WHEN TRUST MATTERS

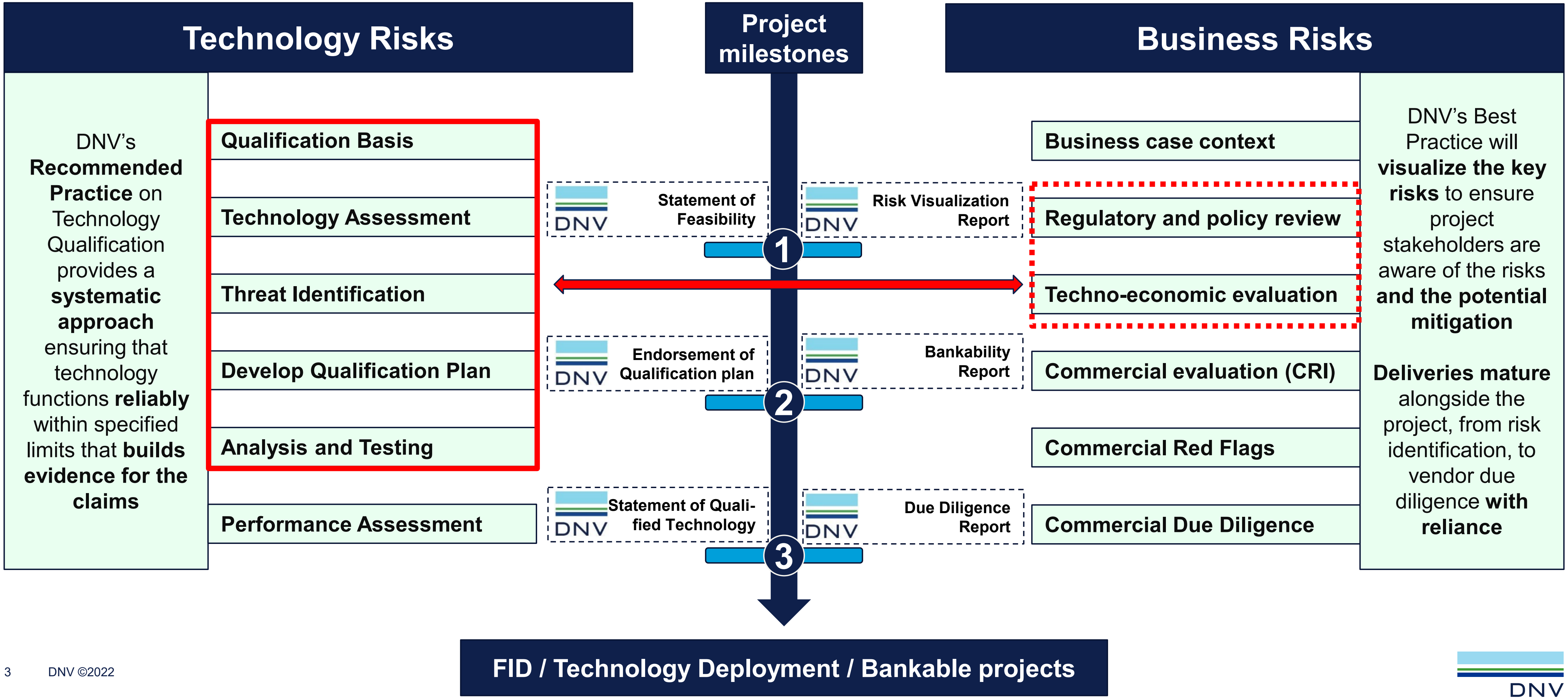
Managing the scale-up of PtX

4th European Conference Hydrogen & PtX

Dr. Felix Weise

15 June 2023

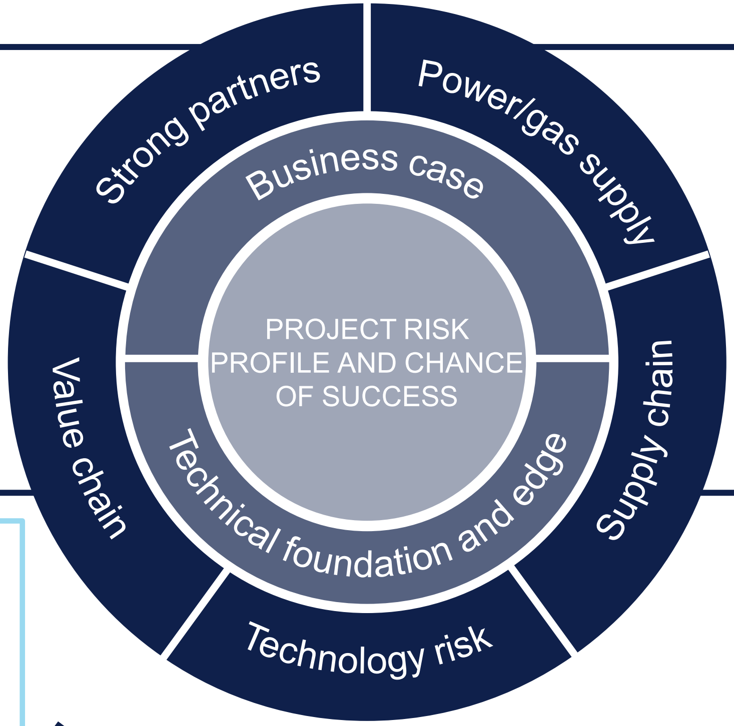
Maturing technology and the business case
– *by reducing risks*



DNV

What makes a robust hydrogen and PtX project?

- **Partnerships and market positioning**
  - Hub potential and partners
  - Access to funding and regulatory support
  - Market access and offtake strategy
  - Growth staircase with partners/clients to hedge sector exposure



- **Competitive LCOH and emission control**
  - Cost effective upstream energy supply
  - Low-cost storage and delivery solutions
  - Long term agreements or dedicated production
  - Understanding of risks through value chain
  - Control of GHG emission footprint

- **Supply chain control**
  - Availability of essential equipment
  - End product control – ammonia or other through suppliers and partners
  - ESG risks

Technology risk management

- Safety philosophy
- Control of technical and HSE risk factors
- Suitable maturity and technology risk profile
- Piloting supporting full scale development
- Control of key processes
- Favorable location for chosen technology – limited site-specific risks

1. Make it right the first time!
2. Early involvement from knowledge partners to be due-diligent
3. Structured approach to focus on mitigating major risks and ensuring inherently safe design

01 Introduction

02 Ammonia & Hydrogen safety properties

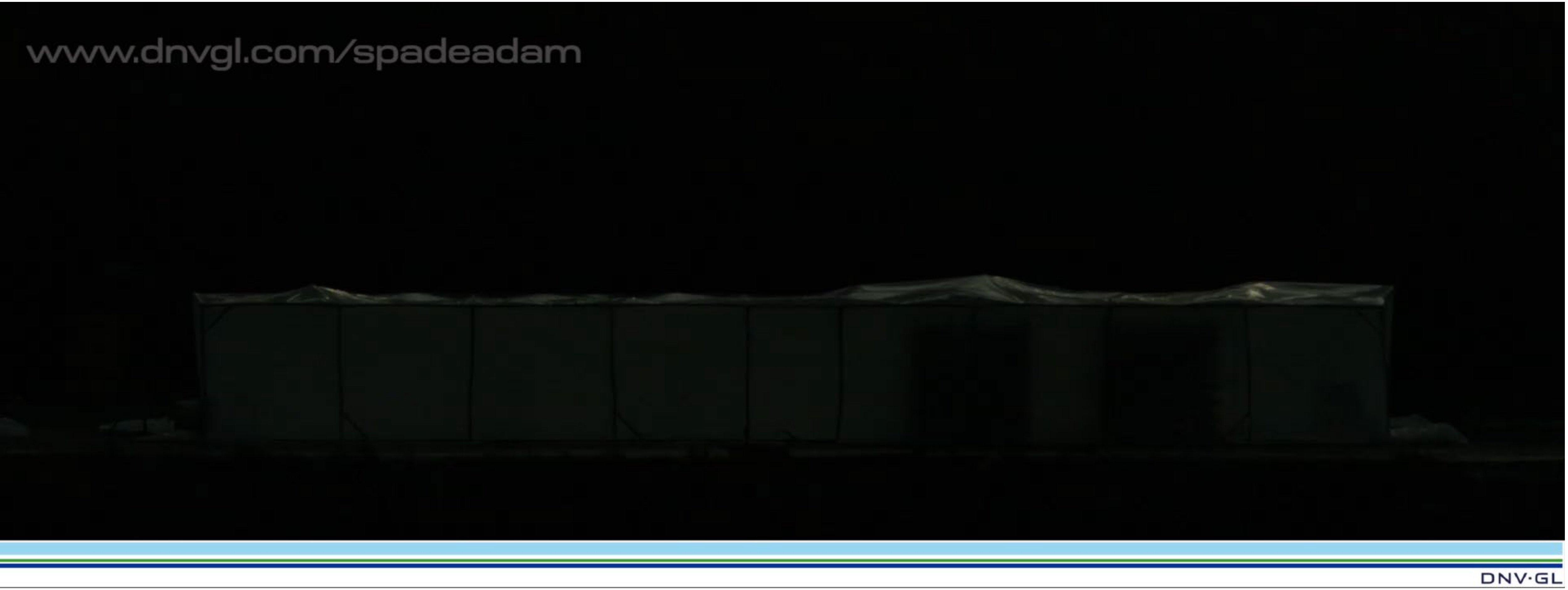
03 Manage safe up-scaling

04 Outlook & Summary

Natural gas versus hydrogen – selected features

	Hydrogen	Natural gas
Flammable range	Ignites in a much wider mix range (4% to 75% of volume)	Narrow flammability mix range (5,3% to 15% of volume)
Ignition energy	Ignitable by low energy sources - phones, and human static electricity (0.020mJ)	10 times higher than H2 (0.29mJ)
Flame velocity	3.2 m/s 8 times faster flame velocity than NG - much higher explosion pressure potential - detonation possible which requires higher focus on QRA & fire/explosion studies	0.4 m/s Mainly no detonation
Dispersion	Disperses much faster than NG. Limited potential for ground accumulation	Large gas cloud may form. In some conditions as heavy gas on the ground (LNG)
Regulations	SEVESO not (yet) really fit Lower TIER: 5 t Minimum Mass Tetryl 0.8 g	SEVESO & other regulations specifically include natural gas

Deflagration to Detonation Transition (DDT)



Methane & Hydrogen Explosion Comparison

Same volume (~ 7kg vs. 0.5kg)

Adding another risk category

Ammonia adds toxicity to the risk picture Detection limit by humans: 0.04 to 53 ppm

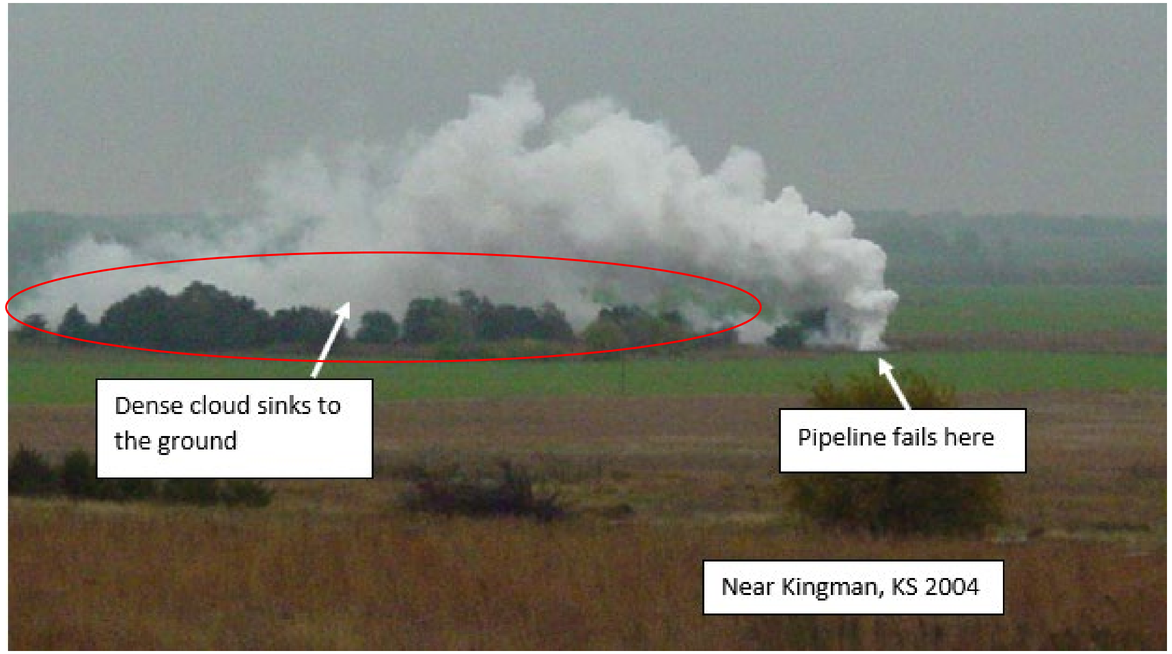
Table 3-1 Exposure guidance (Karabeyoglu A, Brian E., 2012)

Effect	Ammonia concentration in air (by volume)
Readily detectable odour	20 – 50 ppm
No impairment of health for prolonged exposure	50 – 100 ppm
Severe irritation of eyes, ears, nose and throat. No lasting effect on short exposure	400 – 700 ppm
Dangerous, less than ½ hours exposure may be fatal	2000 – 3000 ppm
Serious edema, strangulation, asphyxia, rapidly fatal	5000-10000 ppm

Kingman – USA - 2004

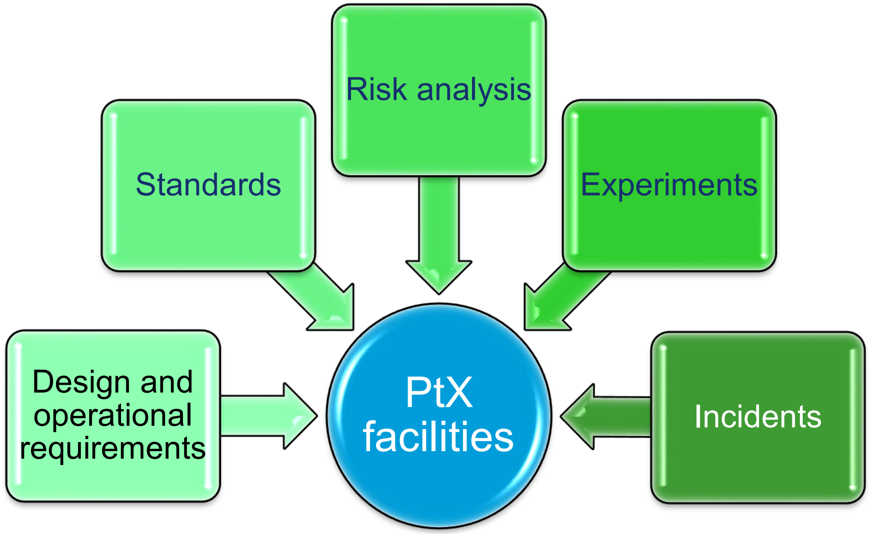
Ammonia pipeline

- **760 m³ release of liquid ammonia**
- **Consequence:** material and environmental impact, loss of production
- Illustrates how different the spread of ammonia liquid & gas is



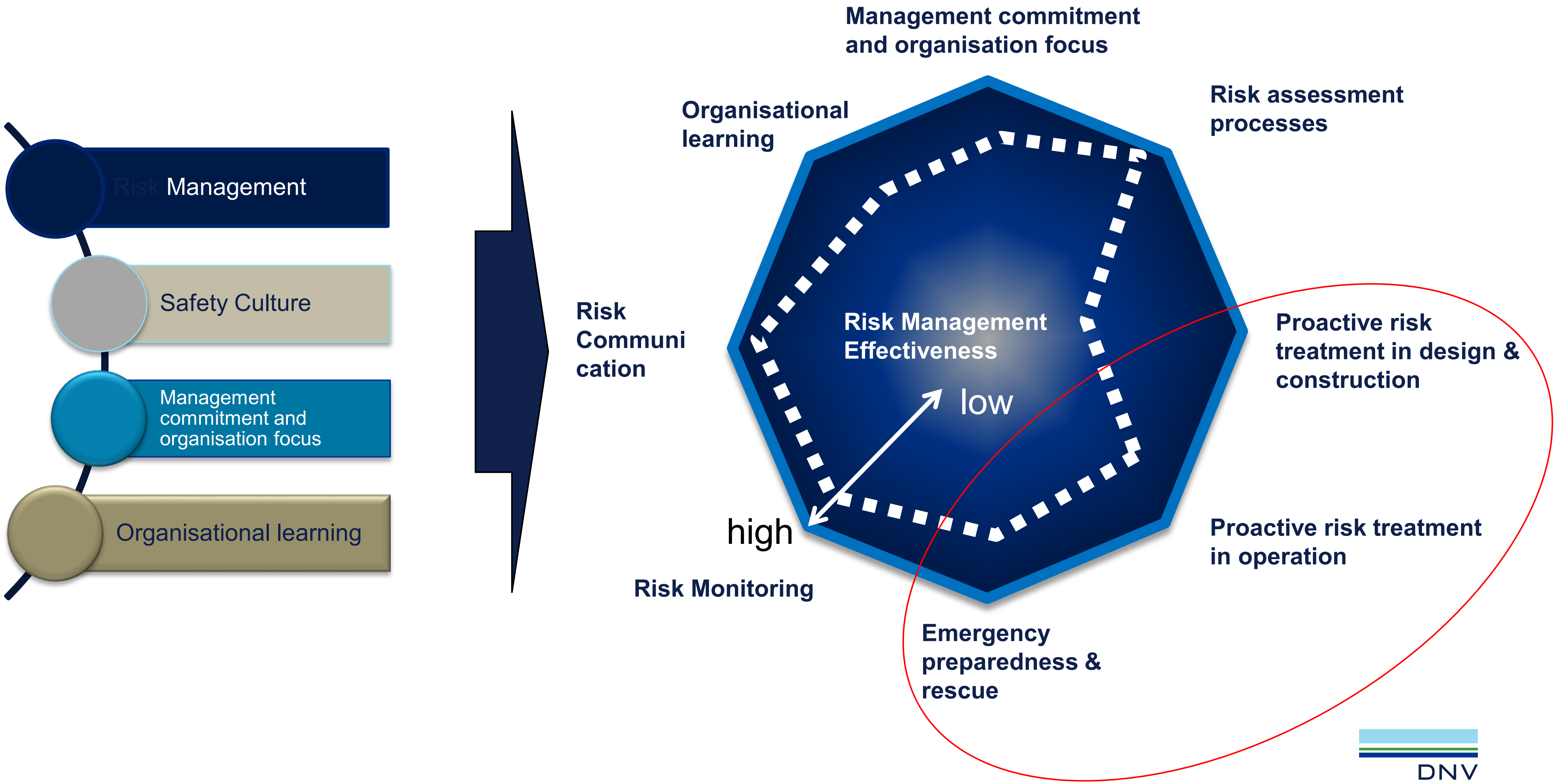
Introduction the scaling challenges

- Hydrogen & Ammonia are most mature green technology for the larger transport segments
  - ➢ Hydrogen technology is mainly developed for smaller scale facilities
  - ➢ Ammonia technology is available at large scale but applied mostly on dedicated industrial sites
- Several projects are planned with a siting plan next to grid connection and closer to cities, etc.
- Partially new operators without large scale background in hazardous material handling
- Standards and regulations are less developed for larger scale facilities
- Hydrogen experiments are available mostly at smaller scales
- Explosions are known to be super-sensitive to upscaling
- Simulation tools for risk assessments are available for large scale plants, hydrogen requires more qualification



We have learned that major accident risk can be controlled through some key elements

Safety improvements have been driven by accidents



DNV

Dynamic toxic cloud means time varying concentration for the observer

- Especially toxic attributes of ammonia require intense gas dispersion modelling within siting phase
- Inherently safe(r) design does not add large budgets if done in the early phase

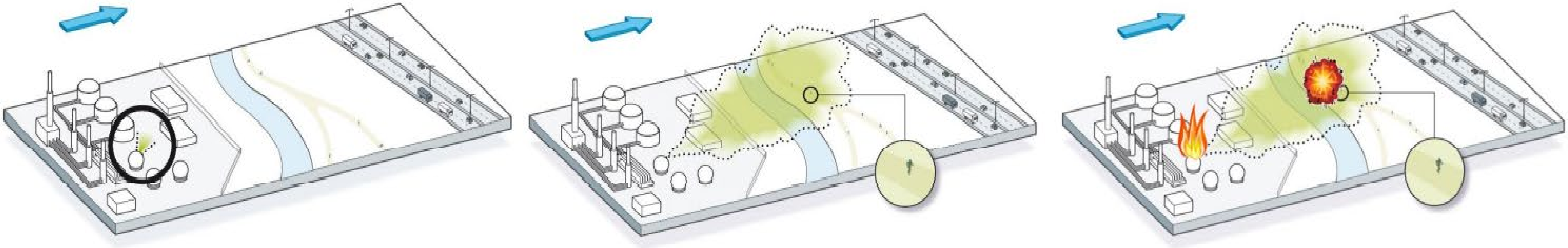
Table 3-2 EPA Acute Exposure Guideline Levels (EPA, 2016)

Ammonia 7664-41-7 Expressed in ppm					
	10 min	30 min	60 min	4 h	8 h
AEGL 1	30	30	30	30	30
AEGL 2	220	220	160	110	110
AEGL 3	2700	1600	1100	550	390

AEGL 1: Notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

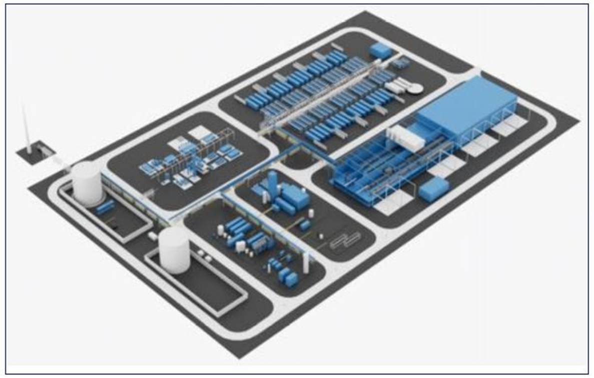
AEGL 2: Irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

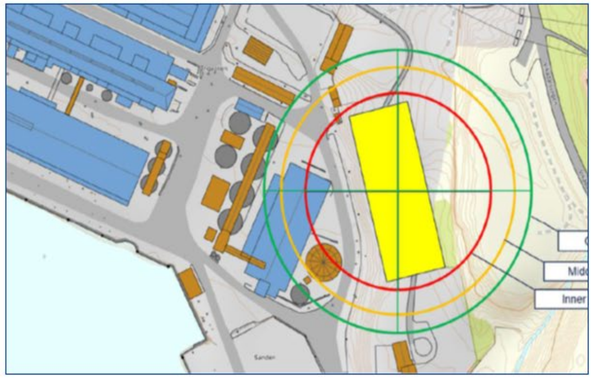
AEGL 3: Life-threatening health effects or death.



Advanced modelling and qualification of software load factors to be taken into account (DNV JIP)
-> Both local and global risk

Siting study is critical to ensure inherent safety
Also consider total risk from all facilities





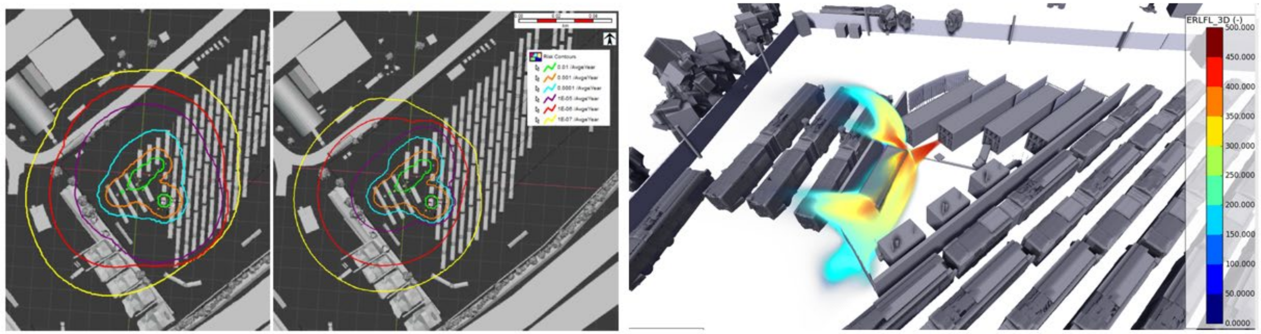
- Consider total aggregated risk from all facilities
- Domino effects barrier management
- Integrity damages due to pressure waves from explosions/detonations?

- Combined plants of hydrogen & ammonia require additional efforts
- Industry clusters and e.g. port environments, urban locations, etc. need to be assessed for domino effects
- Some specifics for hydrogen need further qualification

- Distinguish between
  - «inside» and «ouside» the fence
  - Size of the plant: Upscaling into GW does change the risk picture!

Critical leak and dispersion effects in open areas
- Without blastwalls
- With blastwall all around

Orders of magnitude numbers



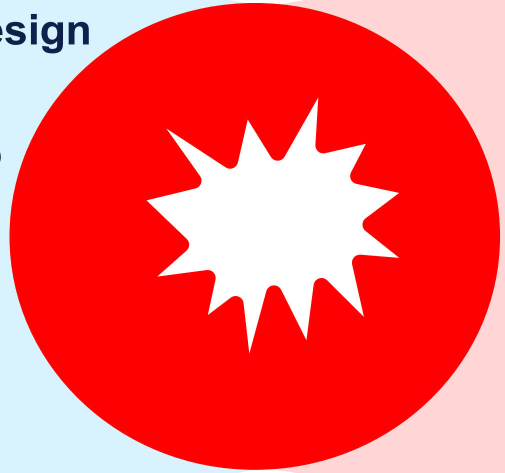
- Leak rates from 0.1 kg/s can cause critical cloud sizes (1 kg/s for methane)
- Leak duration from 1-3 s can create critical cloud sizes (10-20 s for methane)
- Gas clouds can collect at lower elevations due to jet release

Upscaled PtX ➡ upscaled measures

Using QRA actively in development show the following:

PREVENT

- Inherent safe designs – **avoid detonations by design**
  - Avoid gas cloud build-up in congested regions
  - Separation between equipment to prevent gas build-up
  - Improve natural ventilation by one ventilation direction
  - Reduce exposure to ammonia leakages to inherit toxicity of ammonia
- High integrity on equipment to prevent leaks
  - High quality material, welded connections, less flanges
  - High reliability on safety systems to prevent failure cases



MITIGATE

- Use blast walls if needed
- Build strong enough to prevent flying projectiles
- Drag and explosion loads found from Explosion Risk Analysis
- Fire protection need to work after an explosion
- Siting study can minimize most relevant risk
- Technology assessments help to balance safety and economy

CFD, QRAs and experiments ➡ robust and safe designs faster

What has to be done?

Formal <u>and</u> informal acceptance criteria, inside and outside the fence

Explosion and fire protection

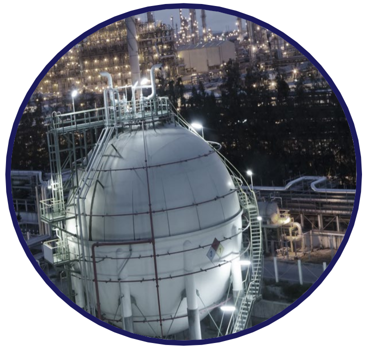
Primary
Avoidance of explosive mixtures

Secondary
Avoidance of ignition sources

Tertiary
Inherently safe design with barriers

Gas dispersion

Primary
Avoid loss of containment

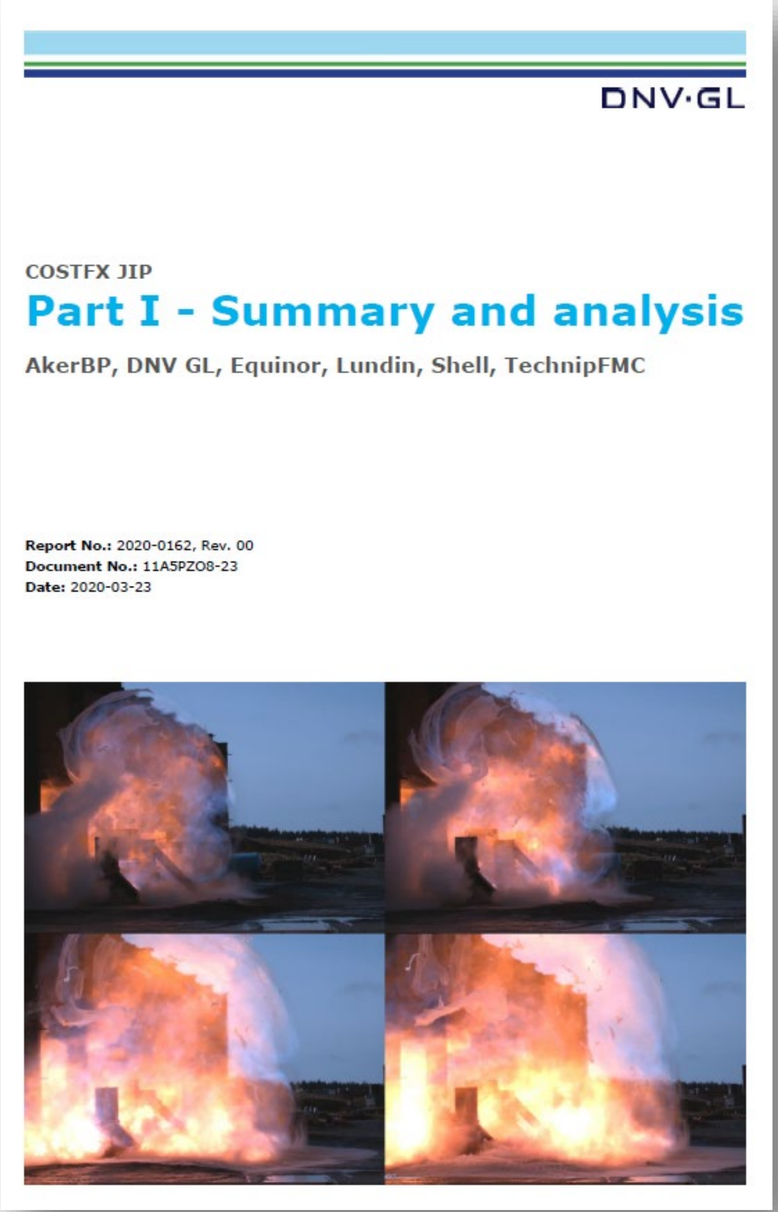


Secondary
Minimize amounts

Tertiary
Inherently safe design with barriers

JIPs on hydrogen safety and green hydrogen, visit: DNV JIP landing page

- **<u>Example</u>: CostFX JIP** – DNV Led. Simplify and reduced drag loading on pipe support. Experiments, CFD and Finite Element simulations.
  - Phase I with natural gas. Finished in 2020.
  - Phase II starting now. Hydrogen and Natural gas. Inhomogeneous clouds. Validation of CFD and FE codes, understanding of explosion loads. Can give improved designs and reduced cost and weight
- **H2Pipe JIP** DNV are leading a project for standardization of new and repurpose offshore hydrogen pipelines
- **Certification of Electrolyser Equipment JIP -** with partners setting the future standards for electrolysers
- **H2MET – JIP** Leading the development of hydrogen metrology
- **CO2 Safe and Sour - JIP** iincrease levels of H2S will vs. SSC



VERIFICATION OF POWER-TO-X FACILITIES

- A structured framework and methodology for the planning, preparation and execution of independent risk-based verification or certification for PtX facilities.
- Intended to minimize risks for all stakeholders, by defining assurance activities for the safe design, development, construction and operation of PtX facilities
- Focus also on interfaces and early design, affecting purchasing and equipment demands (OEM)


DNV

SERVICE SPECIFICATION

DNV-SE-0656 Edition June 2023

Verification of power-to-X facilities

SERVICE SPECIFICATION SE-0656

The PDF electronic version of this document available at the DNV website dnv.com is the official version. If there are any inconsistencies between the PDF version and any other available version, the PDF version shall prevail.

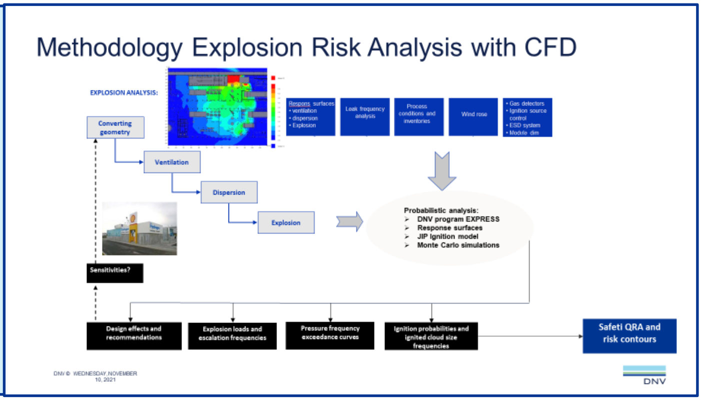
DNV AS

DNV is derisking vRES PtX projects

Joint Industry Projects (JIP)

Regulation gaps and permitting

Modelling with Hazop and QRAs



Labs and test sites for hydrogen

DNV

Summary – PtX upscaling

Safety in Design

- Management through barriers to prevent a major accident
- Hierarchy from avoidance to emergency response
- Inherently safer design is important and not necessarily expensive in early design
- Right siting can avoid increased exposure and domino effects

Hydrogen & ammonia properties

- Hydrogen has high reactivity and is much more detonable than hydrocarbons
- Need to avoid situations where high (>15%) hydrogen concentrations are present as much as practicable
- Ammonia add toxicity to the risk picture, handling and safety requirements

Design to Operations

- Lack of standardisation, knowledge and history introduces uncertainty
- DNV is about to qualify and close gaps with JIPs, own research and analysis as well as modelling tools
- Original design intent needs to be communicated and embedded in procedures and maintenance

Questions?

Happy to discuss!

Reach out for further details and discussions

Felix Weise
Head of Risk Management
Energy Systems North Europe
E-mail: felix.weise@dnv.com

www.dnv.com