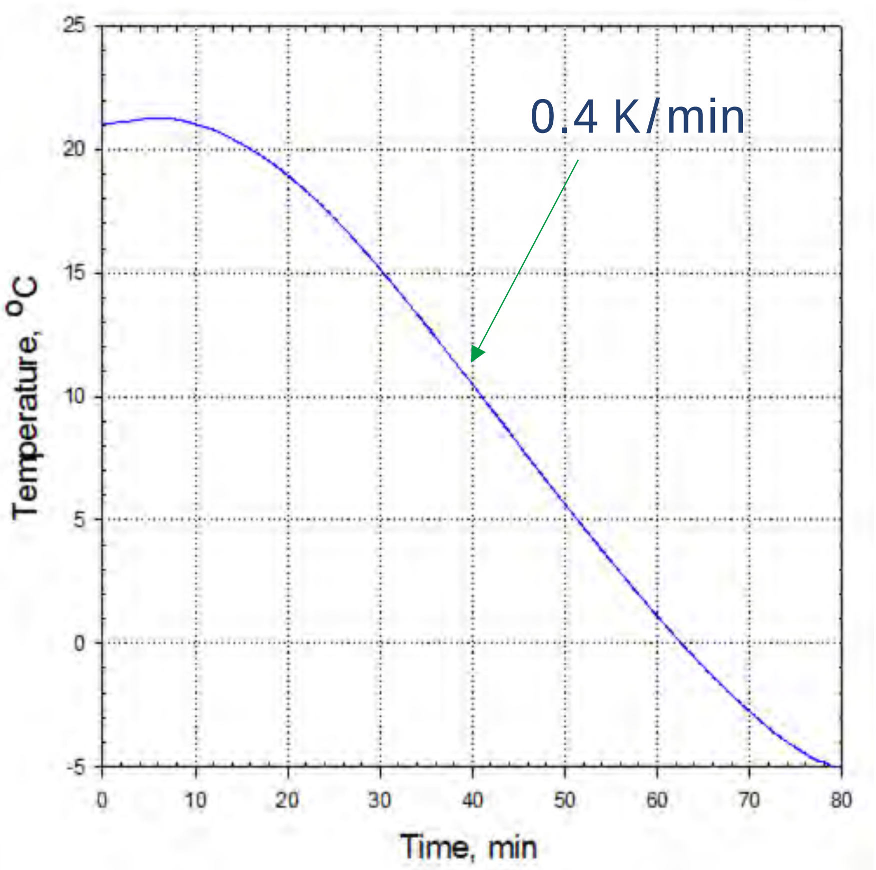
	Banana	Raspberry	Potato
Process time	20 min	20 min	20 min
Temp. decrease	20^oC to -5^oC	22^oC to -18^oC	22^oC to – 2^oC
Cooling rate	4.0 K/min	4.4 K/min	1.2 K/min
Mass loss	11%	19%	12%

RESULTS

Cooling rate 5 times higher for ENOUGH freeze-dryer



Temperature profile for ENOUGH freeze-dryer



Temperature profile for standard freeze-dryer

ON-GOING WORK AND FURTHER IMPROVEMENT

- Optimisation of the vacuum freezing control strategy
- Energy consumption comparison for standard and vacuum freezing aided freeze-dryers
- Detailed analysis of the integrated crystalliser performance

CONCLUSIONS

- Vacuum freezing technology was implemented in domestic scale freeze-dryer
- Initial control algorithm for vacuum freezing process was developed
- Vacuum freezing application resulted in rapid cooling process of the food samples
- The cooling rate for vacuum freezing was 5 times higher comparing to standard freeze dryer
- Up to 19% of water mass removal during the vacuum freezing
- Expected overall process time and energy demand reduction

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