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4th EU + OECD Webinar on Hydrogen Fuel Risks
Hydrogen Fuel Risks Associated with Ammonia as a Hydrogen Fuel Carrier
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European Commission

DECARBONIZED BUT NOT DE-RISKED: THE CASE OF GREEN AMMONIA

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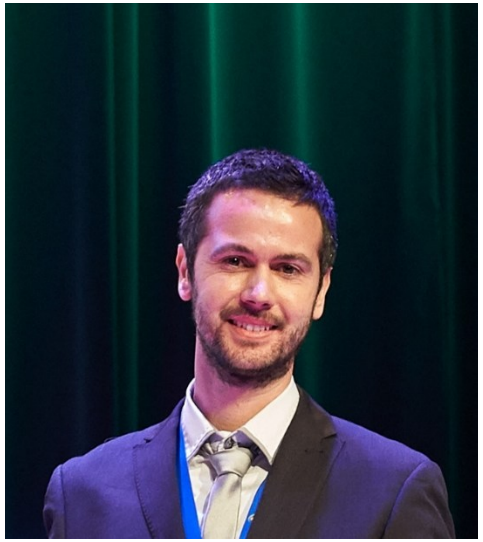
SPEAKER PROFILE



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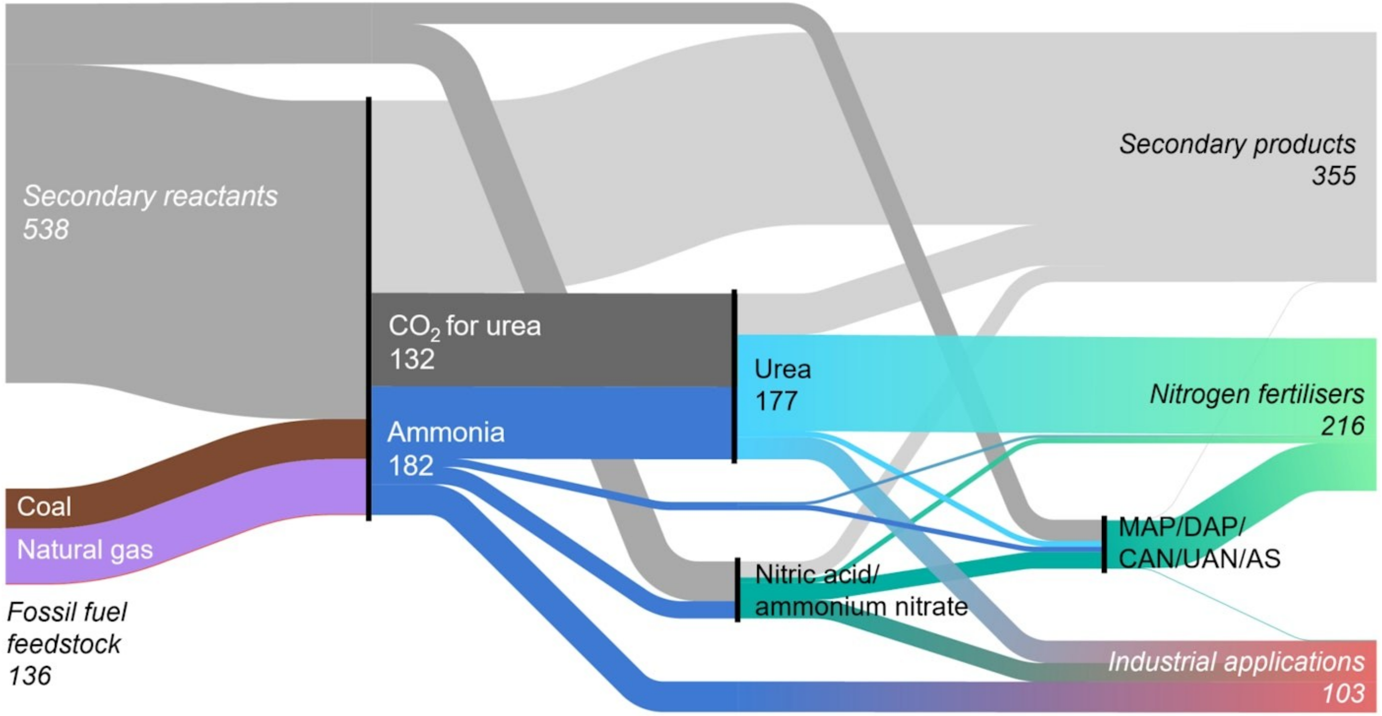
PRESENTATION OUTLINE

- Ammonia in the Energy Transition
- Production, Use, and Future Outlook
- Safety Challenges and Risk Profiles
- Infrastructure, Operations, and Human Factors
- Conclusive remarks and Path Forward

CURRENT PRODUCTION AND USE OF AMMONIA

Global production of ammonia (NH_3): **150 Mt** (2023).
Regions with the highest production: East Asia (65 Mtons), Russia, US, India.

>70-80% is used in agriculture
(chemical fertilizers)
Other applications:
Manufacturing of nitric acid, hydrazine, cyanides, amino acids; explosive materials and polymers; refrigeration fluid, removal of NOx_s.



Current NH_3 (> 70 %) is primarily made via the *Haber-Bosch* process based on **fossil-fuel derived H_2** (grey ammonia) which is produced via **Steam Natural Gas/Methane Reforming** (SMR).
But **green NH_3** may be on the horizon if the H_2 is made by other means.

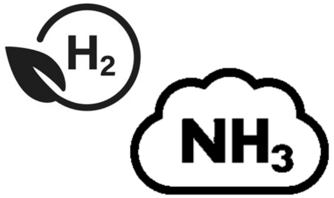
KEY CONCEPTS ABOUT THE ROLE OF NH_3

Key role of ammonia

- Ammonia is an essential global commodity.
- ~ 85% of ammonia is used for synthetic nitrogen fertilizer.

Hydrogen dependency

- Ammonia production accounts for 45% of global hydrogen consumption.
- Second-largest hydrogen user after the refining industry.



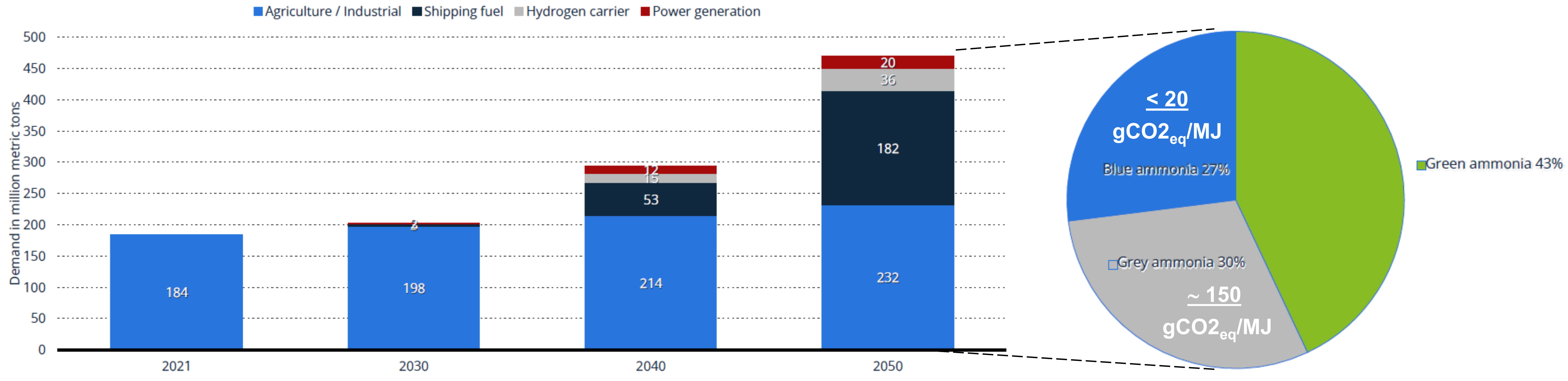
Decarbonisation potential

- Transition to "renewable ammonia" (i.e. from renewable H_2) supports chemical sector decarbonization.
- Promising applications: zero-carbon fuel (maritime sector, stationary power); H_2 carrier (long-range transport).

Source: IRENA and AEA (2022)

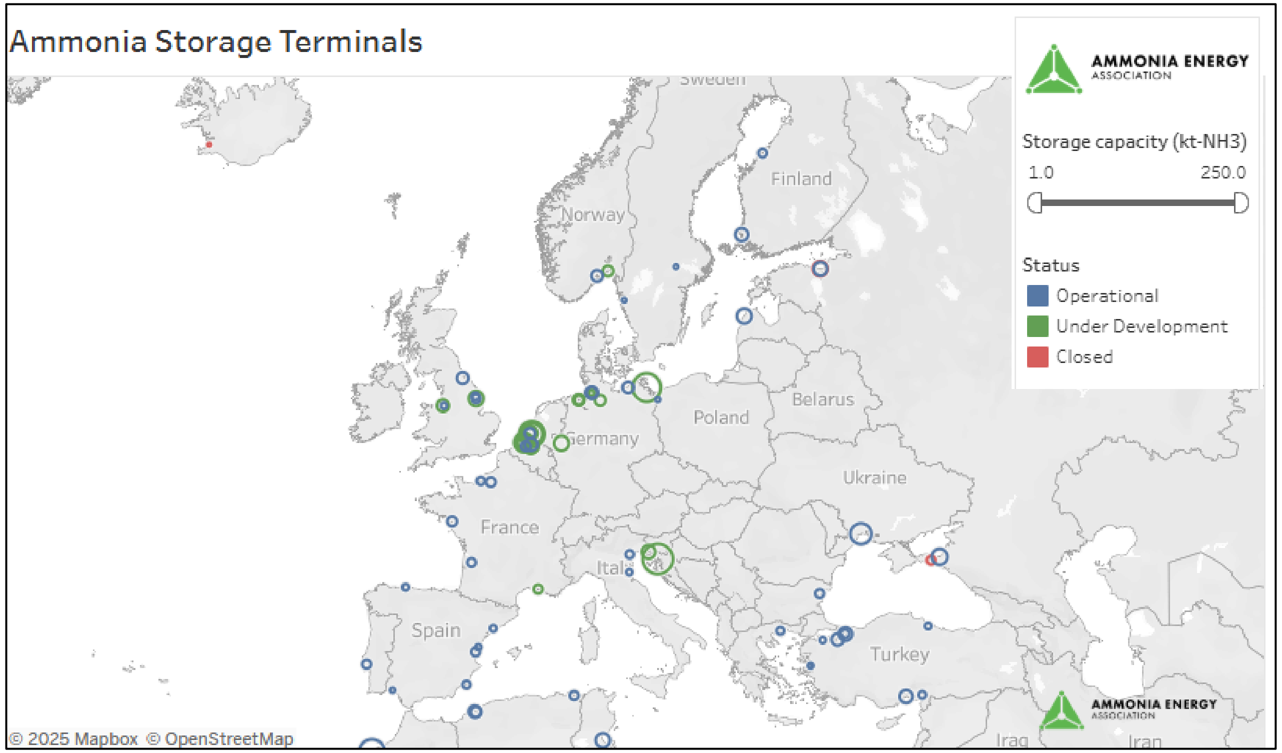
Ammonia can be an option for the Energy Transition

- **Versatile hydrogen carrier** → simplifies storage and transport; no need to return dehydrogenated carrier.
- **50 % cheaper** to produce from electricity than synthetic hydrocarbons or methanol
- Overall round-trip efficiency: **68 %** (similar to LOHCs).
- **Challenge as a fuel** → difficult combustion; requires equipment modifications.



STATISTA, 2025

NH_3- RELATED INFRASTRUCTURE



BULK-CARRIER PORT TERMINALS

UPSTREAM

NH_3 BUNKERING VESSELS
LARGE TERMINAL STORAGE
(and **BOG systems**)

(centralized) **CRACKING PLANT** (thermo-catalytic) → H_2

NH_3 REFUELING STATIONS

MIDSTREAM

TRANSPORTATION (truck, train, pipe)

(decentralized) **CRACKING UNITS** (electrical) → H_2

FINAL USES
(Fertilizers, industry, co-firing, marine fuel)

DOWNSTREAM

The **LNG import and storage facilities** (existing) can be converted to ammonia services but require additional (**and relevant**) design considerations (materials, structural design, insulation, safety devices).

AMMONIA STORAGE

Mature ammonia storage methods are currently available and the main factor determining the type of storage is the **ammonia storage capacity** and **economics**.

Type	Pressure range, bar	Design temperature, °C	Capacity, t NH_3	Refrigeration compressor
Pressure storage	7 ÷ 18	Ambient temp.	< 1500	None
Semi-refrigerated storage	2 ÷ 4	- 9 ÷ 4	450 ÷ 2700	Single stage
Low-temperature storage	Close to 1 bar	- 33	4500 ÷ 45000	Two-stage
Solid-state storage	1 ÷ 30	20 ÷ 250	-	-

Ammonia terminals involve a combination of pressurized spheres (rail, road) and refrigerated storage tanks (ships).

AMMONIA BUNKERING

There are **three main strategies** of NH_3 bunkering:

1. Truck to Ship
2. Ship to ship
3. Terminal to Ship

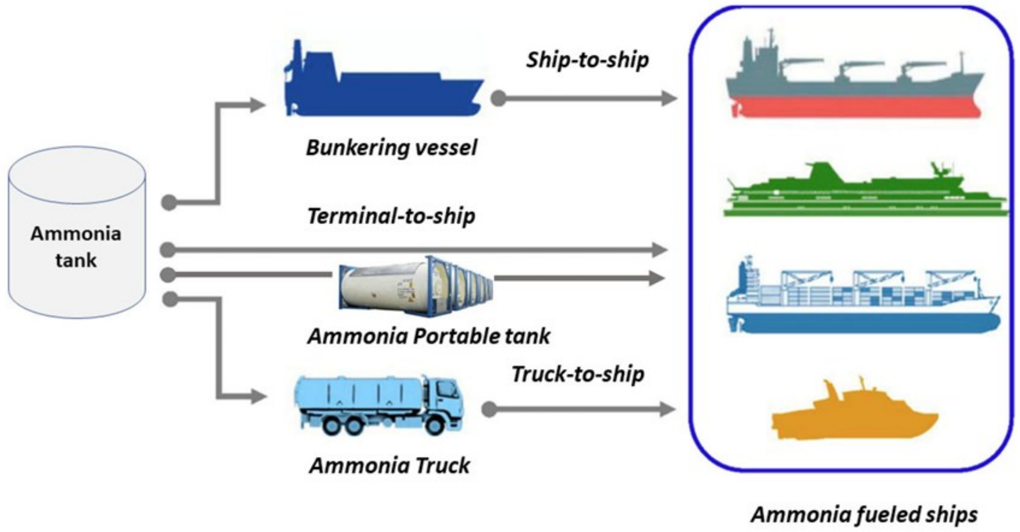
Each comes with **safety concerns**:

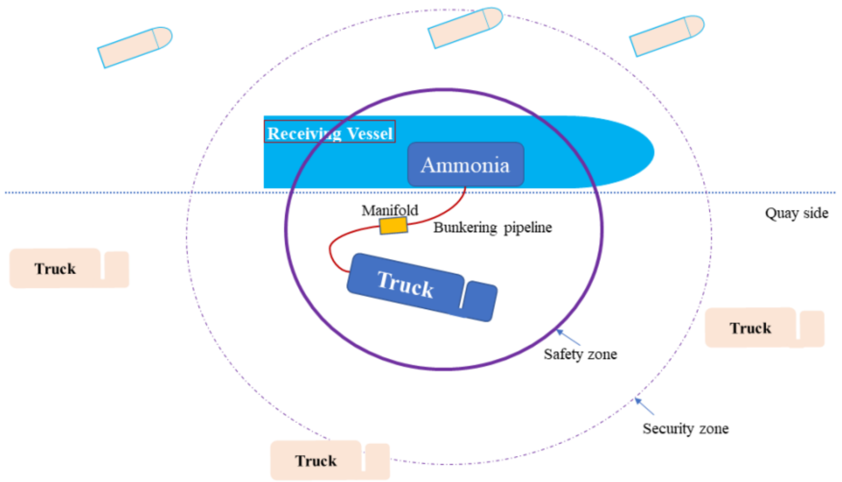
1. *frequent connection/ disconnection operations;*
2. *spills on water;*
3. *large hold-ups.*

Bunkering operations are potentially hazardous due to **high likelihood of leakage** of NH_3.

Criticalities:

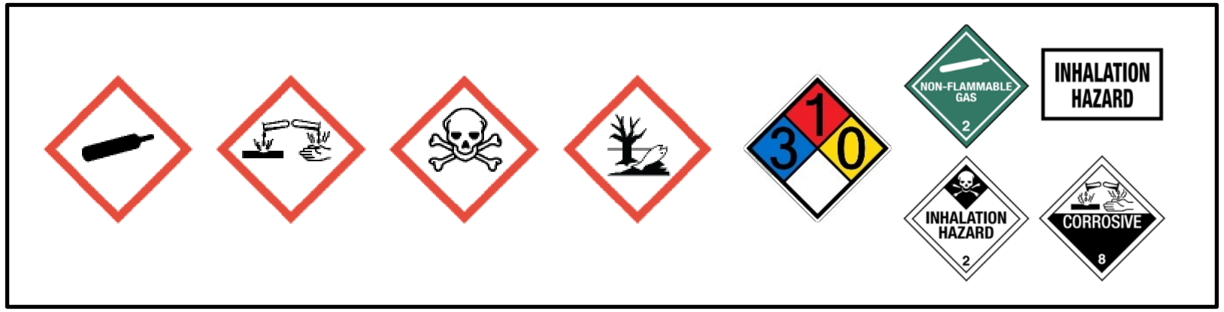
- Risk assessment guidelines for ammonia bunkering.
- Need for specific risk assessment and safety barriers.
- Gas dispersion analysis and determination of controlled zones.





GENERAL SAFETY PROFILE OF NH_3

- **Colourless** (but with a strong smell), **reactive** and **lighter-than-air** gas that **dissolves readily in water**, releasing heat.
- **Only marginally flammable** but **does explode** within certain vapor concentration limits (16-25 %) and in the presence of **strong ignition** sources.
- **Highly toxic**, causing serious health effects at low exposure levels (IDLH = 300 ppm; AEGL-1 = 30 ppm; AEGL-2 = 220 ppm; AEGL-3 = 2700 ppm at 10 min) (NIOSH)
- Solutions of ammonia are **alkali** and **corrosive** when concentrated → material degradation.
- **Environmental hazard**, aquatic life is harmed by ammonia (and by the water used to depress an ammonia cloud).
  Ammonia releases can lead to soil contamination.



COMPARATIVE SAFETY PROFILE

Density relative to air: similar to methane (~ 0.5-0.6)

➡ **Accidental releases**: liquid entrainment and low temperatures create heavy aerosol clouds

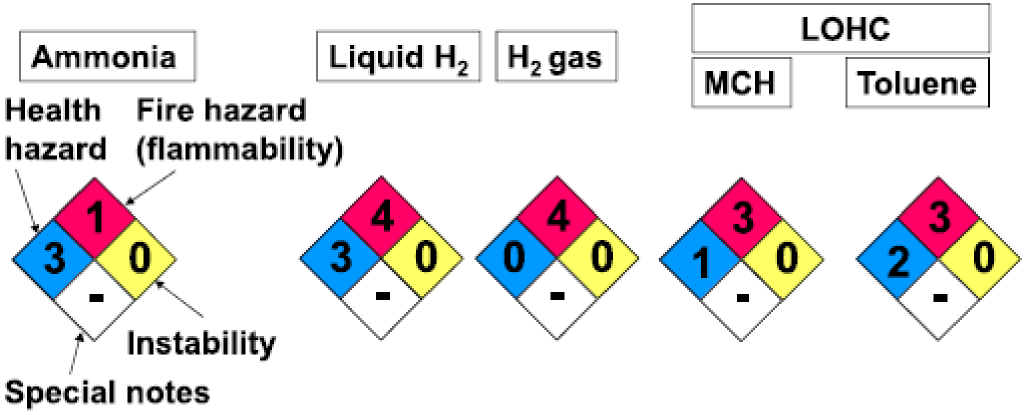
Burning velocity: < 0.07 m/s (vs. > 0.3 m/s of hydrocarbons)

Minimum ignition energy: very high (> 600 mJ vs 0.1-0.2 mJ of hydrocarbons)

Autoignition temperature: higher than most heavier hydrocarbons

➡ **Difficult to combust in air**, **but can explode in confined spaces** (> 16% in air)
Critical scenarios: boiling liquid pools, flash fires
Extinguishing agents: CO_2 or powders

Toxicity and ecotoxicity: several orders of magnitude higher than other energy carriers.



Toxicity-related events are critical in the case of ammonia

STATISTICS ON NH_3 ACCIDENTS

Ammonia-related accidents (particularly in industrial settings) have been a significant concern due to their potential **health** and **environmental** impacts.

> **250** accidents (1970-2024) (ARIA database), ~ 100 since 2018 (eSPIRS)

> **100+ accidents in Europe** (1986-2022) (eMARS)

(mostly related to ammonia as a refrigeration fluid)

DAKAR, 1992

> **Anhydrous NH_3 releases**
> Involving **pipelines, marine** and **road transport**
> **Accidents** with **fatalities** (15-30%), **injuries** (50-70%)
> Common targets: workers

The human consequences may involve workers and the general public !

CAUSES

- Equipment / component failure
- Corrosion / damaged piping
- Maintenance / procedures

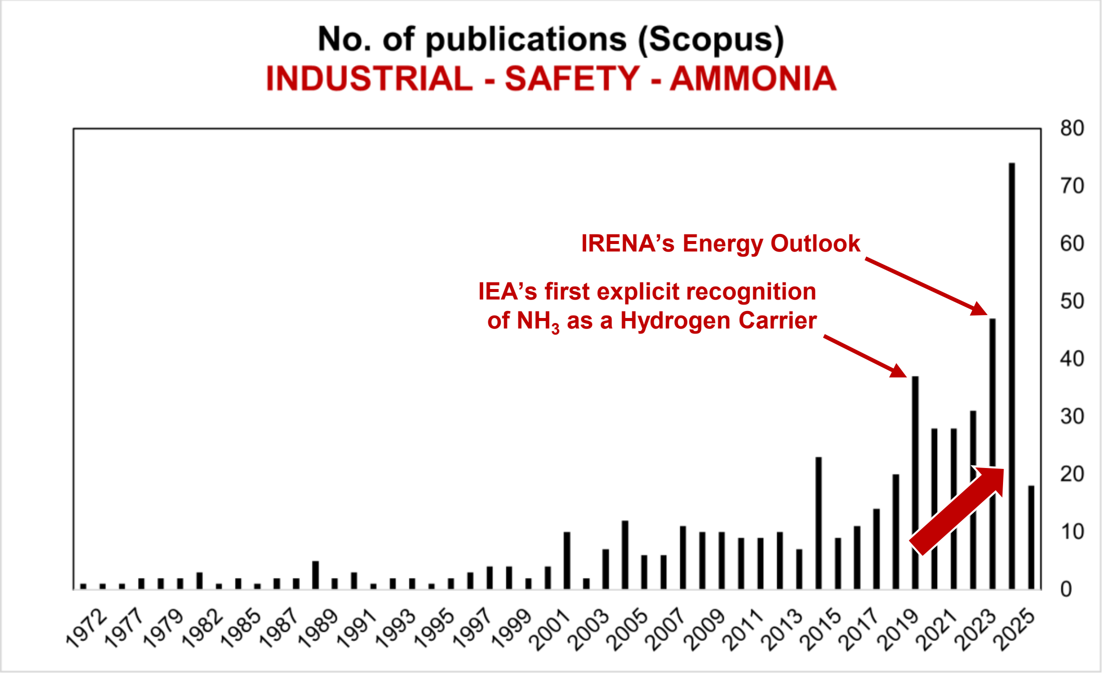
> 80%

(OSHA, 2017)

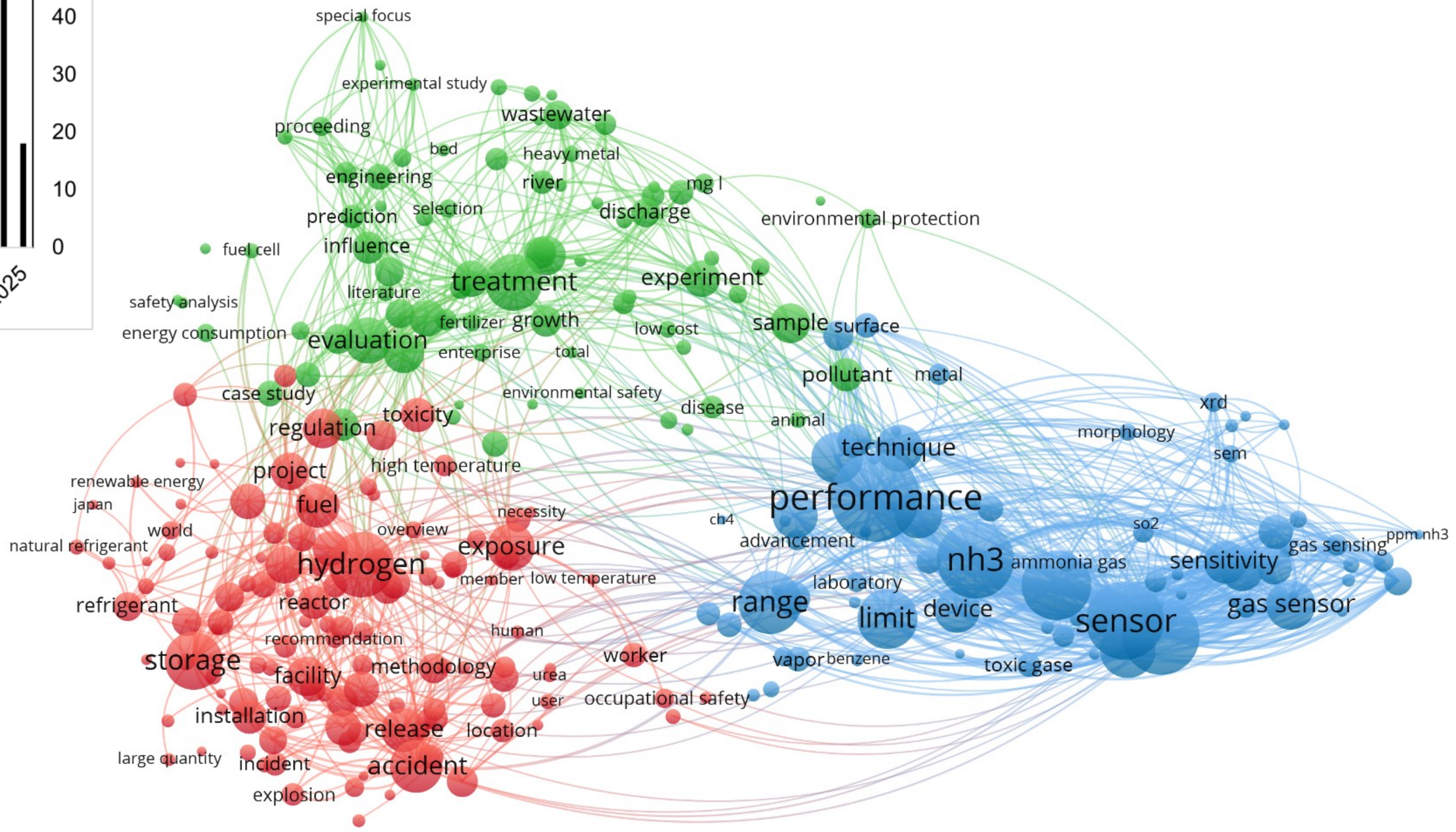
CONSEQUENCES

- Ammonia leak
- Toxic cloud dispersion
- Environmental contamination
- (Flash fires), explosions

KEYWORDS MAP - SCIENTIFIC ARTICLES ON AMMONIA SAFETY



1970-2025: 505 articles
> 2015: 317 articles
> 2022: 170 articles



Accidents and facility risks evaluation

Environmental safety and modeling

Ammonia sensors and detection

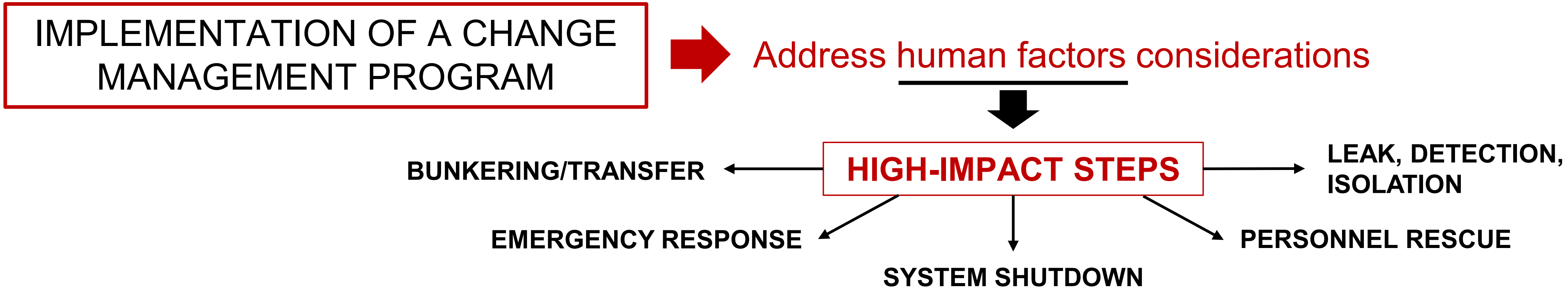
HUMAN FACTORS ARE CRITICAL IN NH_3 OPERATIONS

As part of the transition, ammonia fuel and associated new systems and equipment (especially in non-industrial contexts) will present **new technical and system complexity**.

- New and modified technical and non-technical skills
- “New” occupational health hazards

Most process hazards related to ammonia revolve around the control of storage and handling conditions to **prevent the loss of containment**

- Effective and reliable safeguards → engineering and administrative controls
- Competency and preparedness



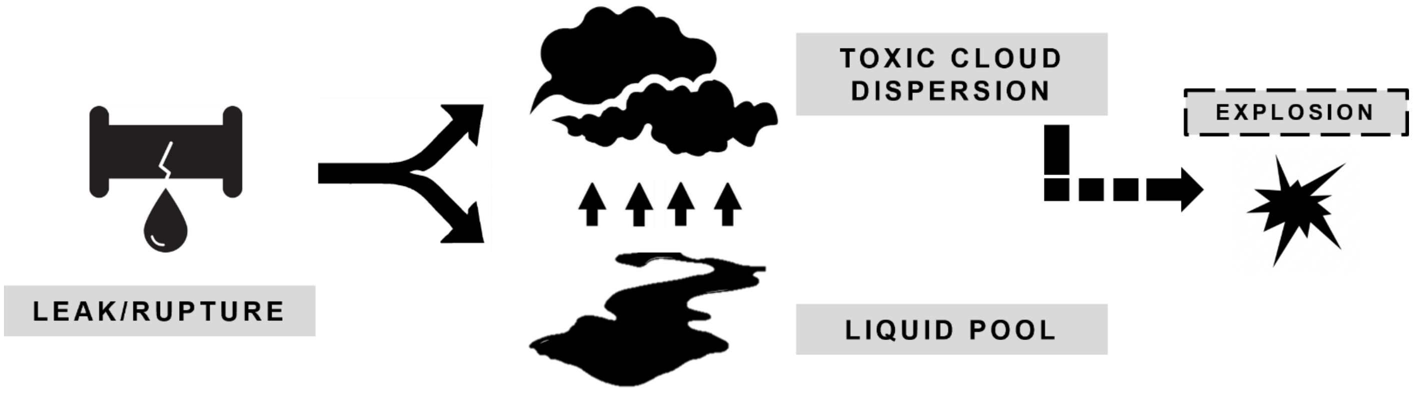
APPROACH TO NH_3 RISK SCENARIOS

Source state

Refrigerated or **pressurized**

Typical sources of release:

Storage tanks, **pumps/compressors**, **pipeworks**, **loading/unloading arms or hoses**, **road/rail tankers**



BARRIERS

- **Spill prevention barrier: gas detectors, emergency shut down, containment**
- **Immediate ignition barrier**
- **Dispersion prevention barrier: passive (containment walls), active (water spray)**
- **Delayed ignition barrier: ignition sources control, ventilation (confined spaces)**

PROTECTION OF THE COMMUNITY

LIMITATION OF THE RELEASE

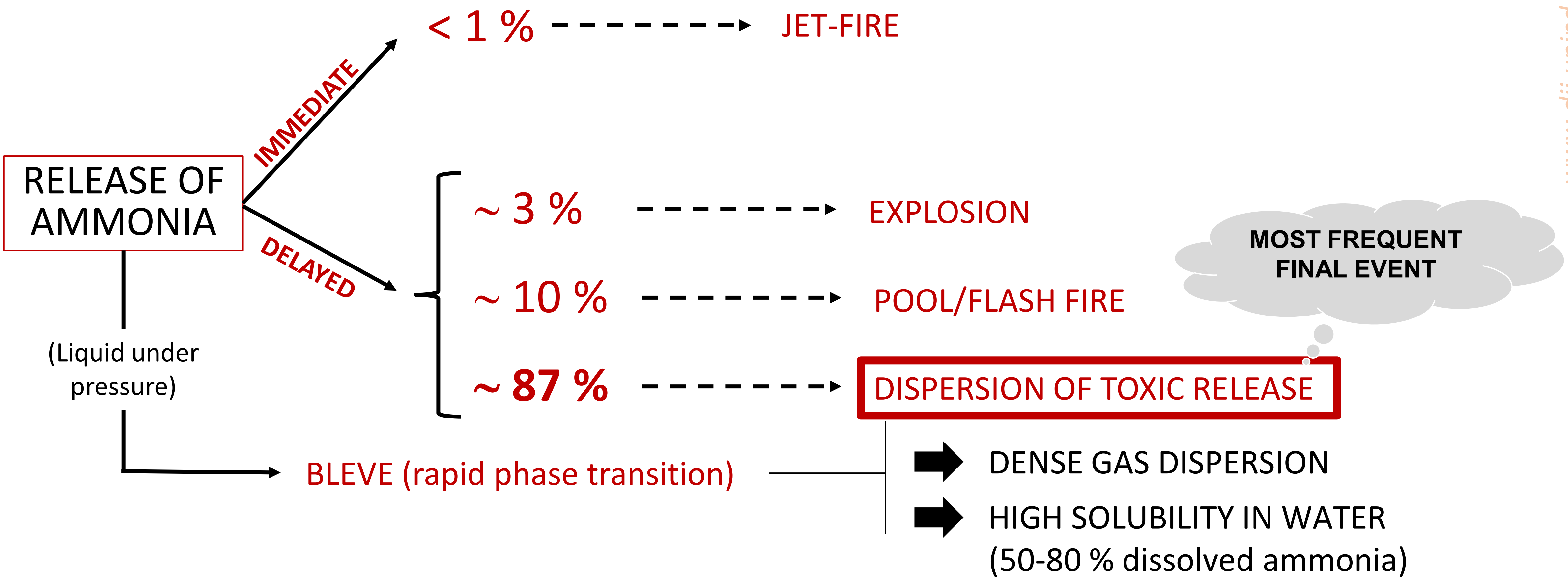
MINIMIZATION OF VAPORIZATION

EMERGENCY MANAGEMENT

ENVIRONMENT

STEPWISE MITIGATION

AMMONIA IGNITION PROBABILITY (TOXIC MATERIAL, MARGINALLY FLAMMABLE)



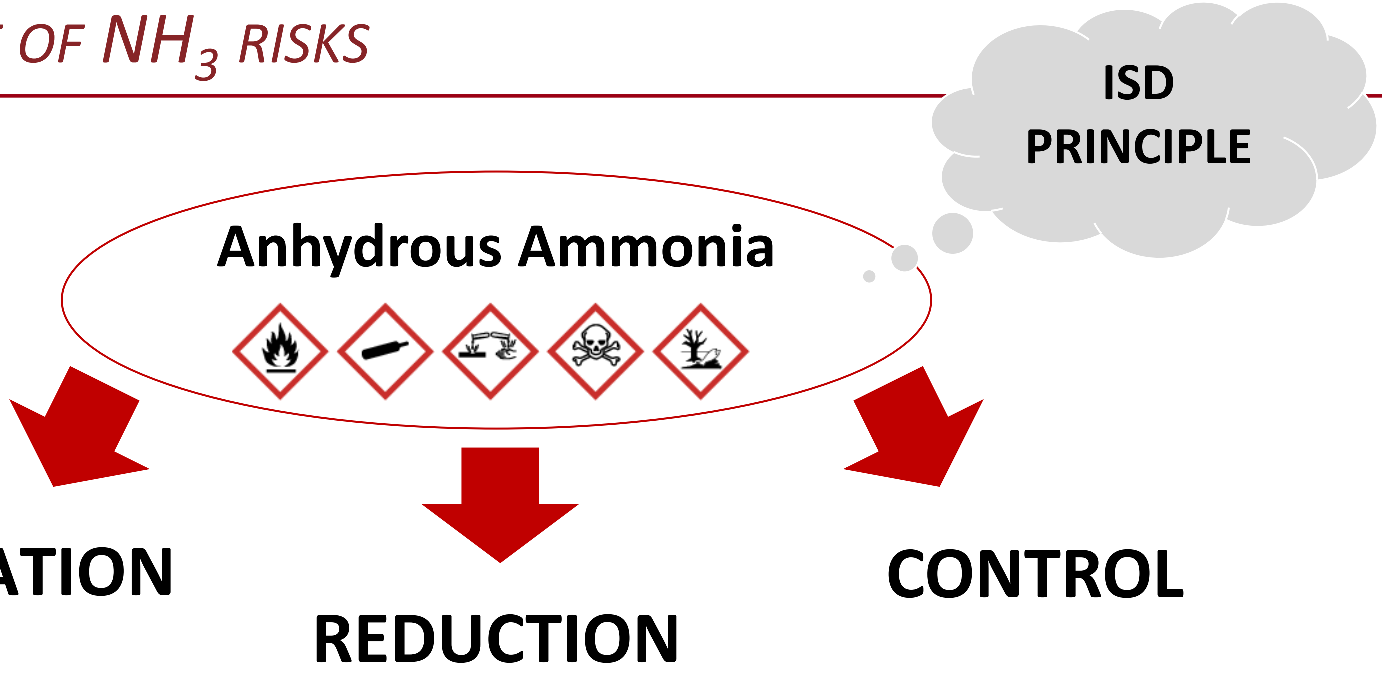
The contact with water evolves heat (extinguishing agents: CO_2, powder).

Aerosol clouds are denser than air (> 4-8 % aerosol). Immediate reactions with air humidity.

Source: CCPS Guidelines for determining probability of ignition of a released flammable mass

CRITICAL AREAS IN MANAGING NH_3-RELATED RISKS

STORAGE CONDITIONS	Lower **storage temperature** reduces the severity (REFRIGERATED < SEMI-REFRIGERATED < PRESSURIZED)
SAFETY BARRIERS	Rapid and reliable (and automatic) **shutdown** in the event of a leak, combined with isolation / sectioning solutions **Secondary containment** is an important risk mitigator Limitation of leak sources Detection of leaks may require a combination of sensors and alarms
INDOOR OPERATIONS	Control of ventilation is only partly effective at preventing toxic concentrations Ammonia intake protection (high-risk spaces integrity) Restricted areas



Construction material selection to prevent degradation mechanisms

Control of stress **corrosion** cracking and corrosion under insulation / **Cold service**

Auxiliary equipment to handle **expected** (PSVs, PRVs; inerting/purging during maintenance and start-up/shutdown) and **unexpected** process releases (early leak detection, automatic isolation, drip trays, water mist systems, spilt ammonia disposal)

Measurement and control of **ammonia emissions** via detectors

TAKE - HOME MESSAGES

✅ NH_3 as a **key enabler** of the energy transition

- Efficient hydrogen carrier with expanding applications (and **emerging risks**)

⚠ **Safety** remains the main challenge

- Toxicity, handling complexity, and environmental risks must be properly addressed

🏗 **Infrastructure** and **operational risk management** must evolve

- LNG facility adaptation, transport safety, and proper siting and zoning

📌 **Process safety culture** and **continuous risk assessment**

- Frequent hazard reviews and audits
- Proper management of abnormal situations and overfilling scenarios
- Follow-through on safety measures

👷 **Human factors** and **emergency preparedness** are critical

- Training, real-time decision-making under hazardous conditions, and robust safety protocols

⚖ **The path forward**

- Balancing decarbonization & safety is key to ammonia’s success
- Strong safety culture and risk perception and communication

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THANK YOU FOR YOUR ATTENTION!

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