



ICR 2023 Workshop:

Training on clean cooling and heating solutions

Natural Refrigerants



Monday 21st August
11:55-12:55
Room 352A

Chaired by Kristina N. Widell, SINTEF Ocean, Norway

Cooling -
responsible for
7% of global
GHG emissions

UN climate priority:
Highly efficient clean
cooling technologies

- High income countries – actions
 - F-gas regulation
 - PFAS
 - = more clean cooling solutions with **natural refrigerants**
- Low and medium income countries
 - Absens of regulations and initiatives?
 - How is the adoption of **natural refrigerants**?

Urgent and should be
accelerated!

Projects and centers behind this workshop:



INDEE

Future Refrigeration India:
INDEE+

CoolFish 

ACES



Africa Centre of Excellence for
Sustainable Cooling and Cold-Chain

Training and
education

Natural
refrigerants

Presentations

- Armin Hafner:
 - How to select the right natural refrigerant for a specific application
- Silvia Minetto:
 - How to talk about energy efficiency in refrigeration systems
- Alexander Pachai:
 - How to pass on safety practices in refrigeration systems
- Judith Evans:
 - How to communicate the resilience, sustainability, and equity of cold chains in developing markets.

How to select the right natural refrigerant for a specific application

Prof. Dr.-Ing. Armin Hafner

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How to convince the end-user?

- This is your major challenge!



How to convince the end-user?

- **Training and knowledge transfer**
 - **Understanding** that **clean cooling/heating** is not at all possible with non-natural working fluids
- **End-user awareness:** inform what kind of equipment they are ordering and become responsible for:
 - Material Safety Data Sheet [MSDS] of the working fluid
 - Seasonal energy demand and total GWP of the working fluid, including production & end of life
 - PFAS...



PFASs → per- and polyfluoroalkyl substances



ANNEX XV RESTRICTION REPORT

PROPOSAL FOR A RESTRICTION

SUBSTANCE NAME(S): Per- and polyfluoroalkyl substances (PFASs)



- addresses the risks to the environment and human health of the use of per- and polyfluoroalkyl substances (**PFASs**) and provides an assessment of the effectiveness, practicability, monitorability and socio-economic impacts of **two restriction options** (ROs) under REACH as the most suitable risk management option (RMO) to address the **identified risks**.

How to select the right natural refrigerant for a specific application?

Talk and understand what the end-user is looking for.

	CO ₂ / R744	NH ₃ / R717	HC	H ₂ O / R718	Air / R729
Domestic applications					
Commercial refrigeration					
Industrial refrigeration and heat pump systems,					
Water and space heating heat pumps					
Chillers					
Vehicle air conditioning					

Where to find the technical descriptions:



INDEE

Future Refrigeration India:
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ACES



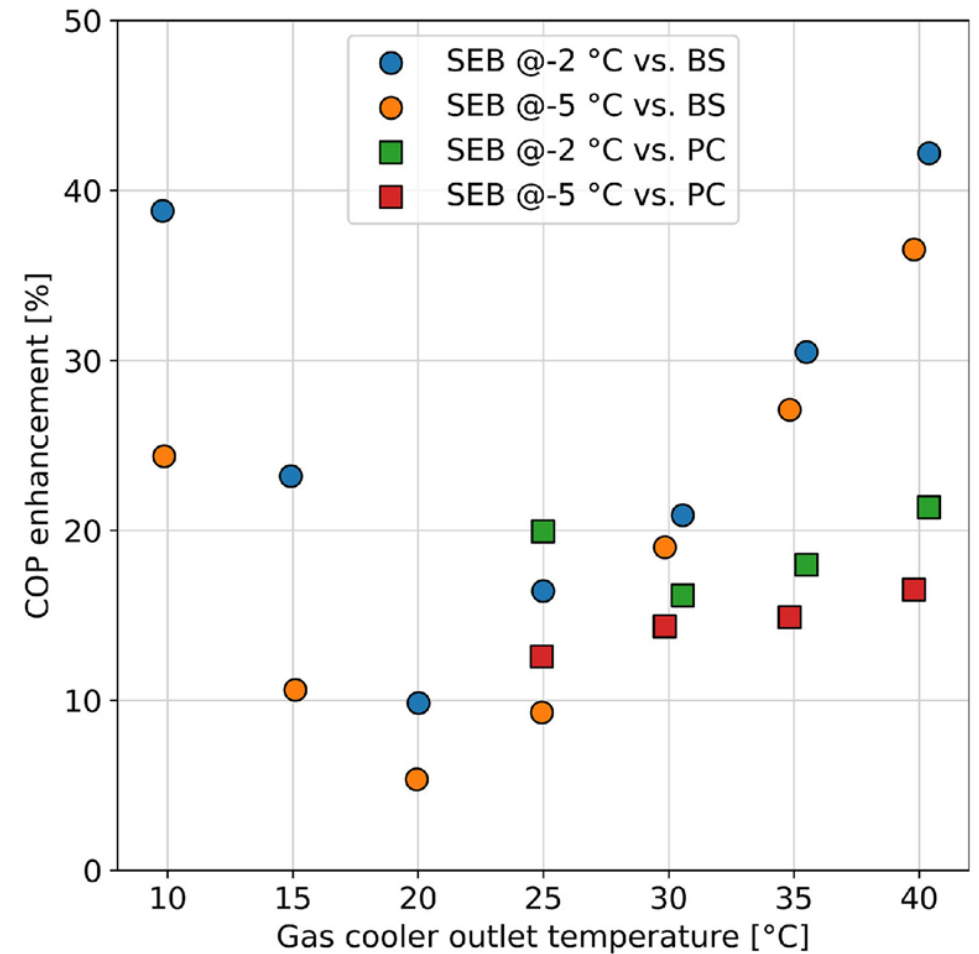
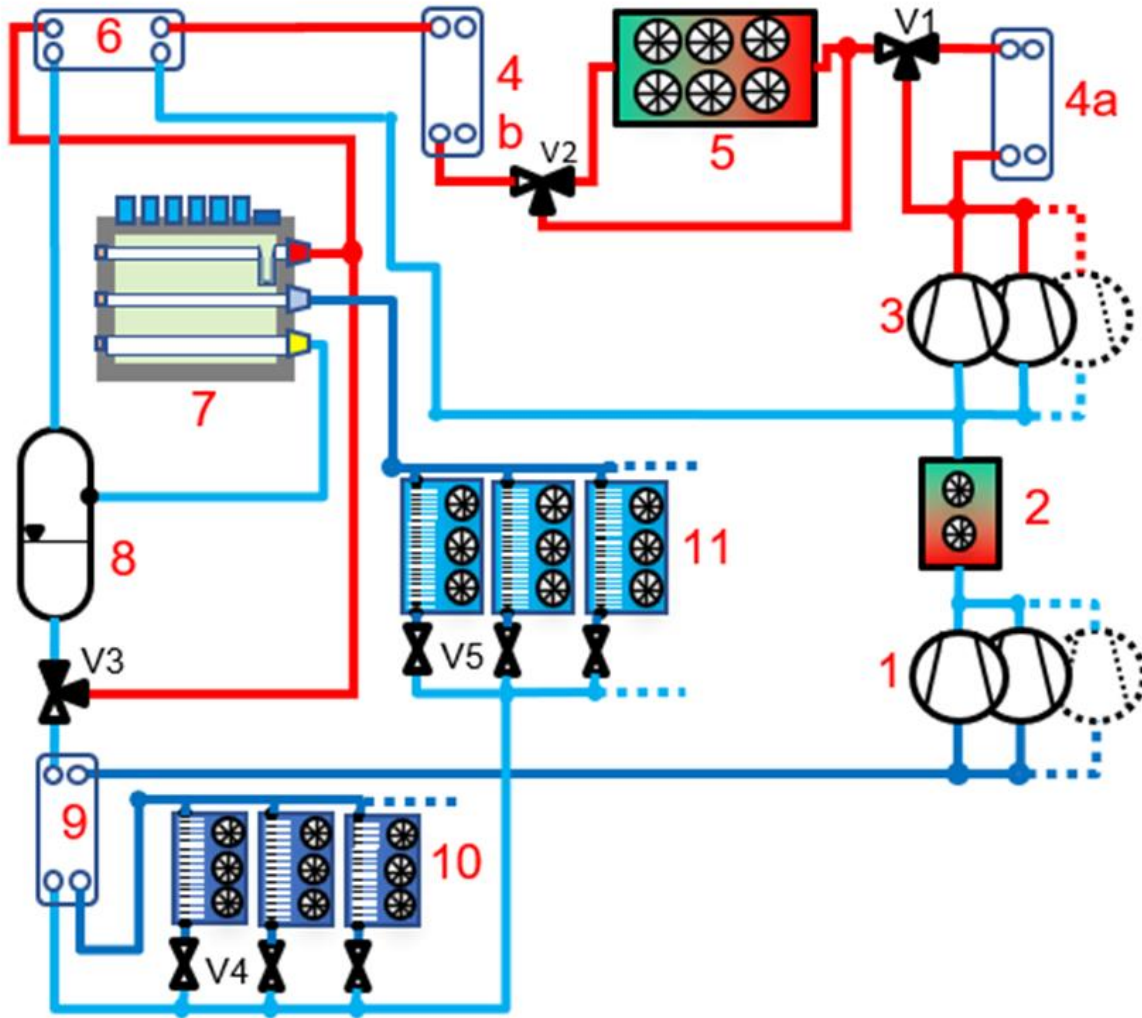
Africa Centre of Excellence for
Sustainable Cooling and Cold-Chain

And now some examples:

What kind of system* depending on demand?

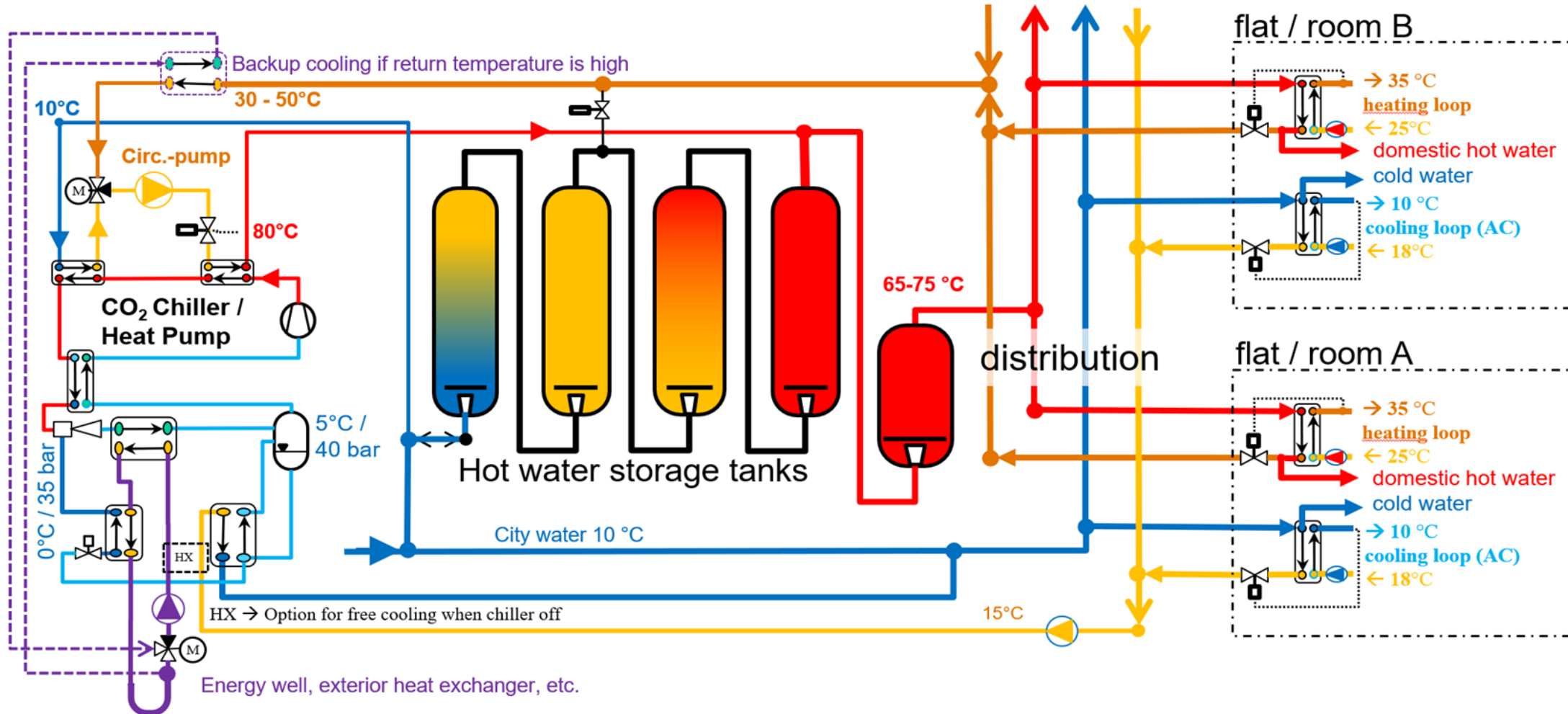
- Hot water demand (10 -> 75 °C): CO₂ heat pump
- Combined AC (12 -> 7 °C, or DX) and hot water demand: CO₂ heat pump chiller
- Industrial freezing av food: CO₂ (-50 °C, DX) NH₃ (-35 °C, DX and indirect)
- Industrial food storage: NH₃ (DX or with CO₂ as a secondary fluid)
- Comfort cooling (AC):
 - Homes: Propane (R290)
 - Trains: CO₂ or Propane (R290)
 - Cars/vehicles: CO₂ or R290
- High temperature heat pumps:
 - District heating: NH₃, CO₂, combined CO₂ and R600 (butane)
 - Industrial units: water (R718), hydrocarbons

Supermarket refrigeration ? (Example R744 / CO₂)

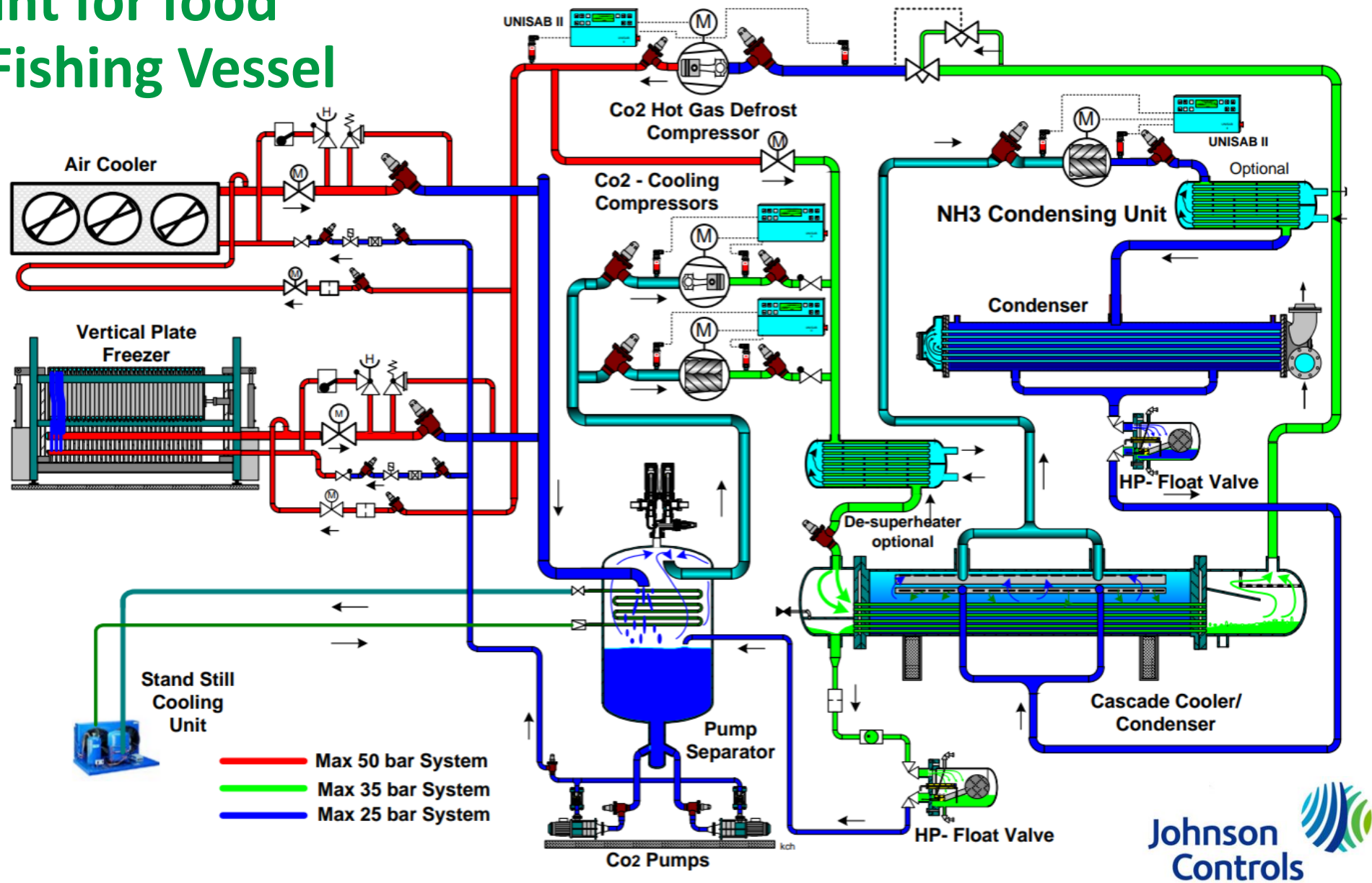


Source: Ángel Á. Pardiñas et al. Next generation of ejector-supported R744 booster systems for commercial refrigeration at all climates, Int. J. Refrig., 2023, <https://doi.org/10.1016/j.ijrefrig.2022.10.027>

Example: Heat pump Chiller with CO₂



Freezing plant for food → inside a Fishing Vessel



Freezing plant for food

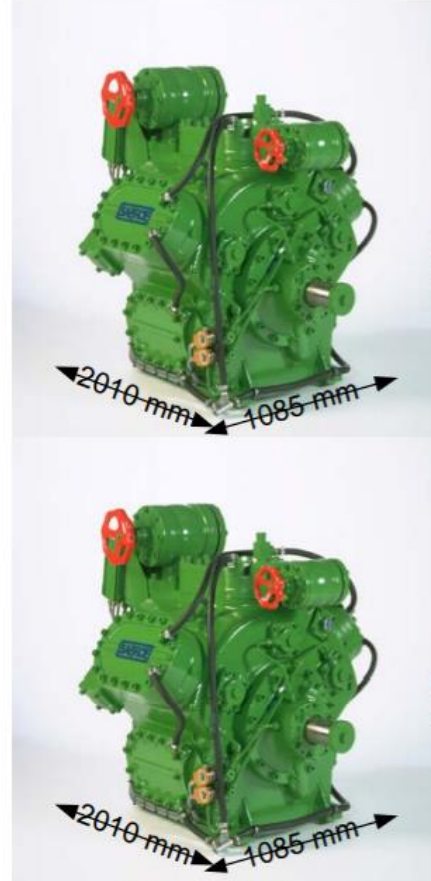
→ inside a Fishing Vessel, where size matters

100 kW@-40/-5°C

Data
Suction line [mm]
Discharge [mm]
Liquid line [mm]



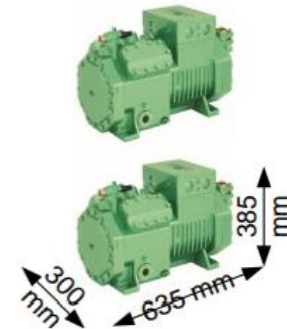
Comparing 100 kW@-40/-5°C



NH3 691 m³/h
1085 kg x 2 without motors



R22 vs R404A
550 m³/h 446 m³/h
1100 kg without motor



R744 63 m³/h
144 kg x 2 with motor

Freezing plant for food

→ inside a Fishing Vessel, all CO₂



SuperFreeze

Evaporation temperature: -50 °C

Capacity range: 50 - 500 kW.



Split AC unit → R290 is there...

Price / Energy Efficiency Analysis of 52 Offered 3.5 kW
Inverter Split-AC Models in German Retail (Online Research,
October 2021)



Midea

<https://www.midea.com> › dam › inverter-ac › S..

Safety Instruction (R32+R290)

Table.1-2 Min. Room Area (m²)

Refrigerant Type	LFL(kg/m ³)	Installation Height H0(m)	Charge Amount in kg Minimum Room Area (m ²)						
			1.224kg	1.836kg	2.448kg	3.672kg	4.896kg	6.12kg	7.956kg
R32	0.306			29	51	116	206	321	543
		0.6		10	19	42	74	116	196
		1.0		3	6	13	23	36	60
		1.8		2	4	9	15	24	40
		2.2							
R290	0.038		0.152kg	0.228kg	0.304kg	0.456kg	0.608kg	0.76kg	0.988kg
		0.6		82	146	328	584	912	1541
		1.0		30	53	118	210	328	555
		1.8		9	16	36	65	101	171
		2.2		6	11	24	43	68	115

Mobil AC and heat pump system for vehicles



How to accelerate phase-in of clean cooling units applying Natural Working Fluids globally?

World Bank, Multilateral funds, national governments and funding programs should support end-users (investors) to cover additional first costs for cooling units applying natural working fluids with affordable loans following the unit. So, the **end-users (operators)** can return the debt during the operational phase.

Investment in **clean** cooling/heating is often 'killed' by slightly higher capital expenditures (CapEx) for new energy efficient NWF systems.

However, these units give significant operation expense (OPEX) savings for the operator.

Summary

- **Food is valuable** and essential for humankind
 - safe and reliable refrigeration equipment is needed to reduce food loss
- **Safety at work** is also important for responsible companies
 - Nobody should become sick due to refrigerants
 - Natural refrigerants are a safe choice
- **Environmental impact** of major importance
 - Only **natural working fluids will survive** towards 2050 (2030?)
 - Great energy efficiency improvements can be achieved
- Let's cooperate and focus on clean cooling

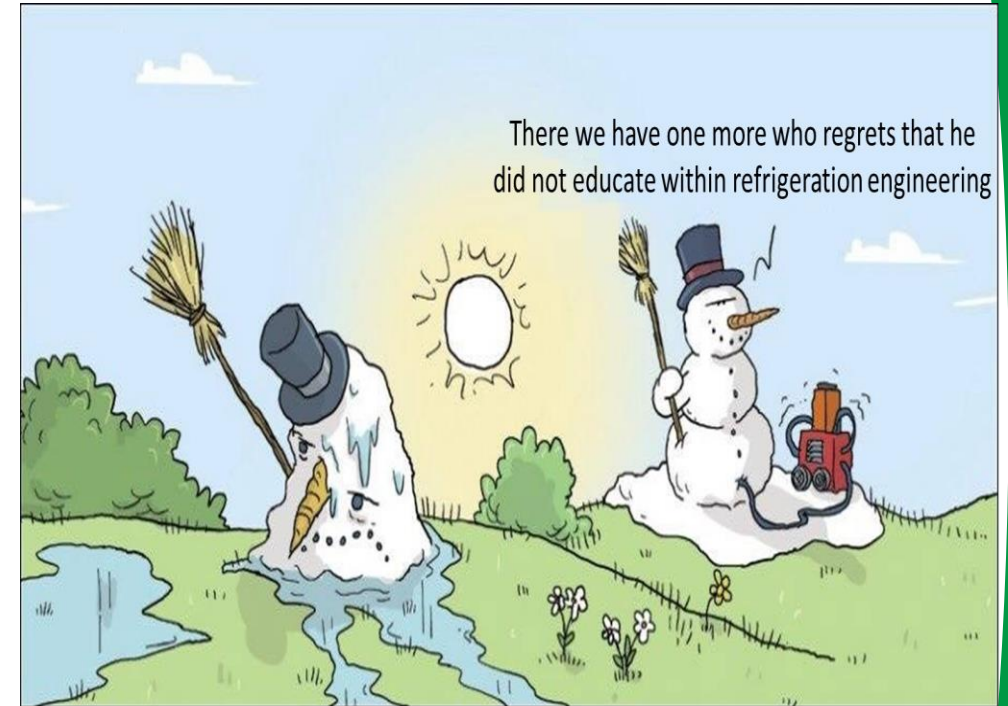
Conclusion

From 2023 on, reminded by the PFAS restriction proposal, there should be now doubt that **our sector must leave the artificial refrigerant chapter**, the sooner the better.

How dare you to continue jeopardizing the ground water sources, food, and health!

Take home message

- Together – lets cooperate and exchange knowledge
- Let's keep it cool – don't waste food
- Keep it all natural



THANK YOU FOR YOUR ATTENTION
Questions are welcome?



How to talk about energy efficiency in refrigeration systems

Silvia Minetto

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What is energy efficiency?

Energy efficiency relates the desired result with resources used to get it

“**Doing more with less**” (EU, 2005)

“ **First fuel** ”, the fuel that you do not need to use

Figures in refrigeration

C.O.P. Coefficient of Performance relates the useful effect to the input

2nd law efficiency is a powerful mean of comparing the actual work needed to provide a certain useful effect to the ideal one; it also allows to identify major losses, but it is not widespread in the sector

What are the benefits of energy efficiency?

Energy savings (reduction in energy consumption: spend less to get the same result)

Lower environmental impact (reduction in greenhouse gases and other pollutants)

Energy security (less dependency on imported energy)

and

Reduced energy costs

Increased economy competitiveness and job creation

What about refrigeration?

Useful effect in refrigeration **not always clearly definable**, as it also involves “quality”, like product quality/safety or comfort

Many **EEI**, to take care of **specific services** provided and **boundaries** and to promote **fair** comparison

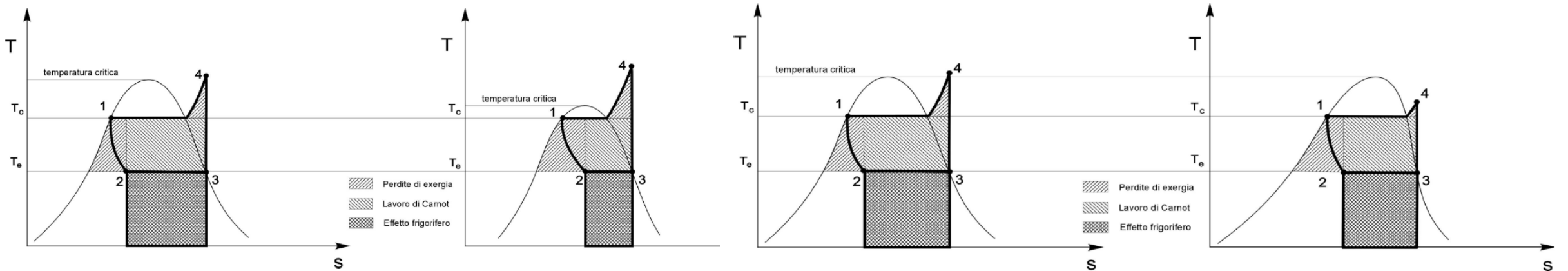
Real demand for selecting the **best option amongst different systems**, especially when new/renewed solutions come to the market to comply with sustainability goals

How to define a « **fair** » comparison in terms of energy efficiency and how to handle it?

Present long term options: natural refrigerants

Present **long-term sustainable options** for VCC refrigeration are **NH₃, CO₂, HC**

Intrinsic losses are in favour of high critical temperature fluids (throttling) and high mass ones (desuperheating)- **Improved cycles** are required to **mitigate**



But many **other refrigerant properties** impact on efficiency

Technological aspects (components size, design, components performance etc),
safety and actual applicability must be considered

Ref: Corradi, 2004, Analisi teorica e sperimentale di sistemi frigoriferi operanti con CO₂, PhdThesis, Padova University

Comparison basis

Finding **the right basis** is a key for comparison

- What is the right temperature approaches and differences when comparing a subcritical and transcritical cycle? (NH_3 or HC vs CO_2)
- What is the right temperature difference in refrigerant/secondary fluid heat exchangers when comparing DX/direct heat rejection systems (CO_2) to secondary fluid systems (NH_3)
- What is the right temperature difference in evaporator/condenser cascade systems when comparing cascade (NH_3/CO_2 or HC/ CO_2) to double stage systems (CO_2 or NH_3)?

Message:

It is very difficult to find homogenous boundaries for comparison

What happens out in the field may be much different from what is expected.
Always cross check assumptions with real data

Unconventional solutions

The need for improving efficiency should stimulate development of **innovative solutions** or borrowal of technologies from other sectors

Example:

Revolution in **DX multiple evaporator system feeding** with transcritical CO₂:

Superheat removal allows for 4-5 K evaporation temperature increase in commercial refrigeration (COP increase up to 15%)

Message: efficiency seek stimulates out of the box solutions

Non-technological barriers (social, behavioural, legislative) to be addresses

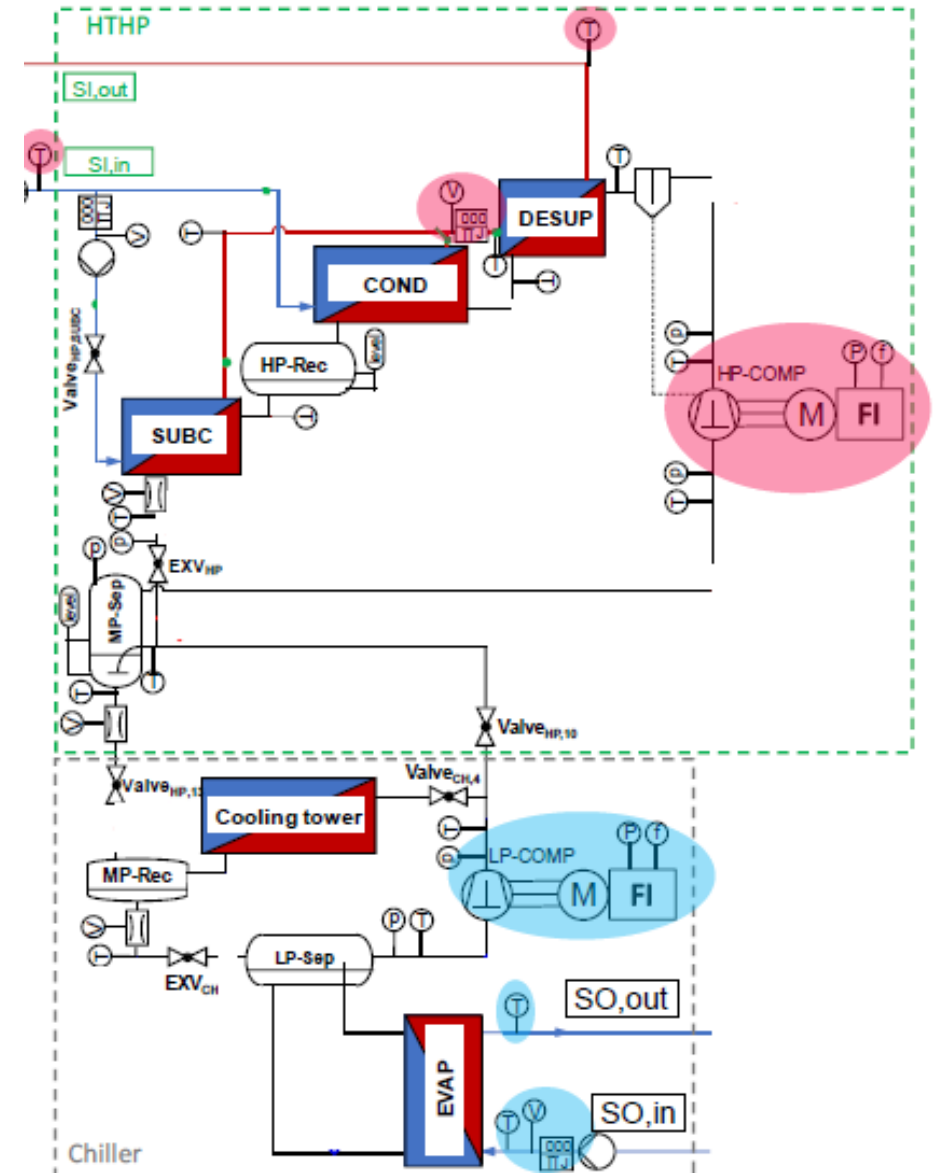
Adequate regulation for innovative solutions

Select proper domain for efficiency calculation

Example:

NH₃ Chiller and NH₃ HTHP developed within ENOUGH project. Useful effects: hot and cold water

Measurement of individual and total COP and PF, under steady state and transient operations



Select proper domain for efficiency calculation

Example:

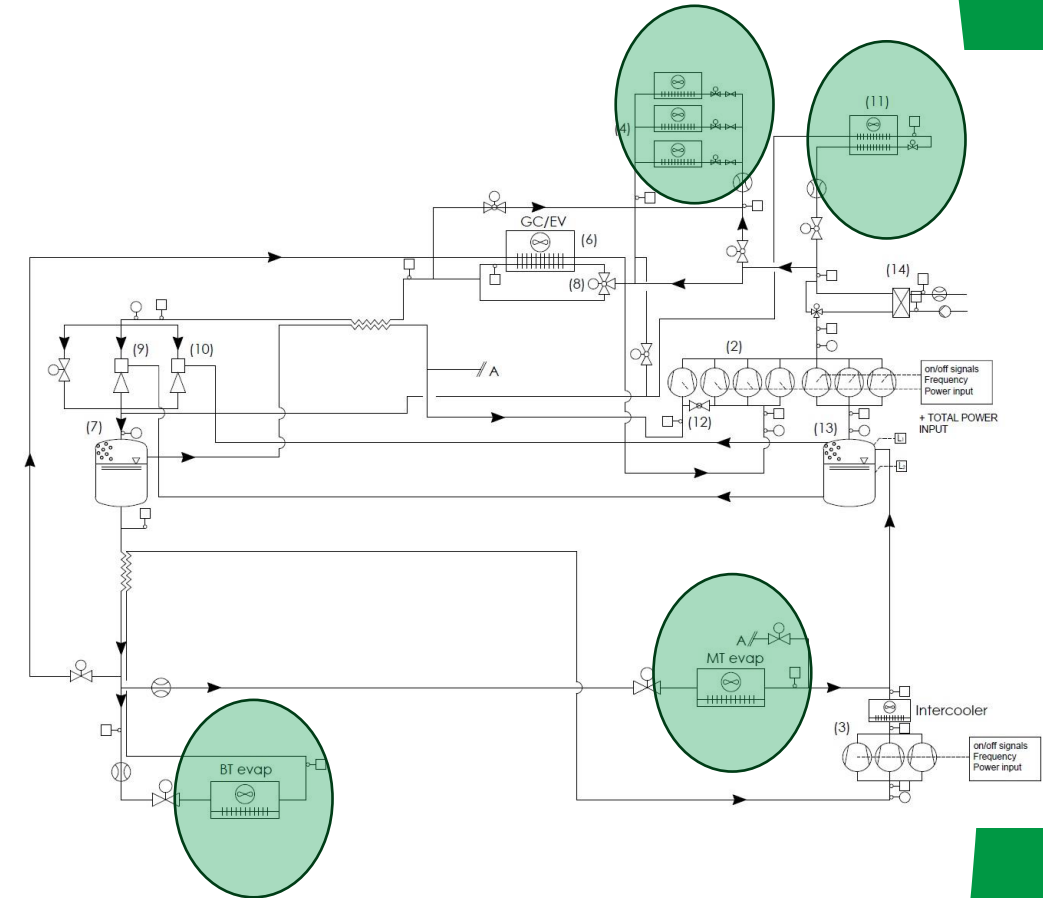
Integrated CO₂ supermarket system

Useful effects: MT and LT refrigeration, space heating, space cooling and DHW

Measured annual specific energy consumption 25% lower than average national (Italy) value

Message: exploit fluid properties and adapt layouts to **integrate/invent** services.

Identify suitable EEI to benchmark the system



Overcome behavioural habits

Some **constraints** come from previous technologies and less sustainable approaches

Critical **revision of habits and usual approaches** to check if more sustainable working conditions are possible

Example:

when using traditional fossil fuel burners, water delivery temperature is typically 80°C

Do we need this temperature? Is there any chance to decrease the average temperature to promote heat pumps?

Message: use the need for more sustainable technical solutions to **revise traditional approaches** and **explore new possibilities** to provide the same (or better !) service with less

Conclusion

- Within a limited number of options (natural refrigerants), **boundaries** (safety, space, size, weight, components availability, cost, service, etc...) **are relevant** for selecting the right fluid
- Efficiency is not limited to a single « number » but must **account for services** and **direct and indirect** benefits. **Additional services** might be discovered with natural fluids
- **The best** out of each fluid must be taken, **exploiting its peculiarities** and accounting for all benefits in the efficiency calculation

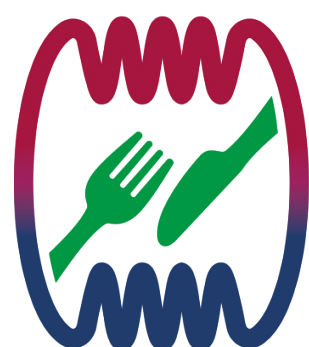
Conclusion

- **Not just try to target the reference «high GWP old technology»** but achieve high efficiency, satisfactory service and overall benefit
- Efficiency determines **operational costs**...to be reminded when investing on a new system

We do not need to set a one-to-one comparison....we need to find the best long-term sustainable efficient solution for our needs



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



ENOUGH

EUROPEAN FOOD CHAIN SUPPLY
TO REDUCE GHG EMISSIONS BY 2050



enough-emissions.eu





How to pass on Safety Practices in refrigeration systems

- Alexander Cohr Pachai
- ACP Global Consultancy ApS, Denmark
- Alex.Pachai@gmail.com

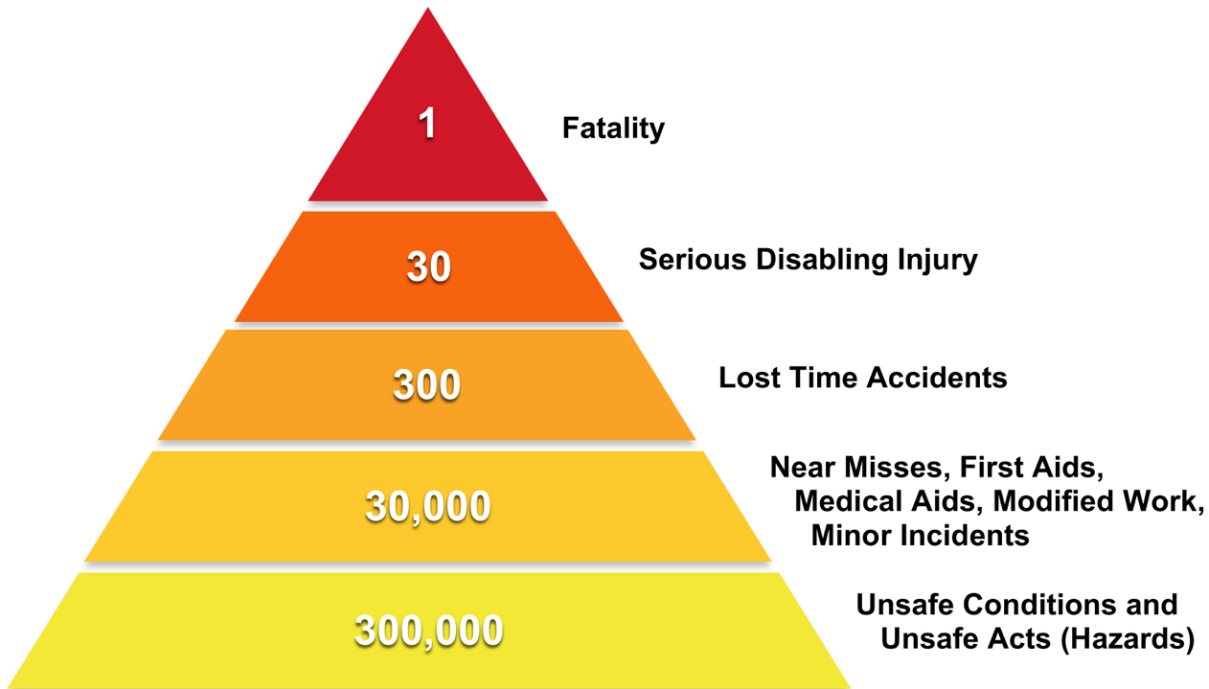
Accidents or incidents – a few words

- The incidents are caused due to 3 broad reasons
 - a) Technical glitch b) Human Performance c) Missing barrier
- Heinrich's Theory:
 - 1) Behind every accident there is a cause
 - 2) Accident don't happen but they are caused
 - 3) 78% of accidents cause due to unsafe act
 - 4) 20% of the accidents are due to unsafe condition

Different ways of estimating the risk

SAFETY PYRAMID

It is far better to be reporting and learning from Near Misses, Minor Incidents and Hazards, where there is little or no loss, than to be reporting actual serious losses.



Heinrich's triangle



Accidents and safety



The most common accident



Avoid distraction

Safety of the system – a short conclusion

- Following standards, guidelines and codes of good practice has reduced the number of accidents
- Some accidents happen when technicians are not properly trained and informed
- Updates from suppliers must be made available also to staff in the field
- Lessons learned by others should also be discussed at meetings in the company
- Finally: A more open culture about risks and near miss situations if we want to pass on safety culture to the coming generations

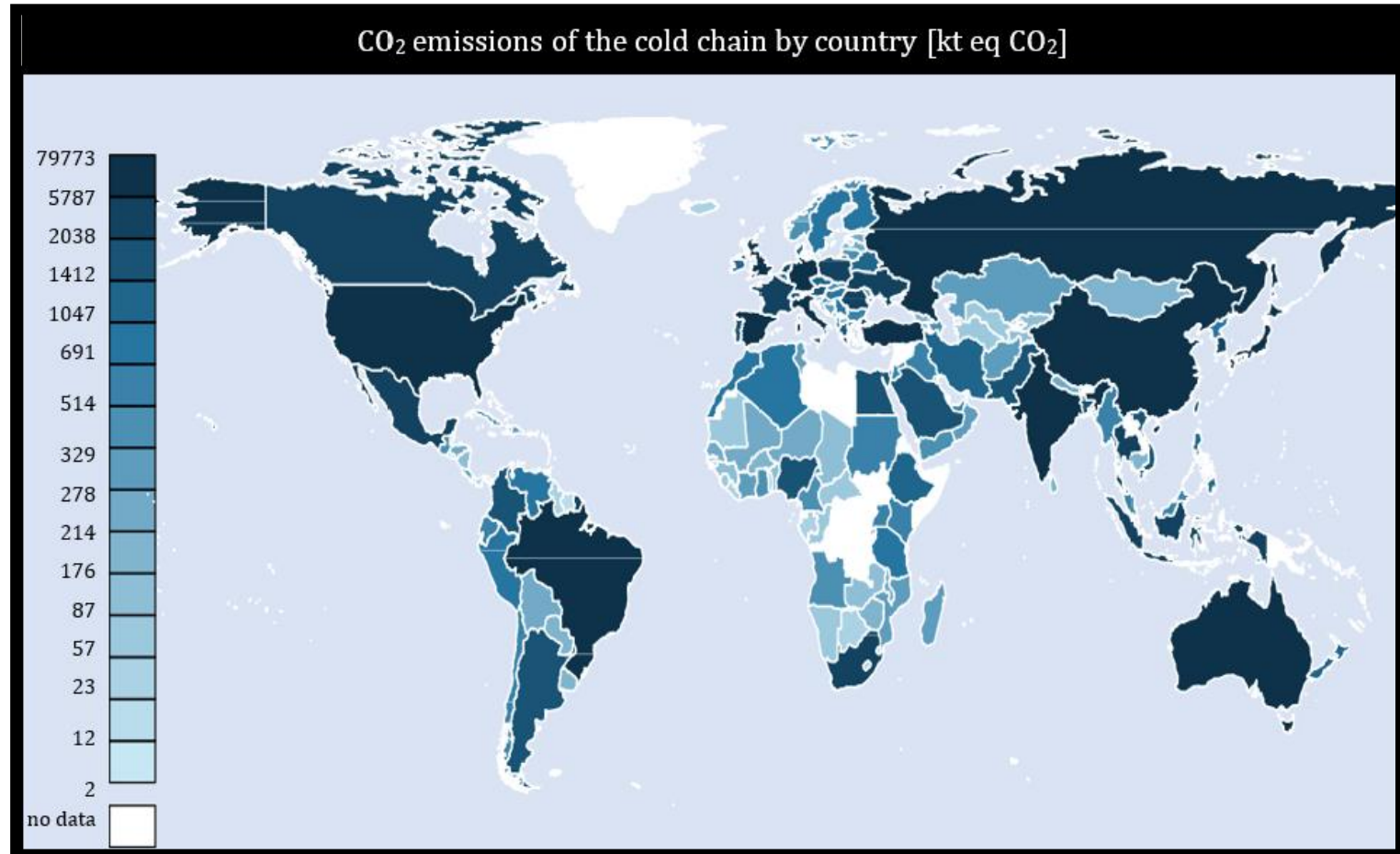
Thank you for your attention

How to communicate the resilience, sustainability, and equity of cold chains in developing markets

Prof. Judith Evans, LSBU

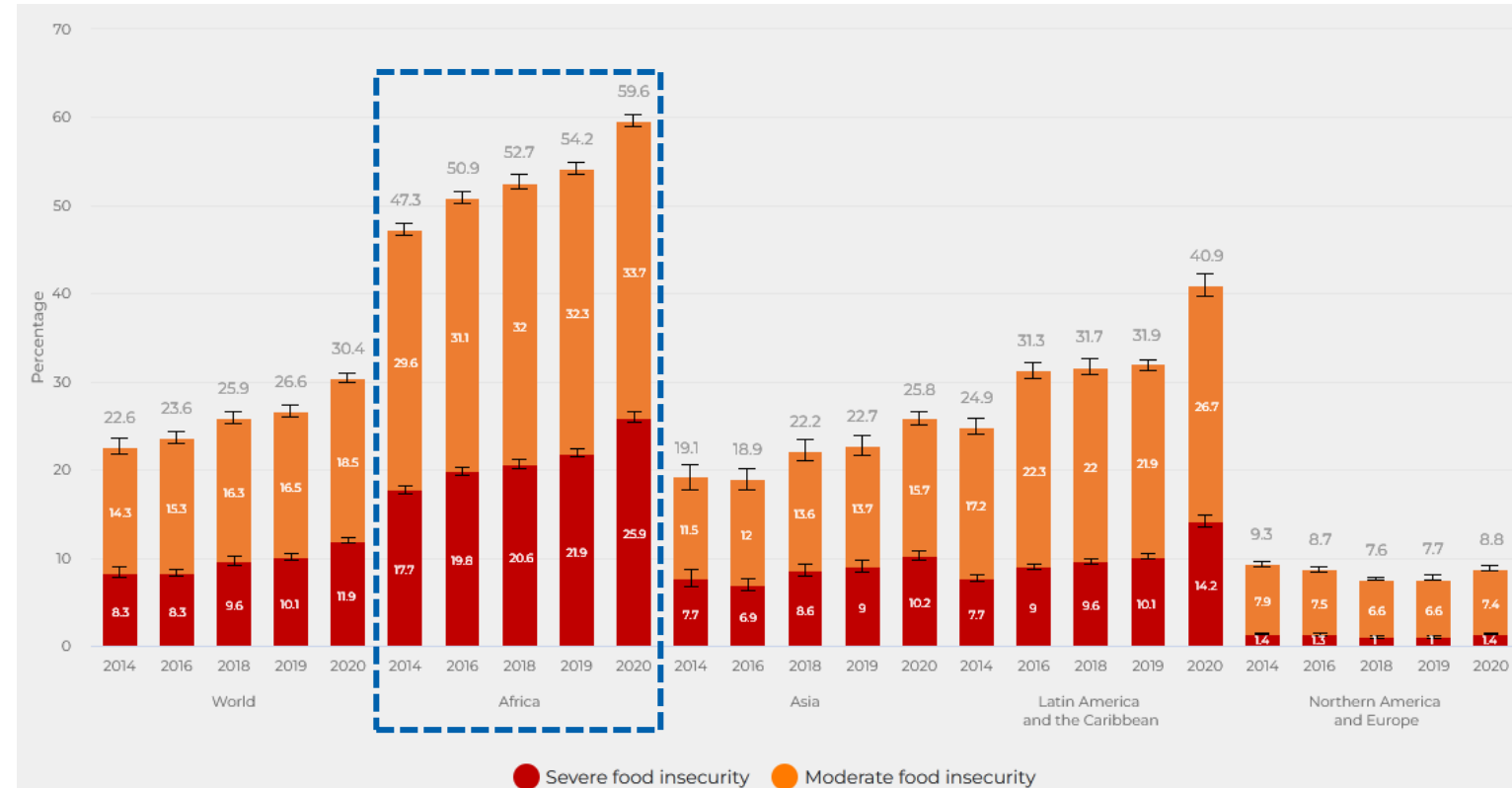
Emissions

- ✓ 26-35% of global greenhouse gas emissions are a result of food and agriculture¹
- ✓ ~18-29% of these emissions are related to the food supply chain (the remaining proportion is related to land use, crop and animal production)²
- ✓ 9–14% from crop and livestock activities within farm gate
- ✓ 5–14% land use and land-use change including deforestation and peatland degradation
- ✓ 5–10% from supply chain activities (includes GHG emissions from food loss and waste)³
- ✓ Total carbon emissions from the global cold chain ~1,265 Mt CO₂eq⁴



Food security

- ✓ Food security
 - ✓ United Nations' Committee on World Food Security definition: 'All people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life'
- ✓ Food loss
 - ✓ 13 % of the food produced in the world lost because of a lack of refrigeration (estimated >475 million tons)
 - ✓ In sub-Saharan Africa, ~37% of ALL food is lost
 - ✓ Lack of pre-cooling estimated to account for nearly 50% of these losses
- ✓ Food safety
 - ✓ According to WHO, almost 1 in 10 people contract foodborne diseases every year
 - ✓ 420,000 deaths, including 125,000 children <5 years, African and SE Asia highest burden

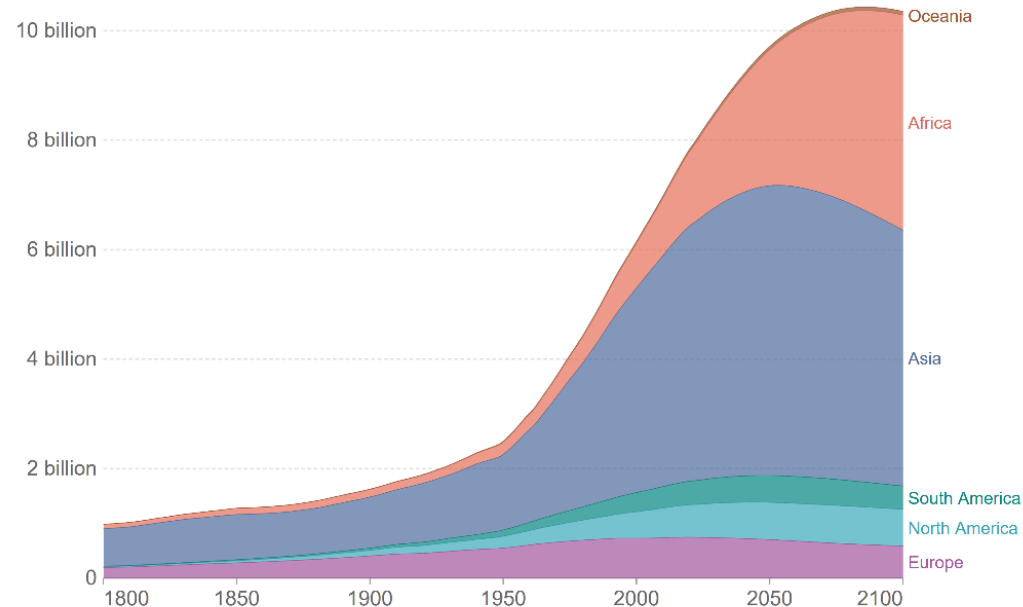


Population growth

- ✓ 8 billion in 2022
- ✓ Predicted to increase to 10.4 billion by 2100
- ✓ Differences between regions

Population by world region, including UN projections

Historic estimates from 1950 to 2021, and projected to 2100 based on the UN medium-fertility scenario.

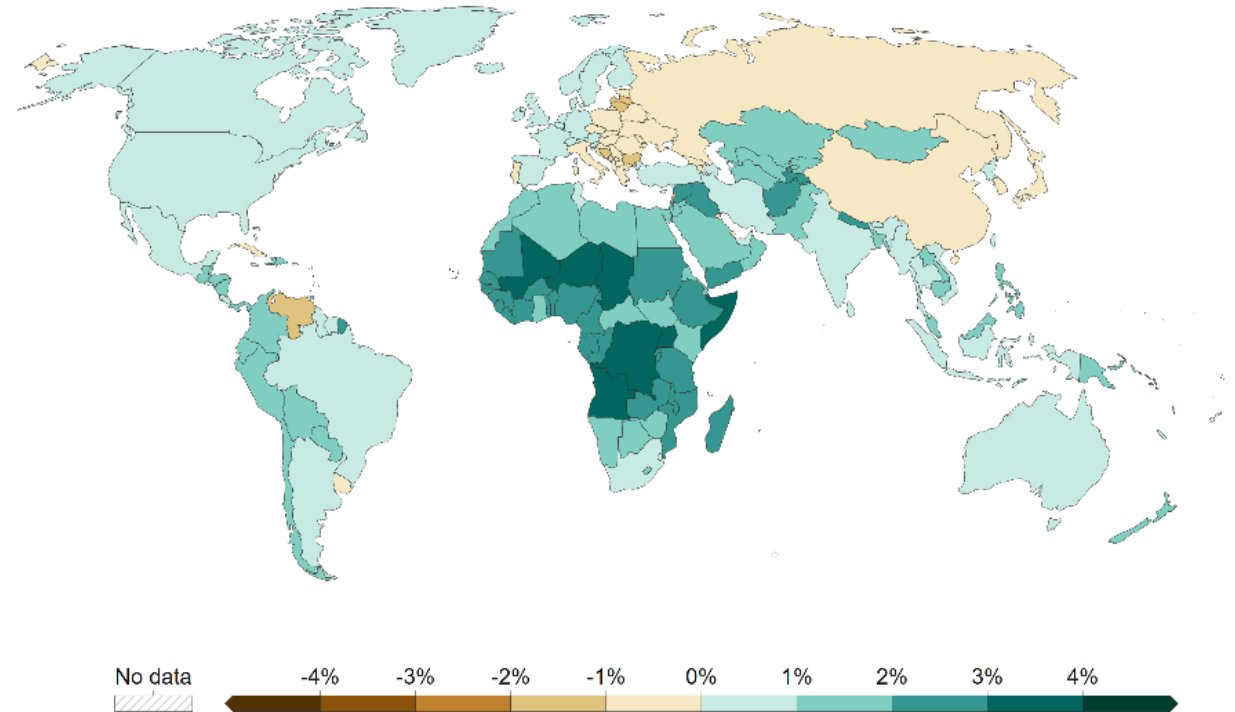


Source: HYDE (2017); Gapminder (2023); UN (2022)

OurWorldInData.org/world-population-growth/ • CC BY

Population growth rate, 2021

This takes births, deaths and migration into account. Historic estimates from 1950 to 2021, and projected to 2100 based on the UN medium-fertility scenario.



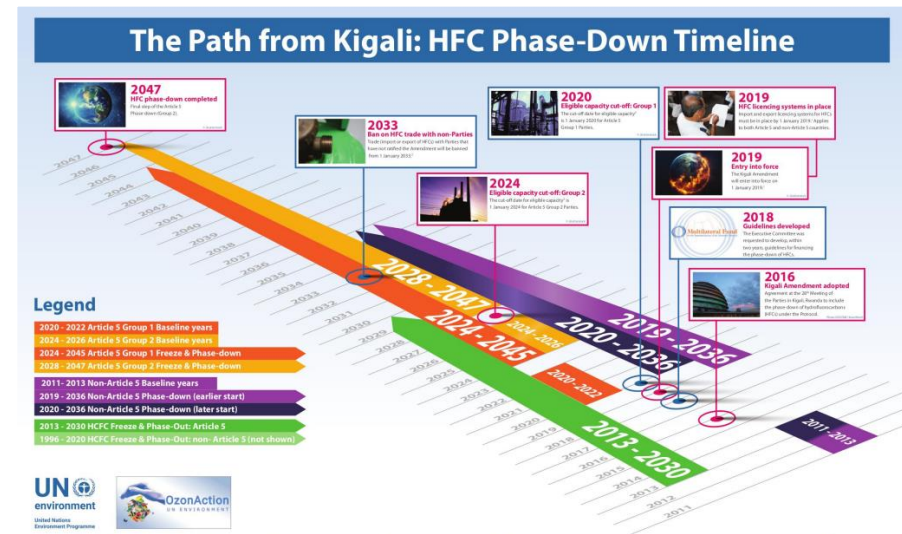
Source: United Nations, World Population Prospects (2022)

OurWorldInData.org/world-population-growth/ • CC BY

Growth is in areas where there is least cold chain development and greatest food loss

Challenges

- ✓ Some technical:
 - ✓ Design of equipment
 - ✓ Use of pre-cooling
 - ✓ Refrigerants
- ✓ Fragmented nature of agricultural land-holdings
- ✓ Resources (land, water, energy, human capital/skills)
- ✓ Business models - models used in more industrialised countries may not always be successful in LMIC
- ✓ Funding - lack of access to finance
- ✓ Knowledge in post-harvest biology and technology, leading to food loss and waste, technical skills to operate and maintain facilities
- ✓ Lack of appropriate training
- ✓ Global warming



What are we doing: ACES

- ✓ **Develop, test, demonstrate and deploy fit-for-market pathways to net zero cold-chain and cooling at scale in Africa**
- ✓ Economically empower farmers and fisheries, increase export revenues, enhance job creation in rural areas
- ✓ Improve nutrition, healthcare and quality of life
- ✓ Mitigate climate and environment impacts and foster low-carbon development
- ✓ Exchange lessons learned via a hub-and-spoke model
- ✓ Also working in India (Haryana and Telangana)



Facilities



✓ 4.8 hectare Kigali: Rubirizi Campus - ACES HQ



✓ Demonstration hall

✓ Chilling (air, vacuum)

✓ Freezing

✓ Storage rooms

✓ CA rooms

✓ Environmental room



✓ Solar powered cold room



✓ Refrigeration training facility

✓ Telemetrics lab

✓ Conference facilities

✓ Supporters area



✓ Offices

✓ Incubation facilities

✓ 200 hectares next to Rubirizi for ACES model smart farm – fully integrated farm-fork

Rubirizi campus

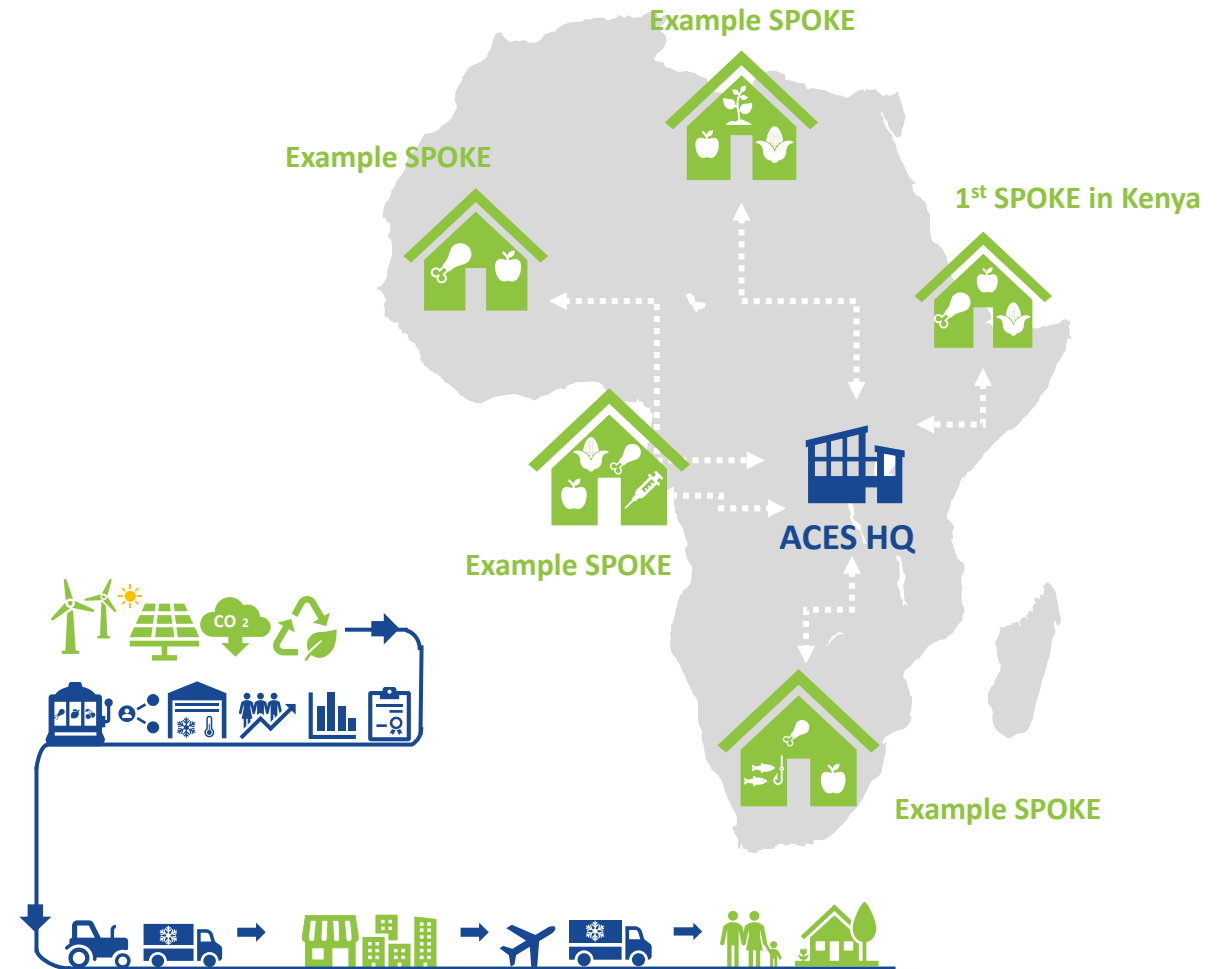


Model farm



ACES “Hub and SPOKE” approach

- ✓ Specialized Outreach and Knowledge Establishments (SPOKES) deployed in strategic locations as real-world applications
- ✓ Specializing in particular needs and opportunities for local markets
- ✓ Fixed and mobile assets – holistic and integrated system approach
- ✓ Provide technical assistance, demonstrations and knowledge transfer
- ✓ SPOKES in Kenya, Rwanda, proposed Senegal, Lesotho, Nigeria
- ✓ Try before you buy



Training

- ✓ Absolutely critical to develop cold chain
- ✓ Flagship programme support development of business models and access to finance
- ✓ Covers:
 - ✓ Needs assessment
 - ✓ Specification, design and commissioning of facilities
 - ✓ Operation
 - ✓ PHM
 - ✓ Finances
 - ✓ Developing a business plan

FIVE PILLARS				
I	II	III	IV	V
Comprehensive flagship programme for farmer co-operatives	Business accelerator	Individual Modules and academic short courses building out to MSc	Refrigeration engineers	Train the trainer
Industry body accredited professional courses and certifications				

Whole-system approach is essential

Enable farmers and companies to deploy sustainable cold chain solutions at scale with fit-for-market technologies and business models



R&D on comprehensive food and vaccine cold-chain solutions

- Future-proof, localised solutions for food loss and supply chain resilience
- Specifications and best practices for refrigeration, pack houses, logistics, etc.
- Integration of renewable energy, e-logistics and other advanced solutions
- Assess market gaps, leverage data acquisition and modelling capabilities
- Collaborative research



Develop, test and demonstrate best available technologies

- Demo hall, SPOKES, TBYB



Deploy solutions and increase market connectivity and uptake

- Implement sustainable business models
- Foster linkages between entrepreneurs, investors, agri-businesses
- Encourage use of standards and certifications



Enhance capacity and raise awareness of rural communities

- Capacity building in the field for farmers and technicians
- Training and skills (inc. installation and maintenance)
- Skills development and innovation support for students and start-ups
- Disseminate key findings, exchange learning, orchestrate communications campaigns on benefits of sustainable cold chain



Contact

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[ACES Webpage](#)

Find out more:

[Industry flyer](#)

[General flyer](#)

Closure & how to get more information?

- enough-emissions.eu
- www.sintef.no/en/projects/2019/coolfish
- <https://www.ntnu.edu/indee>
- <https://coolingafrica.org/>
- <https://www.sustainablecooling.org/>



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Africa Centre of Excellence for
Sustainable Cooling and Cold-Chain

CoolFish 



India-Norway
Collaboration
2021-2024

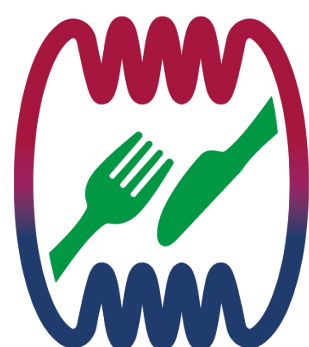
INDEE

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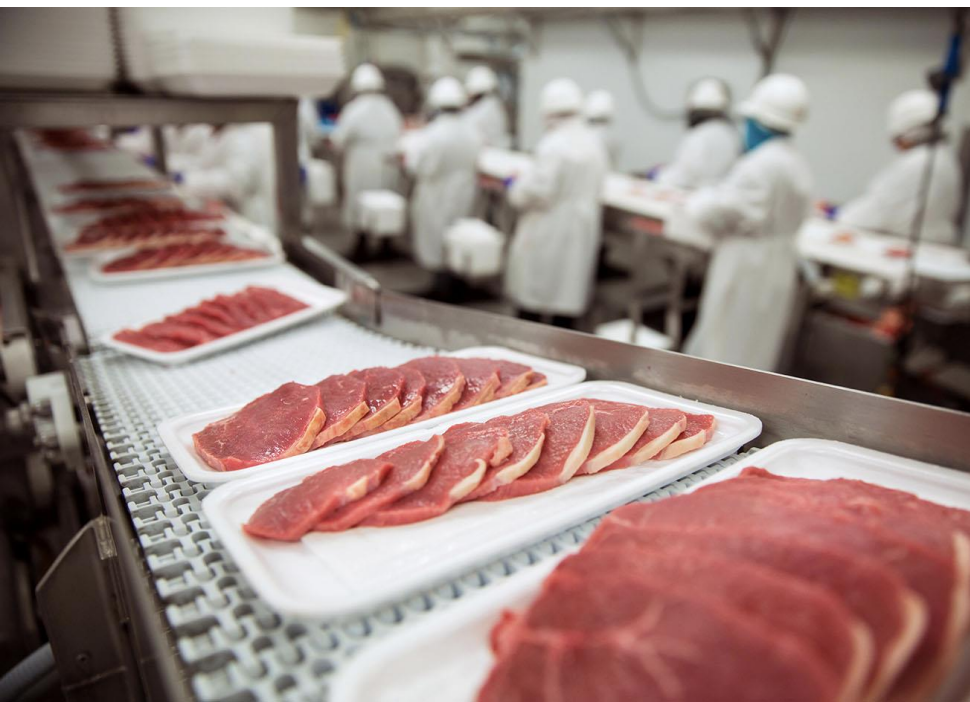
ENOUGH

EUROPEAN FOOD CHAIN SUPPLY
TO REDUCE GHG EMISSIONS BY 2050

THANK YOU !

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TO REDUCE GHG EMISSIONS BY 2050

