Impact of the Energy Transition on Process Safety

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Presenter

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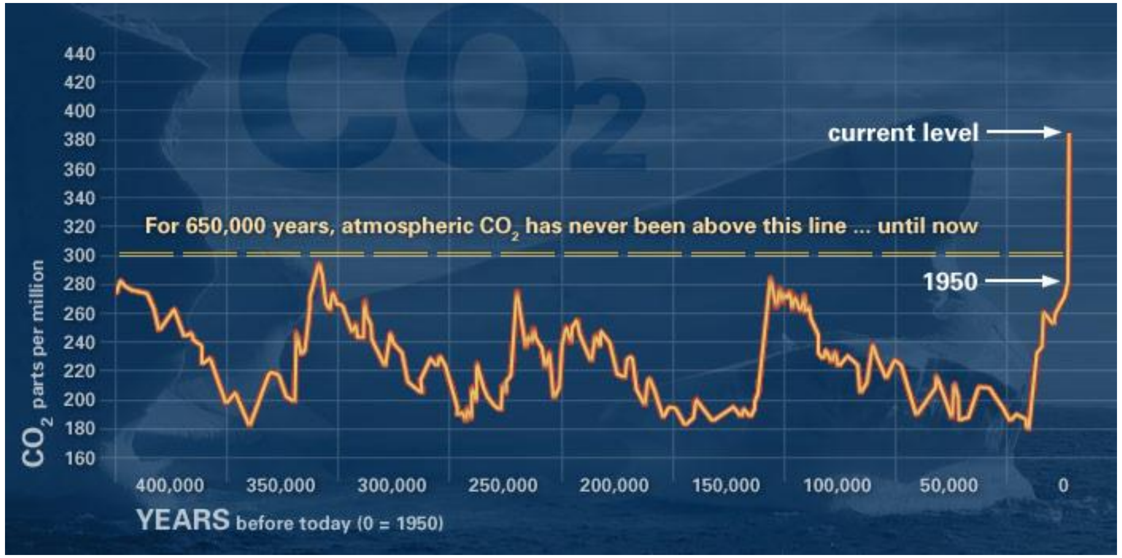
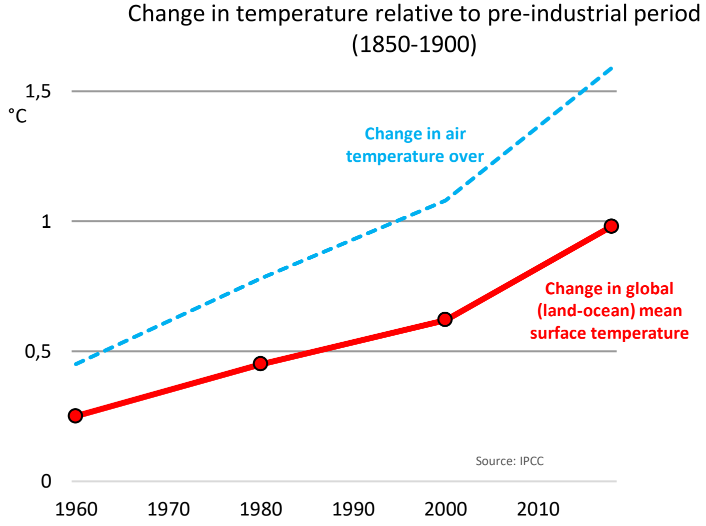
The Need for Energy Transition

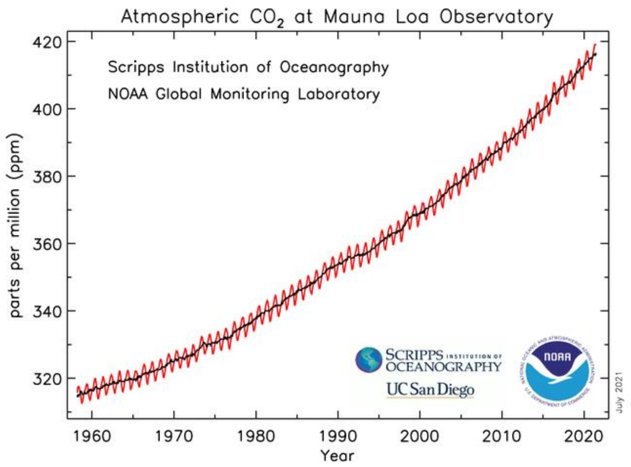
- Why do we need renewable energy resources?
- Why can't we just continue to use non-renewable resources?

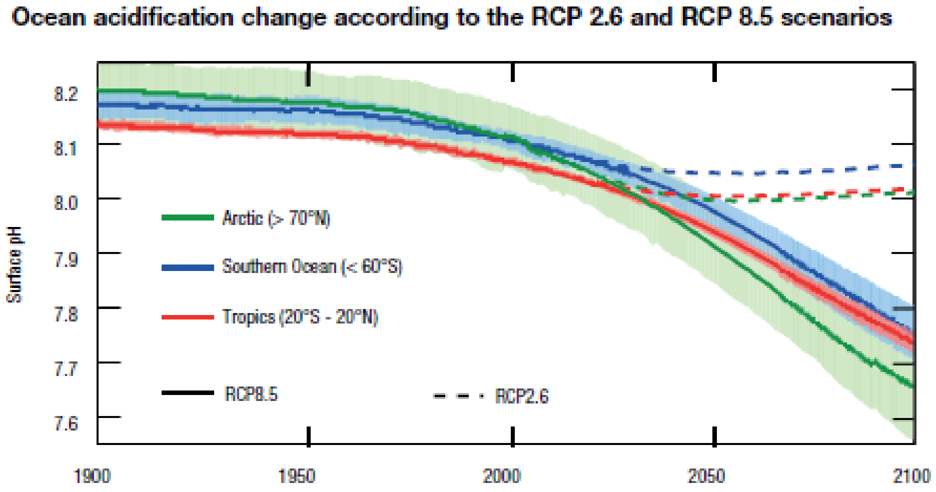
The Need for Energy Transition: Climate Change

- CO_2 is at 415 ppm (2021)
- Global warming ~ 1.1°C in the past 200 years
- Ocean acidification
- Rising sea level ~ 3.2mm each year
- Decreasing ice sheet mass
- Retreating glaciers (Alps, Himalayas,…)
- Decreasing Arctic ice at a rate of 13% each decade (413 Gt/yr)
- **The climate challenge is no longer a scientific debate !**









The Need for Energy Transition: Climate Change

- FaceBook post of Bjorn Moerman (friend and captain/instructor on Airbus A380 overflying the North Pole en route from Dubai to Los Angeles at the end of July 2021):

"Global warming and climate change have become part of our daily vocabularies and often lead to heated discussions on both a political an a personal level. I am not here to say who is right or wrong, but want to share a recent aerial image shot over the North Pole, which is – at least to me – quite telling !"

Extensive studies show that the extent of the arctic sea ice has been on a steady decline since the first reliable satellite data have become available in 1979. The 2021 spring and summer melt till now, shows that this year unfortunately could be breaking the previous 2012 record for the lowest amount of polar sea ice.

The climate challenge is no longer a scientific debate !

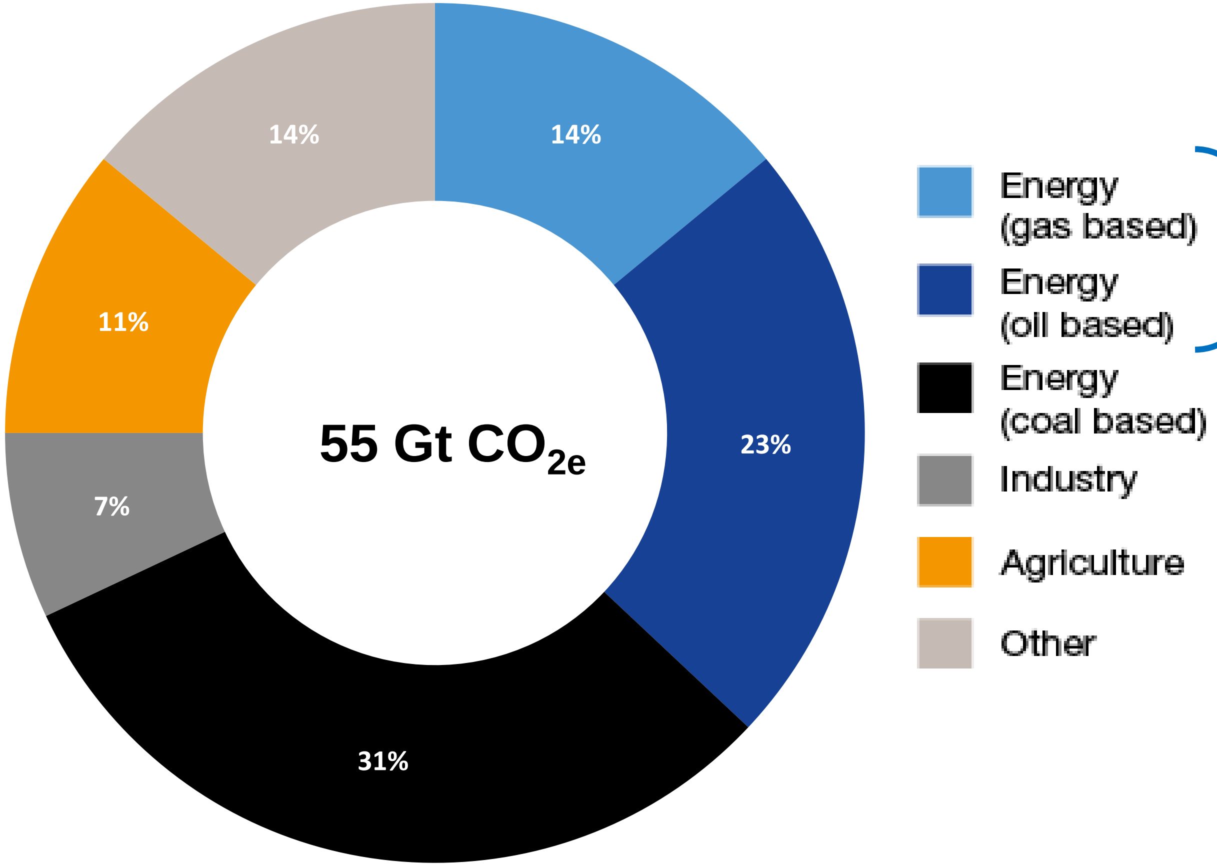
The Need for Energy Transition: Climate Change

- Massive floods in Germany, Belgium, The Netherlands in July 2021

Since 12 July 2021, several European countries have been affected by floods, some were catastrophic, causing deaths and widespread damage. The floods started in the United Kingdom as flash floods causing some property damage and inconvenience. Later floods affected several river basins across northern and central Europe including Austria, Belgium, Croatia, Germany, Luxembourg, the Netherlands, Switzerland and Italy. At least 228 people have died in the floods, including 184 in Germany and 41 in Belgium. Belgian Minister of Home Affairs Annelies Verlinden described the events as "one of the greatest natural disasters our country has ever known." In addition to the confirmed fatalities, the flooding led to widespread power outages, forced evacuations and damage to infrastructure and agriculture in the affected areas. The damage to infrastructure was especially severe in Belgium and Germany. The floods are estimated to have cost up to €2.55 billion in insured losses, with the total damage costs being much higher. In the aftermath, scientists, activists and reporters all highlighted the connection to global trends in extreme weather, especially more frequent heavy rainfall caused by climate change.

The Need for Energy Transition: World Green House Gas Emissions

Global Anthropogenic GHG Emissions (2018)



Oil & Gas ≈ 40% of GHG emissions

10% generated during production & refining

90% associated with the use (combustion) of products

Most emissions are coming from the combustion of fossil fuels at consumer level

Source:
Adapted from CO_2 Emissions from fuel combustion 2016 IEA report and UNEP emissions Gap report

Climate: The Challenges

Mobilizing All Stakeholders

Public Authorities

- Regulatory environment
- International coordination
- Tax policy (social equity, border adjustment, etc.)

Businesses

- Energy efficiency
- Innovation, R&D
- Development of low-carbon products
- Carbon sequestration

Consumers

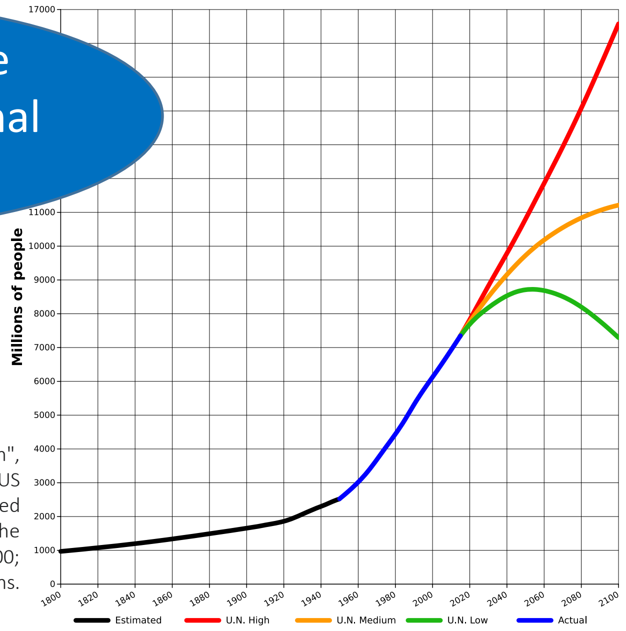
- Sustainable lifestyle
- Energy efficiency
- Responsible consumption

Generating More Energy with Less GHG

Reducing Emissions

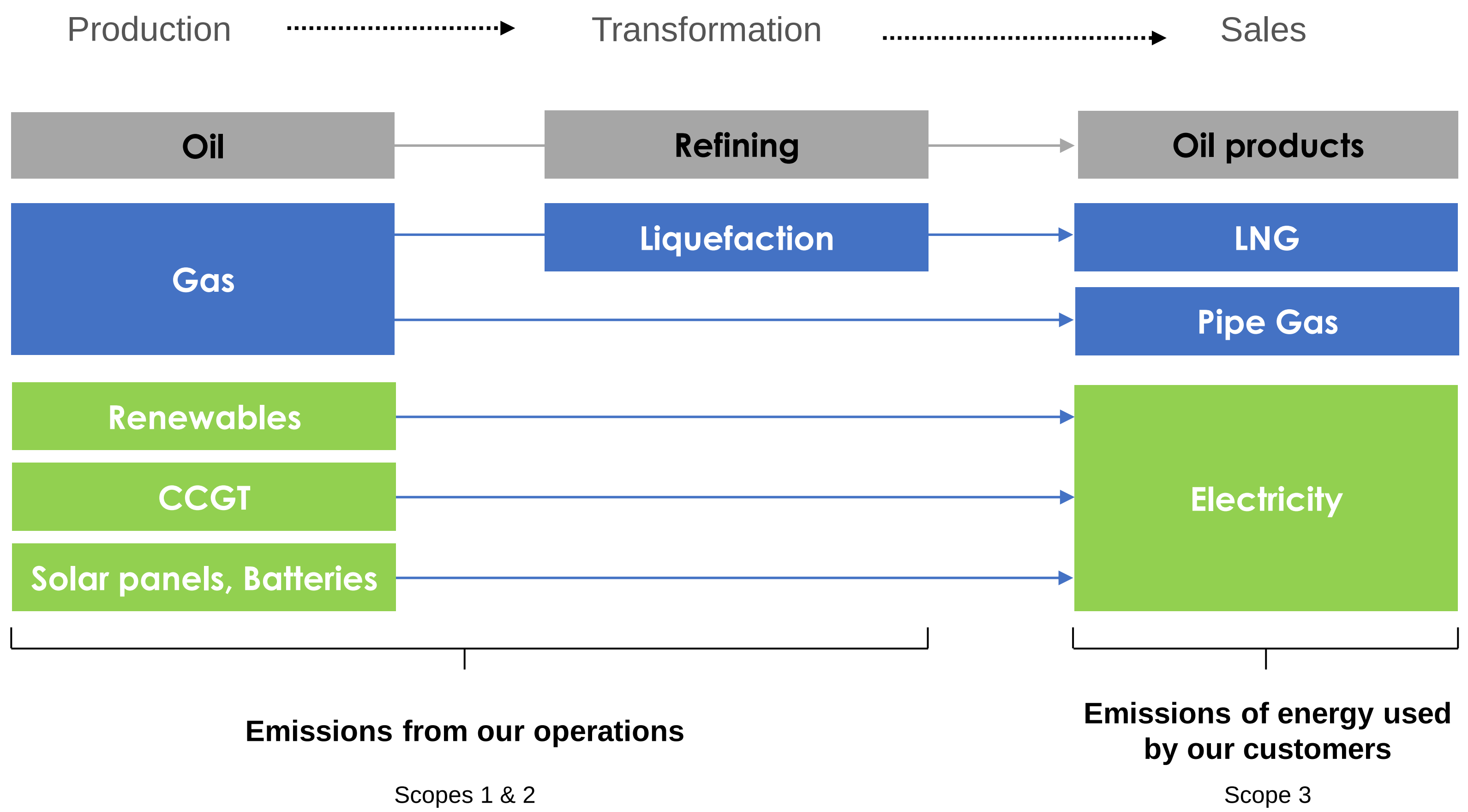
- A society challenge
- A corporate responsibility
- An opportunity as much as a constraint

Providing affordable energy to an additional 3 billion people



World population estimates from 1800 to 2100, based on "high", "medium" and "low" United Nations projections in 2010 and US Census Bureau historical estimates (in black). Actual recorded population figures (as of 2010) are colored in blue. According to the highest estimate, the world population may rise to 16 billions by 2100; according to the lowest estimate, it may decline to 7.2 billions.

Climate: GHG Emissions from Production, Transformation and Customers



Climate: Our Ambition of Getting to Net Zero

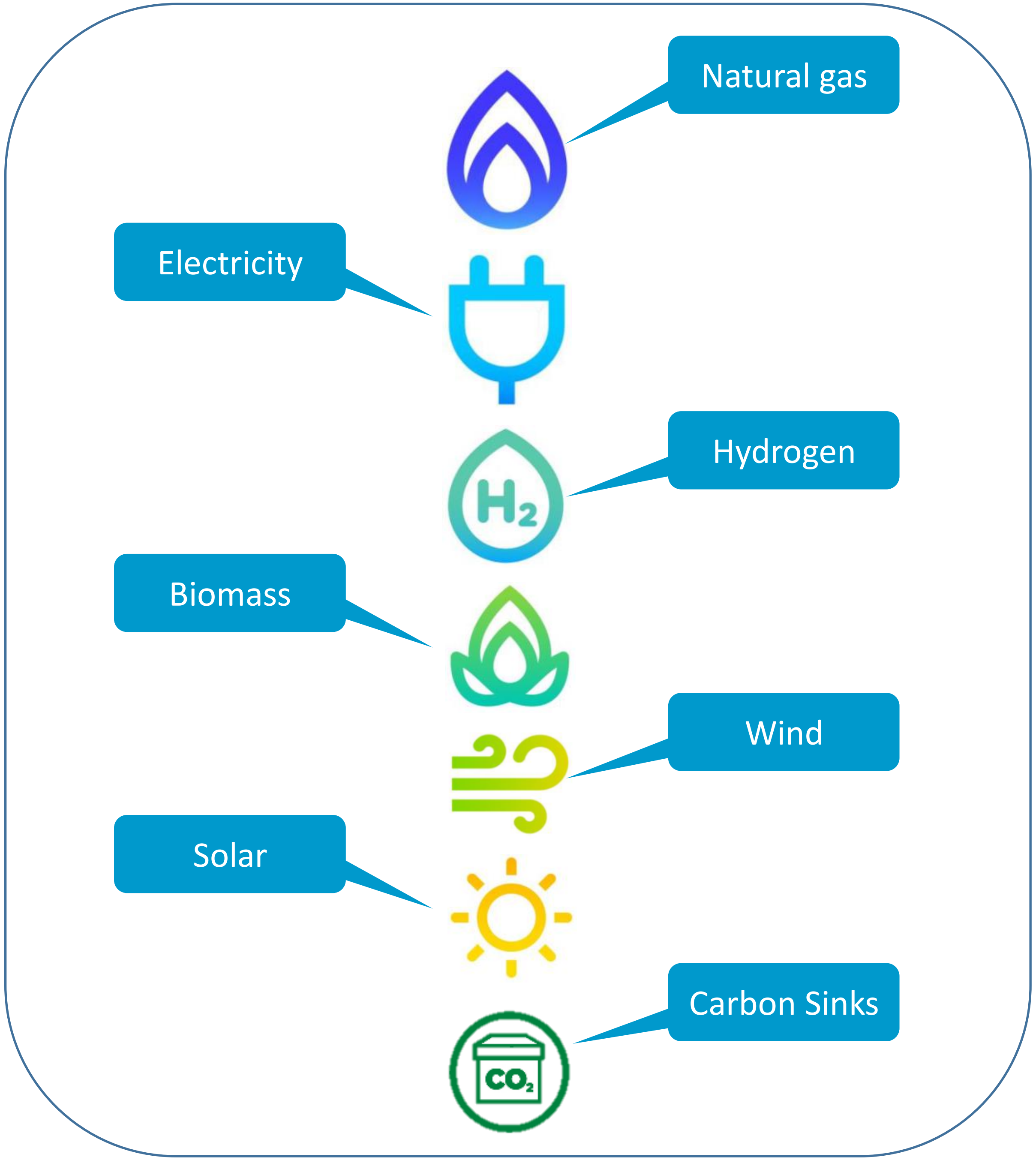
On May 5, 2020, TotalEnergies announced its ambition to reach carbon neutrality for all of its operations, from production to the energy products used by its customers (Scopes 1+2+3), by 2050 together with society.

TotalEnergies

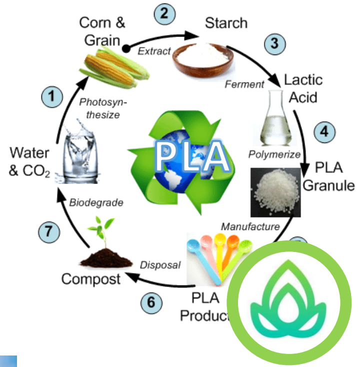
THREE MAJOR STEPS TO GET TO NET ZERO TOGETHER WITH SOCIETY	Realized 2020	By 2030
1. Net Zero across TotalEnergies **worldwide operations by 2050** or sooner *(Scope 1 + 2)*	-15% Scope 1 & 2 emissions	**-40 %** Reduction of net *Scope 1&2 emissions* on operated oil and gas facilities (incl. carbon sinks)
3. Net Zero across **all its production and energy products used by its customers in Europe by 2050** or sooner *(Scope 1 + 2 + 3)*	-15% Scope 1, 2 & 3 in Europe	**-30 %** Reduction in scope 1,2 &3 emissions in Europe compared to 2015
2. Carbon neutrality of **our clients worldwide by 2050** or sooner *(Scope 3)*	-8% Carbon Intensity Indicator	**-20 %** Or more reduction in the average carbon intensity of energy products used worldwide by TotalEnergies customers **Reduction in worldwide scope 3 emissions vs 2015**

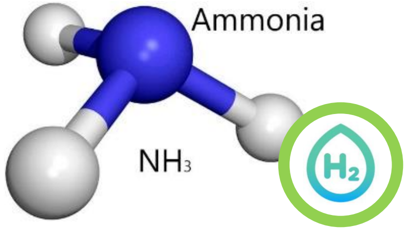
Climate: Activity Areas

➔ Setting up **business structures** in TotalEnergies to develop renewable energy sources:



Climate: Activity Areas





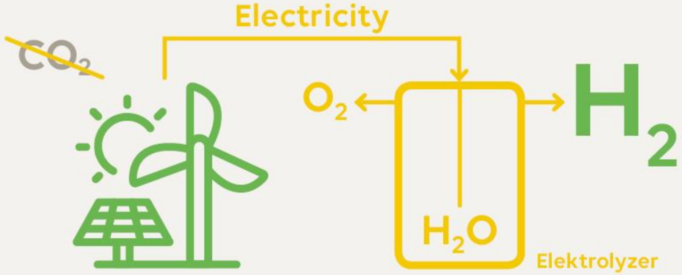
Safety Aspects related to New Energies

Some safety aspects related to the development of new energies are given in the following slides:

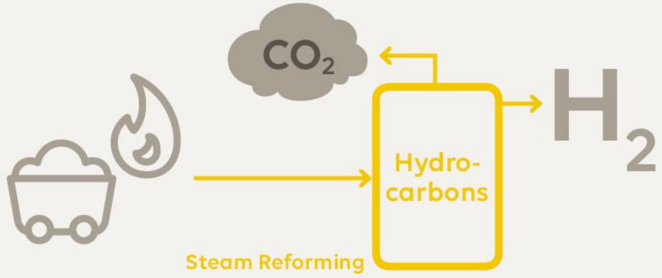
- Hydrogen
- LNG/CNG
- Batteries
- Wind

The colors of hydrogen

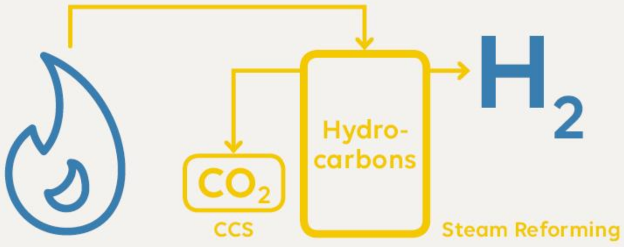
Green



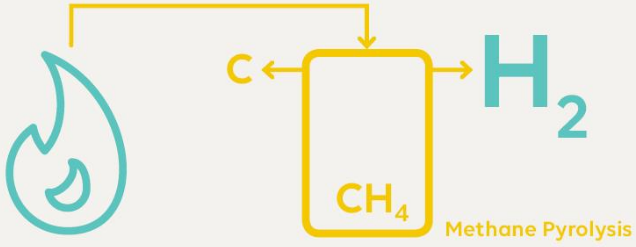
Grey



Blue



Turquoise



Other colors:

- Pink — H_2 produced by electrolyzers powdered by electricity from nuclear power plants
- Black — H_2 from gasification of coal
- White — Naturally occurring H_2
- Yellow — H_2 produced by electrolyzers powdered by electricity from nuclear power plants

Accidents related to Hydrogen

Hydrogen accidents marking the public opinion

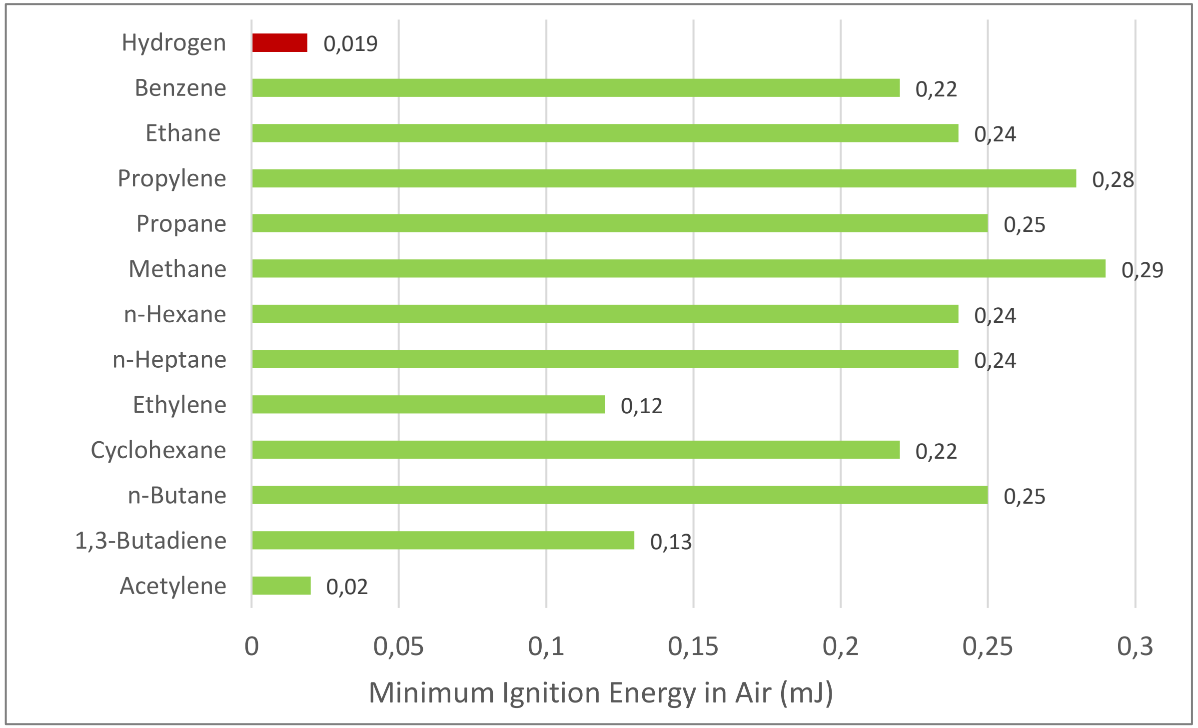
Properties of Hydrogen: Flammability Characteristics

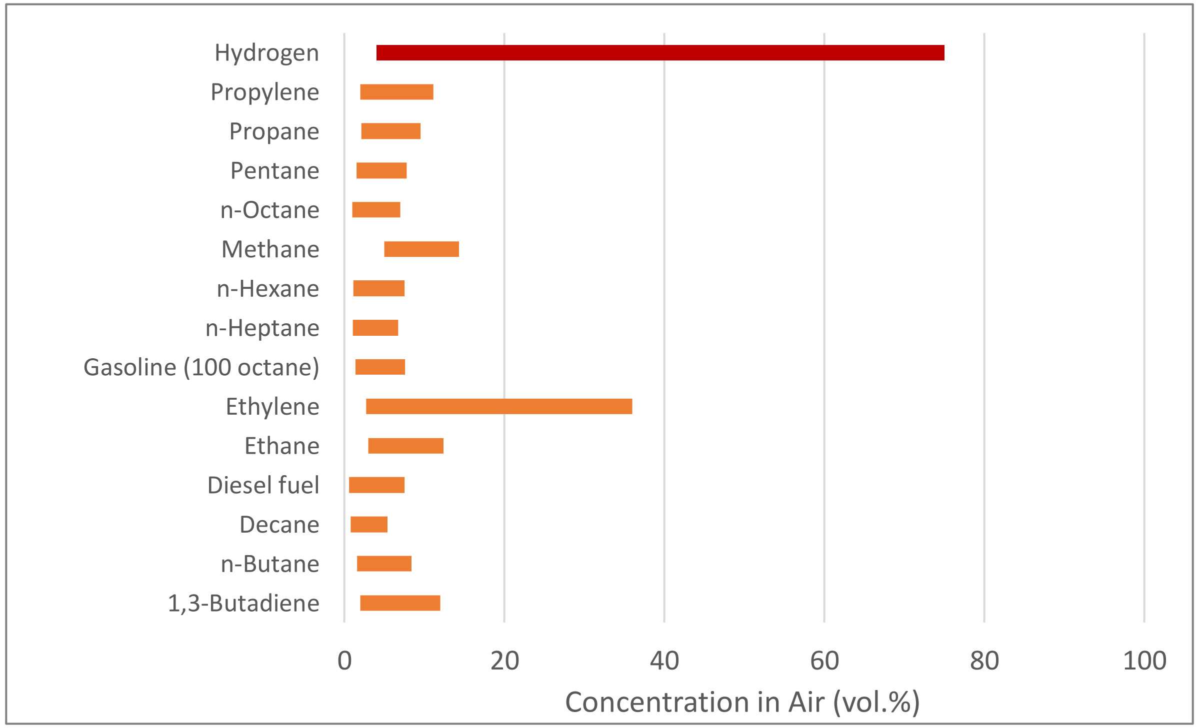
Property	Hydrogen
Molar mass	2.016 g/mol
Flash point	< -253 °C
Auto-ignition temperature	585°C
LFL (Lower Flammable Limit) in air, standard conditions	4 vol%
UFL (Upper Flammable Limit) in air, standard conditions	75 vol%
Minimum ignition energy in air (1 bar, 25 °C)	0.019 mJ

In practice this is a range

Flammable in very wide concentration range

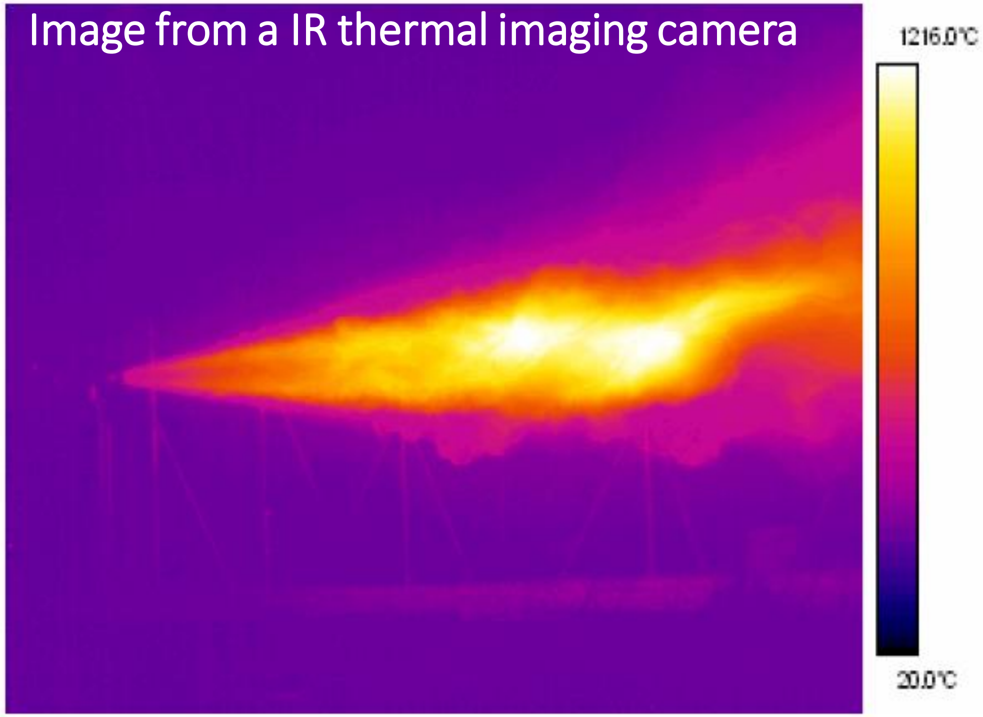
Ignites very easily





Properties of Hydrogen: Flame Visibility

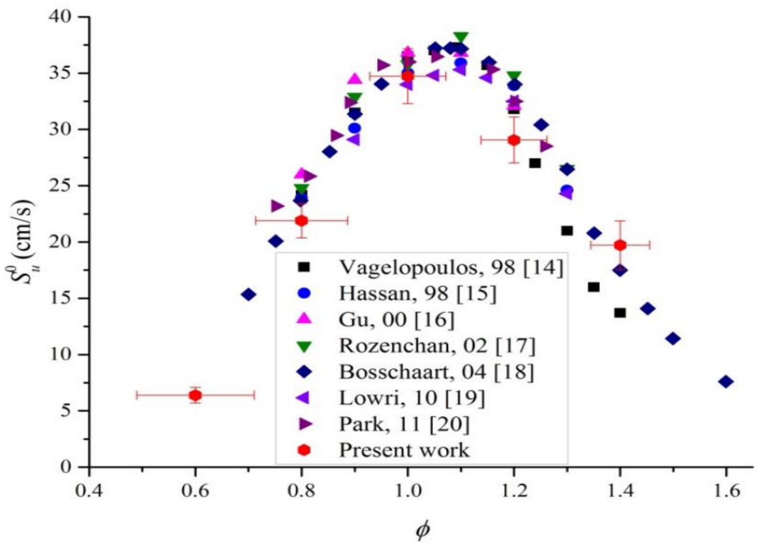
- The flame of a hydrogen fire emits predominantly radiation in the UV region and few in the visible region.
- Hydrogen flames are not (or difficultly visible) in daylight!



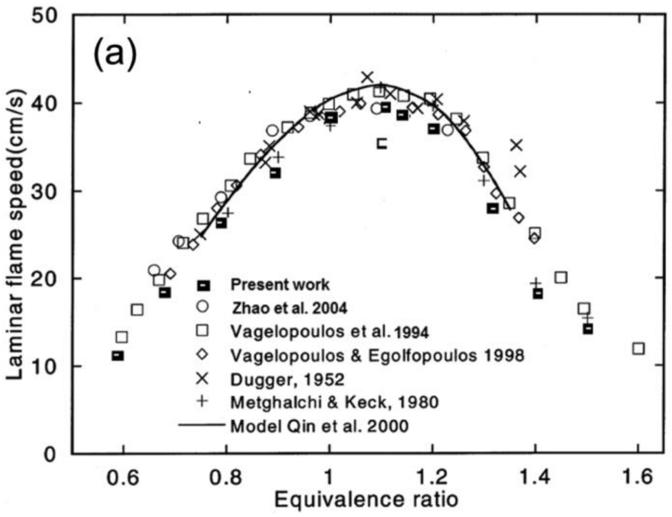
Properties of Hydrogen: Burning Velocities

- The laminar burning velocity is the flame front velocity relative to the unburnt mixture just ahead of the flame when burning in a laminar regime.
- Most hydrocarbons encountered in oil & gas industry have a maximum burning velocity of about 40 cm/s.
- Hydrogen has a much higher maximum burning velocity (about 10 times higher).
- High laminar burning velocities indicate a greater tendency for a deflagration-to-detonation (DDT) transition to occur.

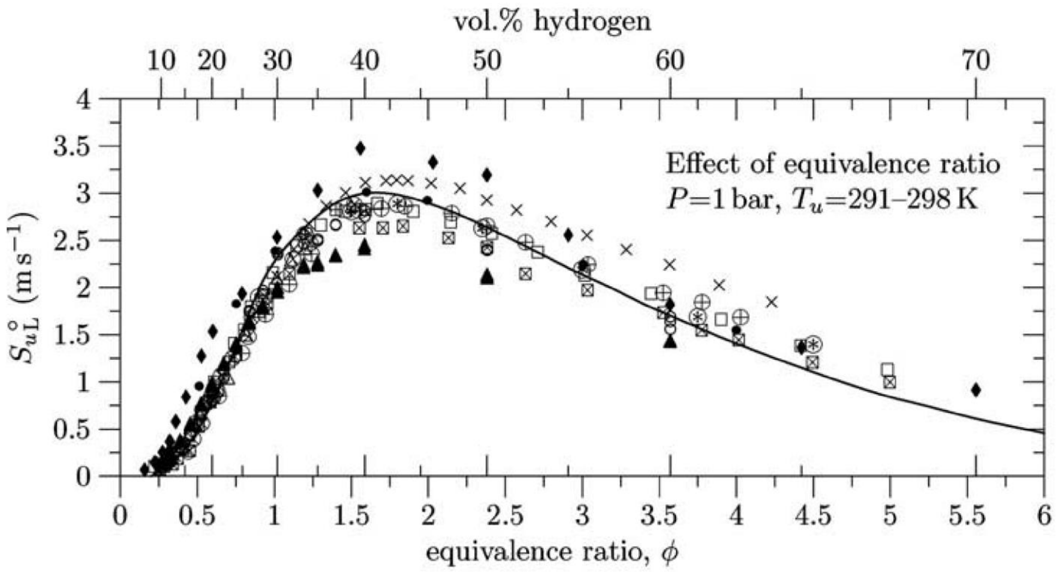
methane/air



propane/air



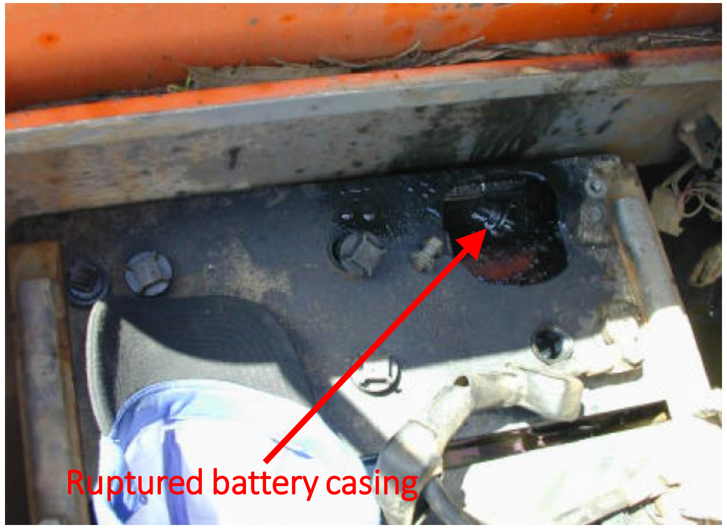
Hydrogen/air



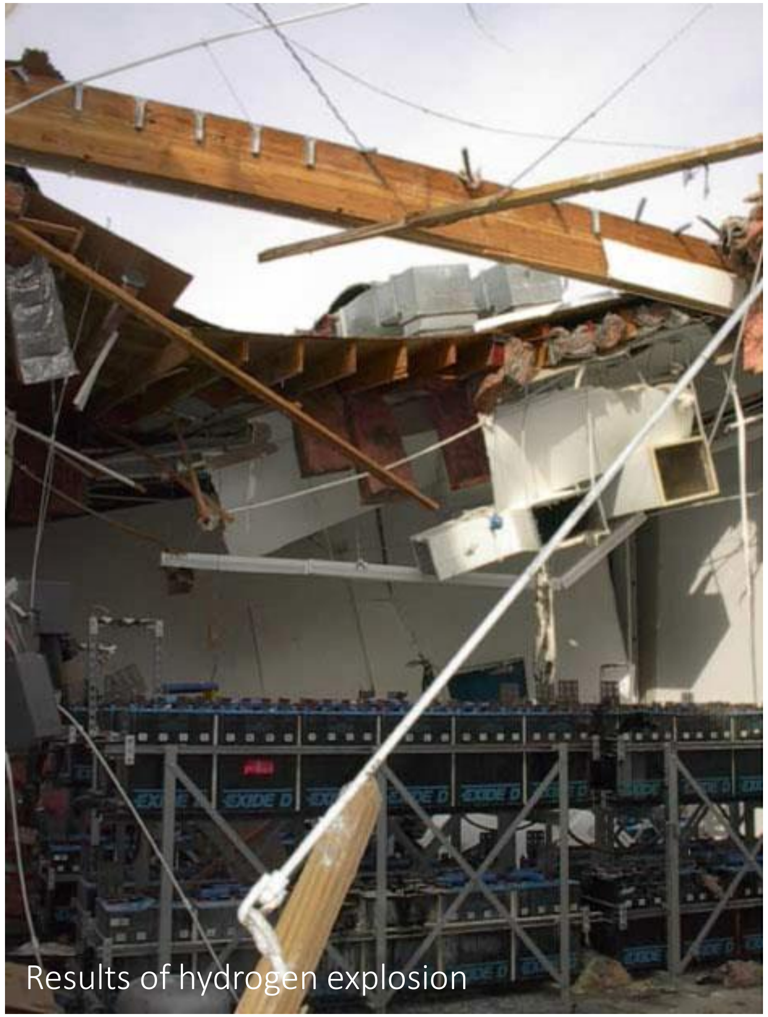
Hydrogen: Accidents

Lead Acid Battery Explosion

- During excessive charging (high current) of lead-acid batteries, hydrogen gas will be produced by electrolysis of the water in the electrolyte
- This phenomena also occurs with valve regulated lead acid (VRLA) batteries, that normally recombines hydrogen and oxygen internally, but can accumulate hydrogen during malfunction or overheating
- In most cases the battery itself will explode. The plastic casing ruptures and acid is ejected. Potential damage is thus related to splashing of the acid or impact by the plastic casing missiles.
- However, especially in large battery bank rooms, hydrogen gas can accumulate in the room. This might lead to more severe impact by explosion in the room. Pictures of the room explosion show the result of an incident during which a local hydrogen detector alarm had been sounding for 3 days at a vacated plant.




Results of hydrogen explosion

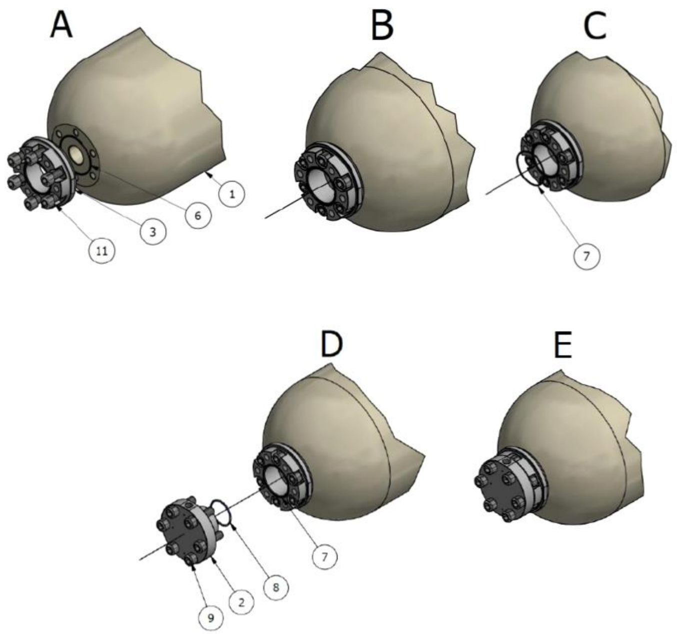

Results of hydrogen explosion

Kjorbo (Norway), 2019

Hydrogen explosion in hydrogen fueling station

1. Starting condition

- Green bolts torqued properly
- Blue bolts not torqued properly

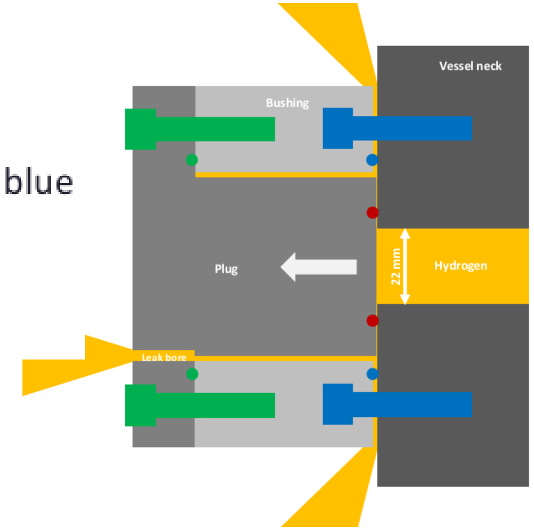


2. Red sealing fails

- Starting with small leak on red sealing area
- Small leak wears red sealing out and escalates
- Large leak exceeding capacity of leak bore, caus increases inside blue sealing area

3. Bushing with Plug lifts and the blue seal fails

- Insufficient pre-tension of bolts leads to lift of the plug and blue sealings fail immediately
- Spread of Hydrogen leaks out in uncontrolled way



Associations on hydrogen

- TotalEnergies is an active member of several hydrogen dedicated initiatives and professional associations:
  - The Hydrogen Council
    - The Hydrogen Council is a global CEO-led initiative of leading companies with a united vision and long-term ambition: for hydrogen to foster the clean energy transition for a better, more resilient future.
  - Hydrogen Europe
    - Hydrogen Europe brings together diverse industry players, large companies and SMEs, who support the delivery of hydrogen and fuel cells technologies in order to enable the adoption of an abundant and reliable energy which efficiently fuels Europe's low carbon economy. Hydrogen Europe represents the European hydrogen and fuel cell sector (260+ companies and 27 National Associations).
  - The European Clean Hydrogen Alliance
    - The European Clean Hydrogen Alliance has been established by the European Commission to support the development of a clean and globally competitive hydrogen industry in Europe and to help the continent to transition to a carbon neutral economy by 2050, in line with the European Green Deal. The Alliance brings together industry, national and local public authorities, civil society and other stakeholders and is strongly anchored in the hydrogen value chain, covering renewable and low-carbon hydrogen from production via transmission to mobility, industry, energy, and heating applications.
  - France Hydrogène
    - France Hydrogène (ex-AFHYPAC) est une association régie par la Loi du 1er juillet 1901. Elle fédère les acteurs de la filière française de l'hydrogène structurés sur l'ensemble de la chaîne de valeur: des grands groupes industriels développant des projets d'envergure, des PME-PMI et start-ups innovantes soutenues par des laboratoires et centres de recherche d'excellence, des associations, pôles de compétitivités et des collectivités territoriales mobilisés pour le déploiement de solutions hydrogène.

Hydrogen Council

Hydrogen Europe

European Clean Hydrogen Alliance

AFHYPAC

R&D programs

Basis for identifying knowledge gaps

- HySafe Research Priorities workshops (last in Buxton 2018)
- Conferences & workshops (ICHS, CERFACS[1], etc.)
- Calls for research, discussions with “classical” R&D partners
  - Air Liquide, GRTgaz, Shell, EDF
  - DNV, Gexcon, SINTEF
- H2-related projects initiated by TotalEnergies [2]
  - HyRISE : mitigation/inhibition of hydrogen explosions using chemical inhibitors (partners: TotalEnergies, SHELL, University of Bergen)
  - LEFEX: high fidelity numerical simulation of explosions using CFD codes, with priority on H2 (partners: CERFACS, AIR LIQUIDE, TotalEnergies, GRTGaz)

[1] Cerfacs is a basic and applied research center, specialized in modeling and numerical simulation. Trough its facilities and expertise in High Performance Computing, Cerfacs deals with major scientific and technical research problems of public and industrial interest. Cerfacs hosts interdisciplinary researchers such as physicians, applied mathematicians, numerical analysts, software engineers who design and develop innovative methods and software solutions to meet the needs of the aeronautics, space, climate, energy and environmental fields. Cerfacs is involved in major national and international projects and is strongly interacting with its seven shareholders : Airbus Group, Cnes, EDF, Météo France, Onera, Safran and Total. It is also associated with partners like CNRS (Associated Research Unit), Irit (common laboratory), CEA and Inria (cooperation agreements).

[2] More information onf HyRISE and LEFEX can be found in the slides in backup

Topics covered in research programs

Explosion prevention/mitigation, transition-to-detonation (DDT)

- A slight change in conditions can trigger a severe explosion up to detonation
- Extrapolation uncertainties of existing “engineering” models (FLACS) are magnified with H2
- DDT would defeat any venting strategy and increase drastically safety distances
- No active mitigation technique available to mitigate H2 explosion
- Debris hazard from H2 explosion is a concern and not entirely predictable

Behavior and control of H2 in enclosed/semi-enclosed spaces

- Experiments and models are available for small releases in naturally-ventilated enclosures (Hytunnel)
- Ventilation model validation is required for sensor placement, robust detection strategy
- Limited testing related to the behavior of jet flames in enclosed space and thermal exposure of vessels, fire partitions
- Lack of studies about flanges, gaskets, hoses, valves under fire attack

Refueling Stations

- Societal acceptance and barriers for wider deployment ⇨ Topic of SHIFT
- Wish to go for simplification, optimization, integrated tools (with mitigations) ⇨ Topic of SHIFT, KPN H2 safety initiative

H_2 in gas distribution networks

- Blends with up to 20%: no major impact on safety distances (e.g. NaturalHy)
- Pure H_2 stream: consequences from large bore releases on pipes as well as end-user hazards are not well supported by experience.

Gas detection

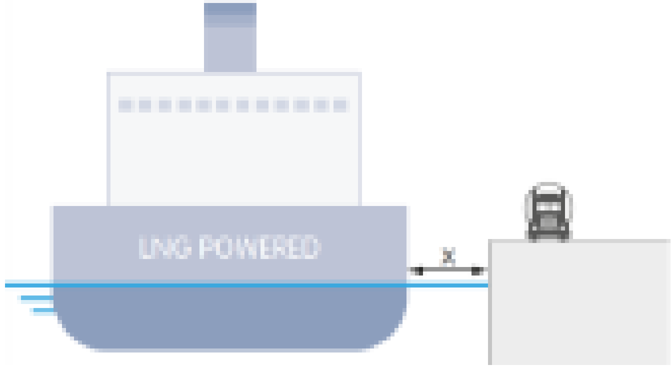
- For hydrogen detection, acoustic based methods are a must-have. Image based detection can help for reliable detection of hydrogen leaks, especially since many installations are operated remotely.
- Discussions are ongoing between TOTAL and Air Liquide to perform testing using the TADI platform.

Natural Gas (CNG, LNG)

- New application as fuel for transport applications (cars, ships, trucks,...)

LNG : 400l #; 170 kg ; 8 bar

CNG : 7 to 12 bottles ; 200 bar



LNG bunkering (ship to ship)

Natural Gas (CNG, LNG): Hazards

Hazards/Risks

- BLEVE of cryogenic storage vessels
- Major release of LNG in ports (during bunkering of passenger ships)
- Flexible hoses for cryogenic applications
- Release of CNG used in transport applications

Pressure safety valve opening on CNG storage bottles on top of a bus during a fire

Catastrophic rupture of cryogenic storage tank

Natural Gas (LNG): Hazards

Cryogenic product storage: around -160°C

- Severe frost injury to men from liquid / spray / vapors: cold burns
- Sudden brittle rupture of non cryogenic materials

High expansion ratio: 1 m^3 of LNG generates 600 m^3 of gas at 20°C

- BOG management
- Rapid Phase Transition (RPT) if trapped, in water for example

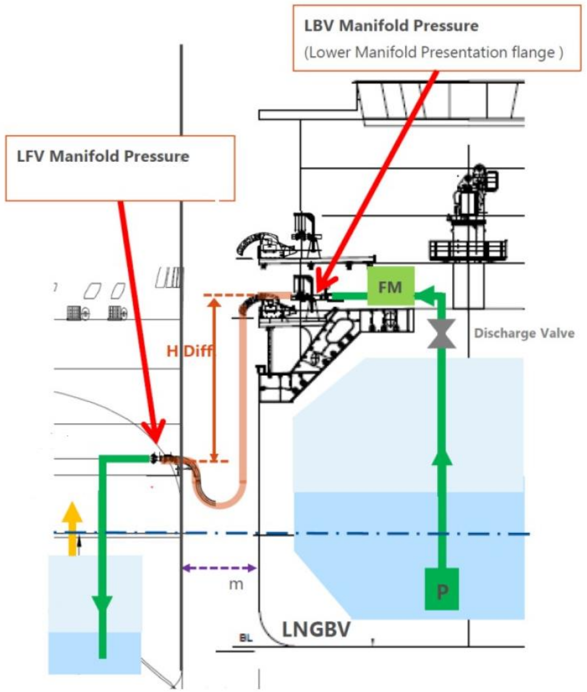
Source: LNG VESSEL CASCADING DAMAGE STRUCTURAL AND THERMAL ANALYSES-Sandia National Laboratories

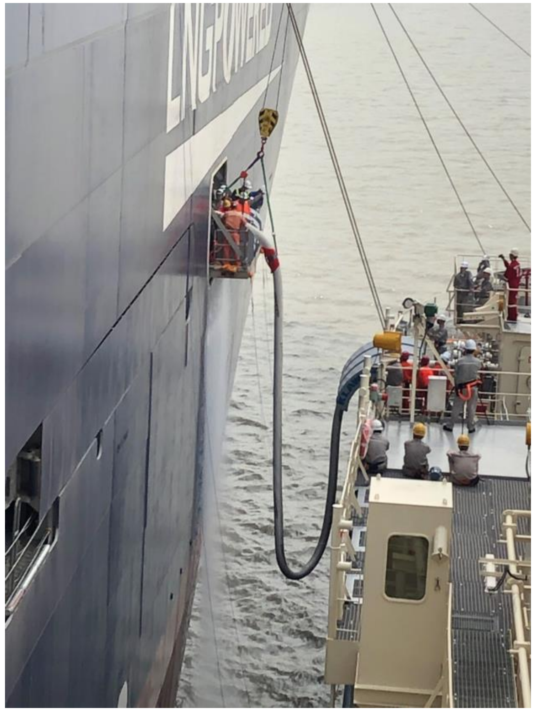
Source:GDF Test RIG Lorient 1982-1984

Natural Gas (LNG): LNG Bunkering

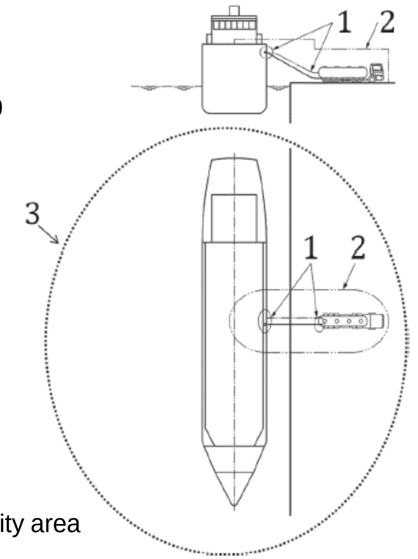
Leak sources

- From Fittings (bunker vessel or receiving vessel)
  - ✓ Instrumentation
  - ✓ Lines damaged
- From LNG transfer system failure
  - ✓ Hose damage
  - ✓ Disconnection
  - ✓ Other



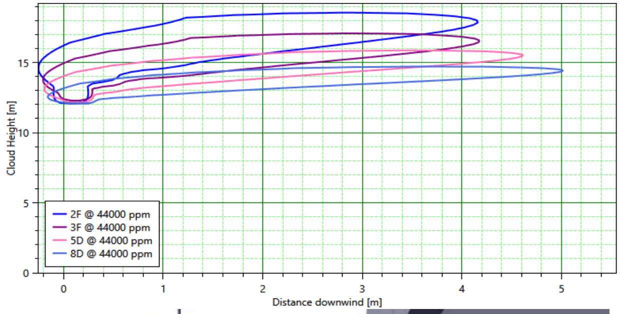


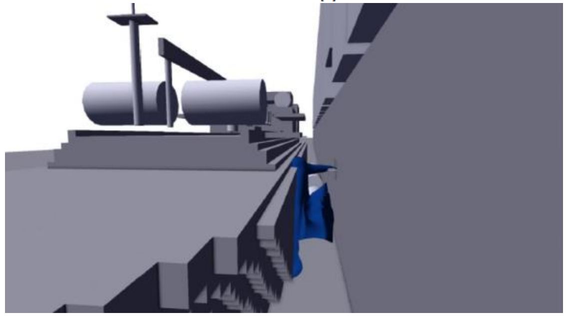
Controlled zones concept – ISO 20519



1. Hazardous zone
2. Safety zone
3. Monitoring and security area

- Safety Zone: Consequence based approach
  - ✓ Predefined credible releases, selected during HAZID sessions
- External Zone: Risk based approach
  - ✓ Using risk contours, individual and collective risks to be compared with predefined **acceptance criteria**





Natural Gas (LNG): LNG Bunkering

Studies

- HAZID (Hazard Identification) and HAZOP (Hazard and Operability)
  - ✓ Brainstorming exercises, using checklist to identify potential hazards of the bunkering operation and focusing on process hazards and operability of LNG transfer system
  - ✓ Participants : vessel's operators, shipyard, Port, Gas System providers,…
  - ✓ Require Basic Vessels Design

- Gas dispersion studies
  - ✓ Analysis of credible leak scenarios (determined by HAZID), to determine the Safety Zone
  - ✓ Require Detailed Vessels Design

- QRA (Quantitative Risk Assessment)
  - ✓ Assess major accidental events (fire, explosion) that may extent beyond the safety zone and impact third parties
  - ✓ Provides an input for emergency response plans

- SIMOPS (Simultaneous Operations) Studies
  - ✓ Analysis of the commercial operations or maintenance work that could be undertaken during LNG transfer
  - ✓ Done by/with client with LBV input
  - ✓ Requires gas dispersion analysis

Li-Ion Batteries

Electricity Storage Systems

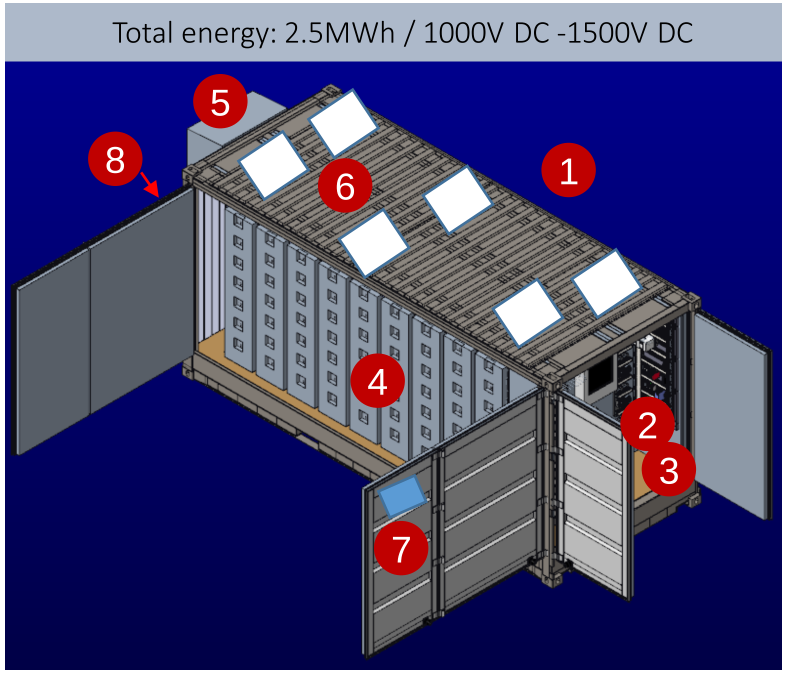
Mechanical	Thermal	Chemical	Electro-chemical	Electrical
○ Pumped storage ○ Compressed air ○ Liquid air storage ○ Flywheels	○ Thermo-chemical ○ Sensible thermal ○ Latent thermal	○ Hydrogen storage ○ Synthetic natural gas (SNG)	○ Lithium-Ion battery ○ Lead-acid battery ○ NaS battery ○ Redox flow battery	○ Super capacitators

Source: World Energy Council, 2016

Li-Ion Battery Applications: BESS

About 40.000 Li Ion cells are present in a typical BESS

- 9 ESSA with 14 modules per ESSU
- 320 Li-Ion cells per module
- Dimensions : 2896 mm x2438 mm x6058 mm
- Energy : ≈ 2.5 MWh
- 126 Modules (with 5 cells in 64 cell blocks per module)
- Power : 1.3 MW
- Technology : Li Ion NMC
- Design life : 20 years



1. 20 ft container with doors on both sides
2. Control room with High Voltage disconnect, BMMs, control panels, & FSS
3. Primary FSS
4. 9 ESSU with 14 modules each (126 modules total)
5. HVAC unit (26 kW) with centralized supply duct & 126 fans
6. Hot /explosive gas panels on the IHE roof
7. Overpressure panel on the door
8. Redundant water FSS

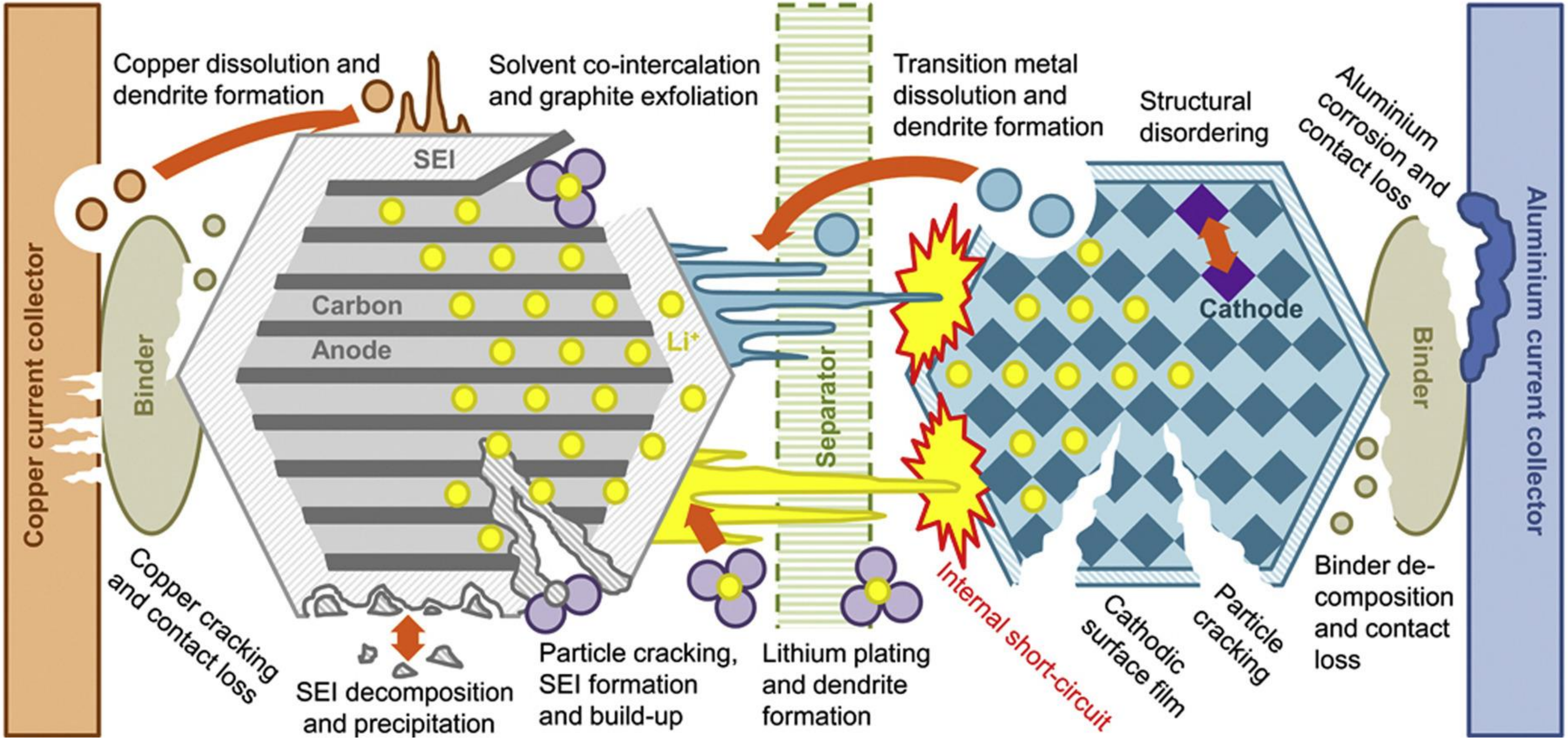
Li-Ion Battery Applications: Transport Applications


TGV of the future


Tesla Model S Battery

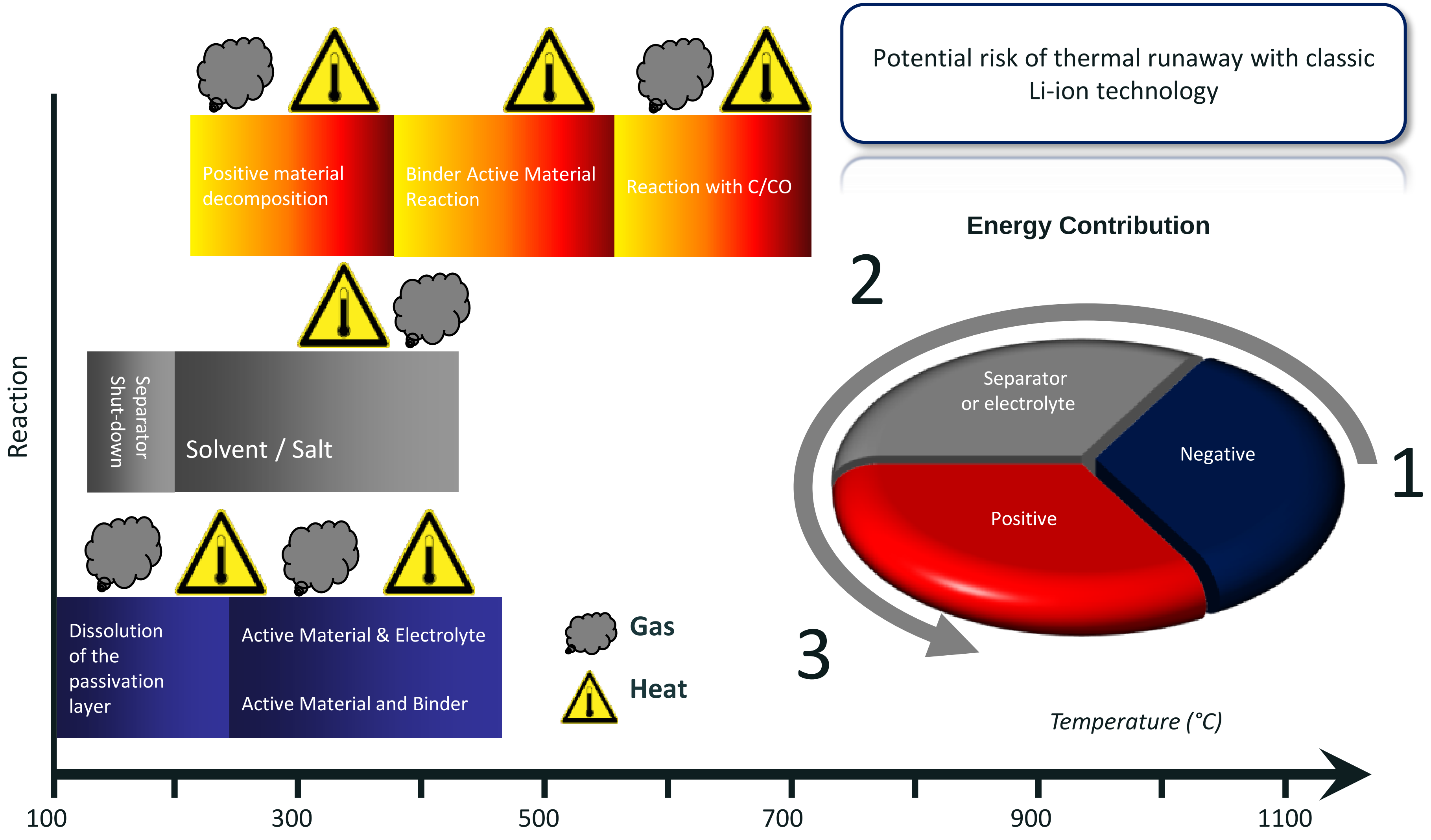
Li-Ion Batteries: Hazards

Degradation in lithium ion (Li-ion) battery cells is the result of a complex interplay of a host of different physical and chemical mechanisms.

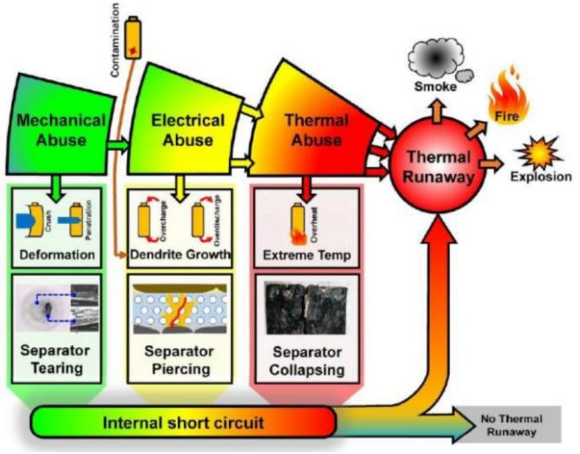


Li-Ion Batteries: Hazards

Chain reactions contributing to heat, smoke, and potential runaway
(General Li-ion case)



- Thermal runaway is a phenomenon which consists in a melting of the separator of the Lithium-Ion cell at high temperature.
- This non-mastered action results to put in contact the positive and negative electrodes of the cell.
- It is followed by a high increase of the internal temperature & pressure of the Lithium-Ion cell.
- It can result into a cell vent opening and electrolyte, carbon powder and gas release.



Li-Ion Batteries: Hazards

Toxic smoke

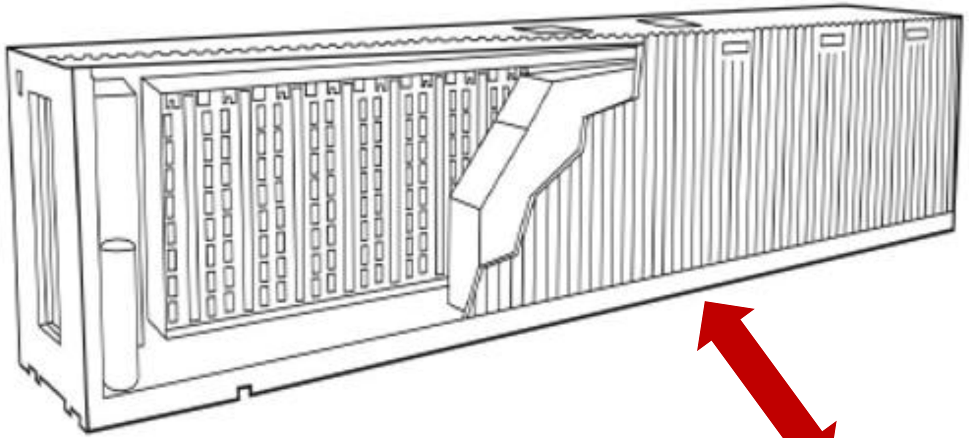
Generation of toxic gases upon thermal runaway of the battery.

Indicative composition :

- 30 % CO
- 30 % CO_2
- 30 % H_2
- 10 % CH_4
- Traces of HF and other components

Fire

Ignition of flammable gases generated during thermal runaway / heating of combustible materials (plastics, electronics,…)



Explosion

Generation of flammable gases generated during thermal runaway of a Li-Ion battery

Electrocution

High voltage current. Risk of electric arc.

Li-Ion Batteries: Experience Feedback

Problems with Li-Ion batteries in Boeing 787 (2013)

Explosion in container transporting Li-Ion batteries (2017)


Fire of ESS (Drogenbos, B) (2017)


Explosion in ESS (Arizona, 2019)


Fire of electric car


Thermal runaway of Li-Ion battery

Li-Ion Batteries: Experience Feedback

Video

Li-Ion Batteries: Experience Feedback

video

BESS Fires & Explosions: Recent Events

France, 2020 (Perles-et-Castelet)

- A fire broke out in a container with 60 Li-Ion batteries on 01/12/2020 at 09:30. Four people living near the disaster were evacuated and relocated. 45 fire fighters were mobilized to fight the fire.

UK, 2020 (Liverpool)

- Fire at the Carnegie Road 20MW battery energy storage system (BESS) project in Liverpool, England (project owner Ørsted). Merseyside Fire & Rescue Service, local first-responders, said that crews were alerted shortly before 1 am on 15 September and arrived to find a “large grid battery system container well alight”. The blaze went on for several hours, with an update from the service at 7:30am noting that although operations at the site had been scaled down, firefighting was ongoing, with two ground monitor units and a main water jet still in use.

China, 2021 (Beijing)

- At 12:17 pm on 16th April 2021, the Fire Command Center of Beijing received a report of the fire accident occurred on the Beijng Jimei Dahongmen power station (located in the south area). 47 fire trucks and 235 fire fighters from 15 local fire brigades were sent to the fire site. Around 14:15 pm, when the fire fighters were dealing with the fire of the power station in the south area, a sudden explosion occurred in the power station in the north area without a warning, leading to the death of 2 fire fighters, injury of 1 fire fighter and missing of 1 employee of the power station.

Australia, 2021 (Moorabool)

- Fire of two containers holding Tesla Megapack batteries (3 MWh) during testing at the newly registered Victoria Big Battery at Moorabool, near Geelong (biggest battery park in Australia, 300/450 MWh). Fire extinguished after 4 days of burning.

BESS Fires & Explosions: Recent Events

TotalEnergies, New Caledonia, 2021 (Boulouparis)

- A fire broke out in 2 BESS containers installed in a solar park
- An explosion occurred in one of the 2 containers a couple of minutes after the door was opened
- The cause of the simultaneous fire in both containers would be related to production errors in the batteries

Li-Ion Batteries: Explosion Risks

- Explosions can occur during charging of EVs as shown in the video below (explosion after extinguishment of the fire).
- These explosions are related to ignition or reignition of flammable vapors generated during thermal runaway of the Li-Ion batteries in the confined geometry of the car or battery

Li-Ion Batteries: Explosion/Toxic Risks

- The gases discharged during thermal runaway of Li-Ion batteries can contain (depending on the chemistry):
  - ✓ Up to 30 vol.% of CO (toxic gas)
  - ✓ Up to 35 vol.% of H2 (highly flammable gas)
- The smoke discharged during thermal runaway of Li-Ion batteries can also contain HF (toxic gas). According to Larsson et al. (2017) the amounts of generated HF can be as high as 20 to 200 mg/Wh.

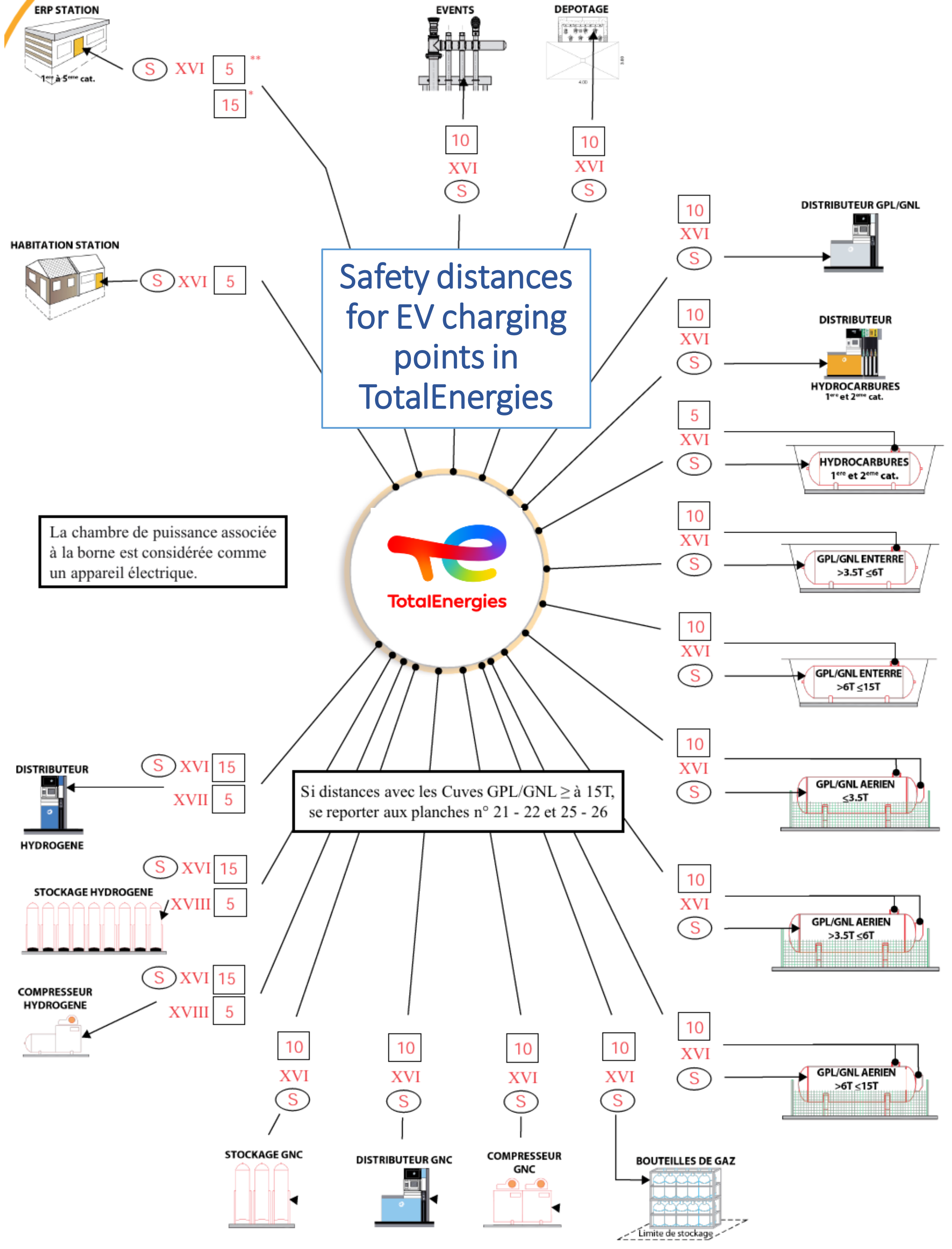
	Somandepalli et al. (2014) Pouch cells			Golubkov et al (2014) Cylindrical cells			Arora et al. (2018) Pouch Cells	Barry et al. (2020) Cylindrical cells
	SoC 50%	SoC 100%	SoC 150%	LNMCO	LCO	LFP	SAFT	
CO_2	32.3	30.0	20.9	41.3	25.0	52.0	42.5	40.1
CO	3.61	22.9	24.5	13.1	27.7	4.8	29.4	12.1
H_2	31.0	27.7	29.7	30.2	30.1	31.0	14.73	31.1
CH_4	5.78	6.39	8.21	6.9	8.6	4.1	7.31	6.1
C_2H_4	5.57	2.19	10.8	8.3	7.8	6.9	2.93	3.4
C_2H_6	2.75	1.16	1.32	0.0	1.2	0.3	0.55	1.2
C_3H_6	8.16	4.52	0.013				0.37	
C_3H_8	0.68	0.26	2.54				0.92	
iC_4H_{10}	0.41	0.20	0.13				0.28	
C_4H_{10}	0.67	0.56	0.39				0.10	
C_4H_8	2.55	1.58	0.60				0.11	


Thermal runaway of Li-Ion pouch battery

Safety Distances

Recommended separation distances for Lithium BESS (Source: NFPA)

ESS Type & Capacity	Object Combustibility	Sprinklered	Nonsprinklered
LFP 83 kWh	Combustible	–	1.8 m (6 ft)
	Noncombustible	–	1.2 m (4 ft)
NMC 47 kWh	Combustible	2.7 m (9 ft)	4.0 m (13 ft)
	Noncombustible	1.8 m (6 ft)	2.4 m (8 ft)
NMC 125 kWh	Combustible	–	1.2 m (4 ft)
	Noncombustible	–	< 0.9 m (< 3 ft)
LFP 31 kWh	Combustible	1.5 m (5 ft)	1.8 m (6 ft)
	Noncombustible	0.9 m (3 ft)	1.2 m (4 ft)



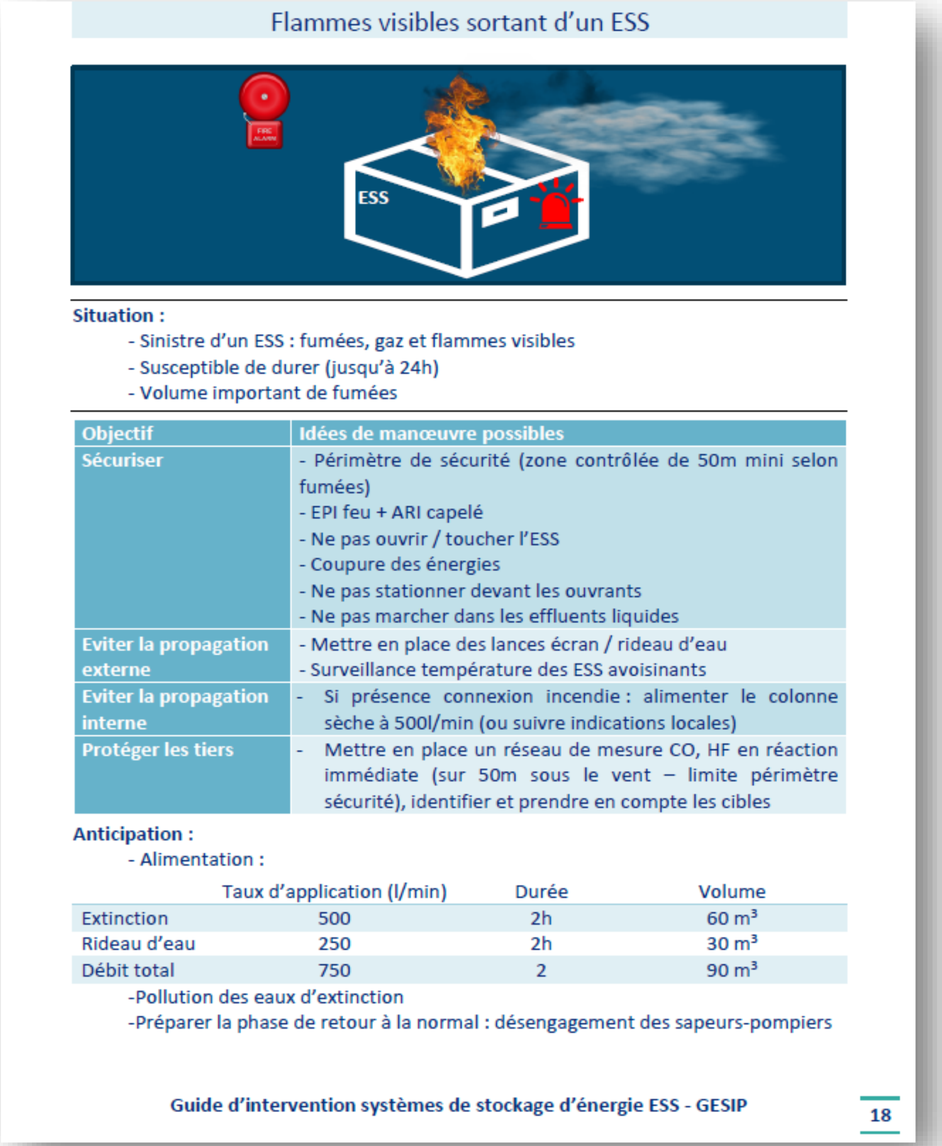
Prevention and Mitigation Barriers

Risk	Description	Prevention Barriers	Mitigation Barriers
Thermal	Large amounts of flammable gases are generated upon thermal runaway of a Li-Ion battery (H2, CO, CH4). However, the radiation levels upon ignitio of these flammable gases is not very high.	○ Fire extinghuising systems : ✓ Inert gas (N_2, Ar…) ✓ Water mist ○ Smoke and/or heat detection ○ Thermally isolated BESS container (walls) ○ Water drainage system to avoid flooding of the container ○ Safety distance between containers to avoid escalation effects	○ Safety perimeter ○ Dedicated vents for evacuation of generated gas / flames ○ Blast panel ○ Water curtain ○ EPI ○ External audible alarm ○ External thermometer ○ EPI ○ Water monitor (variable water flow 500 l/min)
Electrical	Electrocution risk. This risk is relevant for several voltage levels and different current types: ○ 225 kV AC ○ 33 kV AC ○ 400 V AC ○ 220 V AC ○ 690 V AC ○ 1500 V DC	○ Grounding of all components and chassis or electrical isolation ○ Automated battery management system (BMS) ○ Warning signs	Safety perimeter General electrical isolation if available Avoiding standing in water Not touching equipment inside container
Toxic Smoke	Large amounts of flammable gases are generated upon thermal runaway of a Li-Ion battery. Some of the gas components are toxic (CO). Smaller quantities of the toxic HF may also be formed, together with toxic compounds resulting from the thermal degradation of battery components (plastics etc.)	○ Smoke detection ○ Early extinction	○ Safety perimeter ○ Breathing protection for intervention teams during the different intervention phases. ○ Installation of a network of ambient measuring points for CO, HF,…
Explosion	Large amounts of flammable gases are generated upon thermal runaway of a Li-Ion battery (H2, CO, CH4). These gases can form a flammable atmosphere inside the container.	○ Gas detection ○ Inert gas fire extinguishing system (nitrogen, argonite…)	○ Blast panel ○ Safety perimeter ○ Stay out of the line of fire (doors) ○ Monitoring of flammable gas concentration inside container (sampling via openings in the walls if available)

Intervention Strategies

Five scenarios were elaborated to facilitate decision making by intervention teams:

- Scenario 1: Visual and audible alarm without observation of smoke/flames
- Scenario 2: Generation of smoke / gas
- Scenario 3: Flames escaping from e BESS
- Scneario 4: BESS exposed to external thermal impact (forrest fire, fire of nearby equipment,...)
- Scenario 5: Incident during storage, transport, ...



Flammes visibles sortant d'un ESS

Situation :

- Sinistre d'un ESS : fumées, gaz et flammes visibles
- Susceptible de durer (jusqu'à 24h)
- Volume important de fumées

Objectif	Idées de manœuvre possibles
Sécuriser	- Périmètre de sécurité (zone contrôlée de 50m mini selon fumées) - EPI feu + ARI capelé - Ne pas ouvrir / toucher l'ESS - Coupure des énergies - Ne pas stationner devant les ouvrants - Ne pas marcher dans les effluents liquides
Eviter la propagation externe	- Mettre en place des lances écran / rideau d'eau - Surveillance température des ESS avoisinants
Eviter la propagation interne	- Si présence connexion incendie : alimenter le colonne sèche à 500l/min (ou suivre indications locales)
Protéger les tiers	- Mettre en place un réseau de mesure CO, HF en réaction immédiate (sur 50m sous le vent – limite périmètre sécurité), identifier et prendre en compte les cibles

Anticipation :

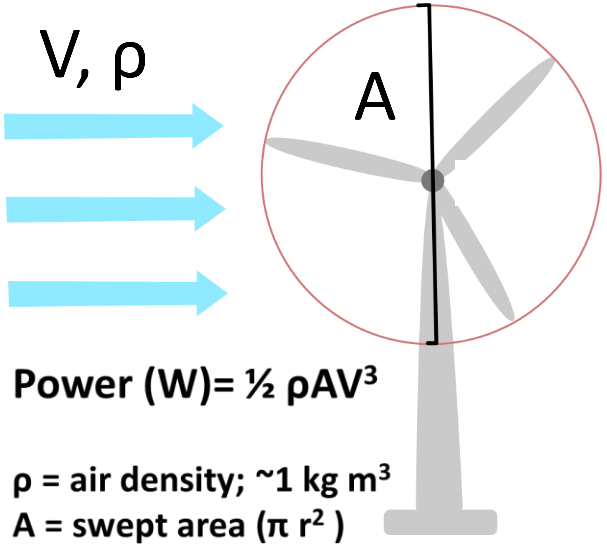
- Alimentation :

	Taux d'application (l/min)	Durée	Volume
Extinction	500	2h	60 m³
Rideau d'eau	250	2h	30 m³
Débit total	750	2	90 m³

-Pollution des eaux d'extinction
-Préparer la phase de retour à la normal : désengagement des sapeurs-pompiers

Wind Turbines

- Horizontal-axis wind turbine (HAWT)
  - ✓ More efficient than the vertical axis turbine
  - ✓ The turbine is mounted on top of a tower.
  - ✓ The rotor and blades of the horizontal wind turbine are connected to the generator by a shaft.
  - ✓ The majority of installed wind turbines are of the HAWT type (approx. 99.9%) and have a high level of maturity.

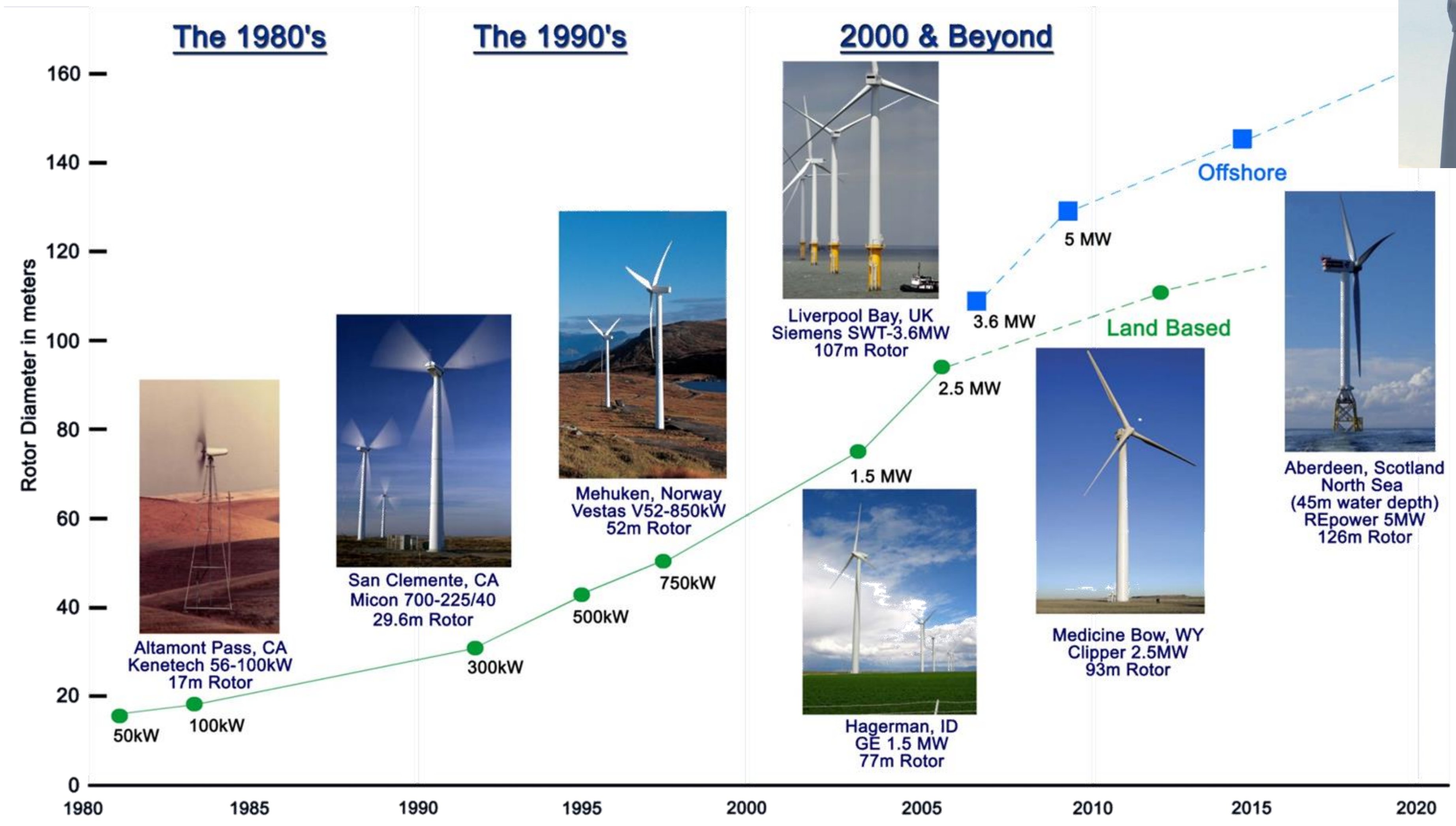


Power (W)= $\frac{1}{2}\rho A V^3$

ρ = air density; ~1 kg m^3
A = swept area (πr^2)
V = velocity (m s^{-1})

- Vertical-axis wind turbine (VAWT)
  - ✓ Shaped like an egg-beater and uses lift forces on its blades to get them to turn.
  - ✓ The design allows the blades to rotate at higher speeds than the wind.
  - ✓ VAWT has only been installed in some experimental facilities and on top of buildings.

Wind Turbines

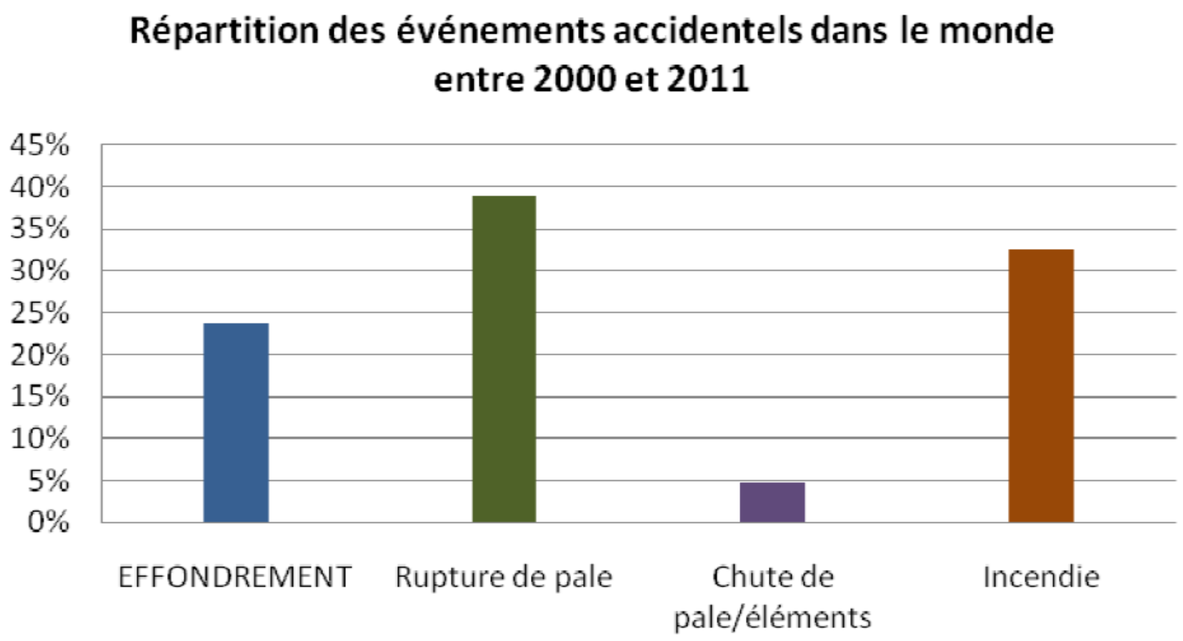


Wind Turbines

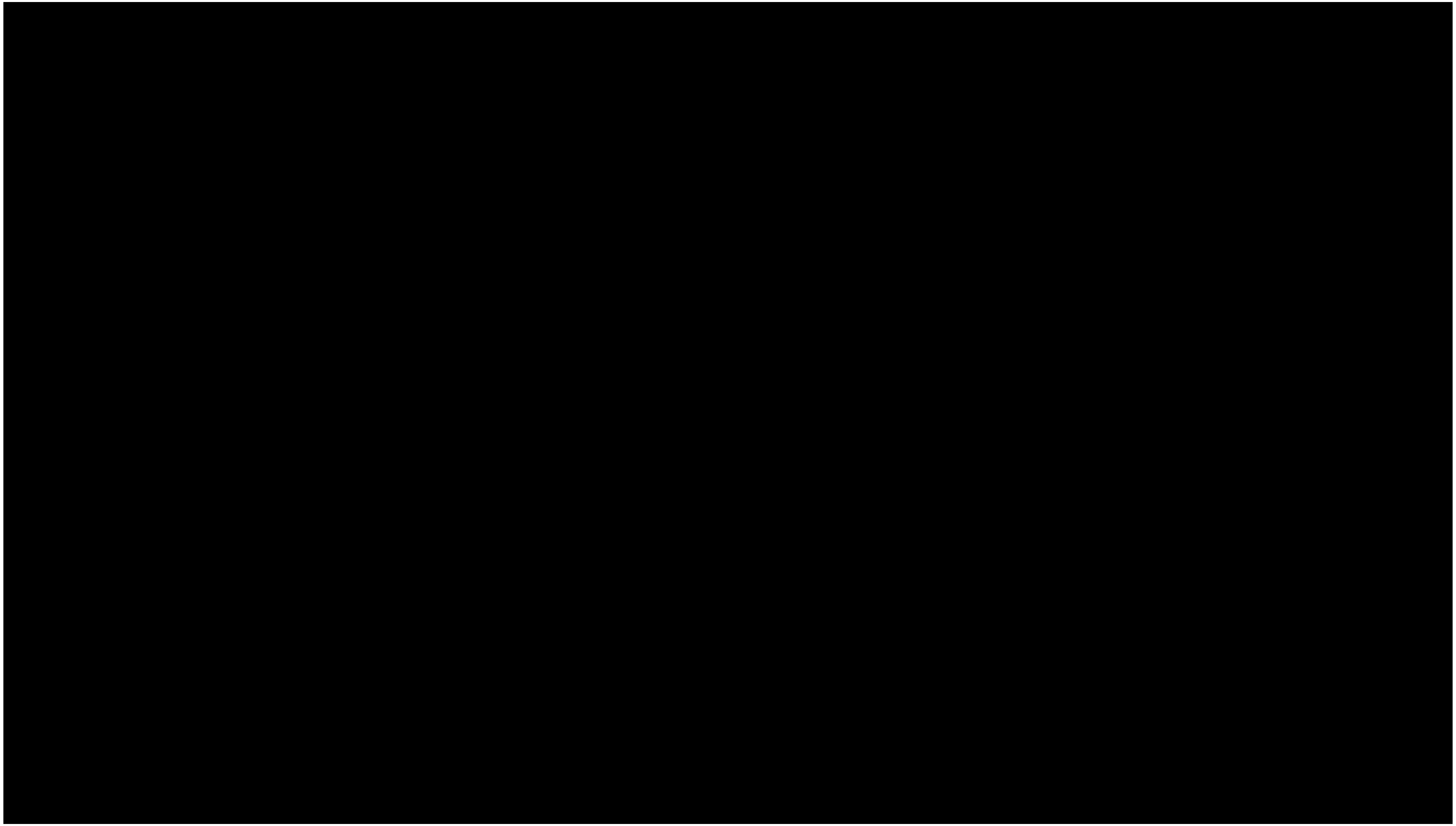
Wind Turbines: Hazards

Hazards/Risks:

- Fall of objects (of nacelle, rotor, pylon/tower,...)
- Fire in nacelle
- Projection of wind turbine blades (missile effects)
- Ship collision (offshore wind farms)



Wind Turbines: Accidents

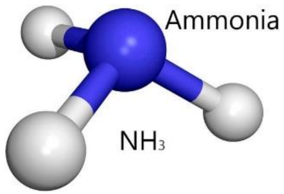


New Energies and Major Risks: Organization

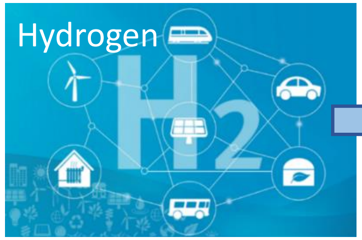
Els
Depraetere

Pascal
Pourcel
(LNG - CO2 storage)

Carbon Capture & Utilisation
Vincent
Dupuy



Dirk
Roosendans



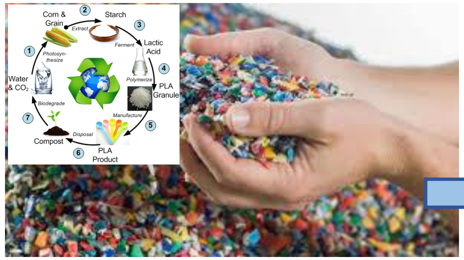
Antoine
Dutertre

Anthony
Leloup

Brahima
Konate

Karim
Zebidi

Mikael
Jurot



Els
Janssens

Cyrille
Barre

Elise
Morand

New Energies and Major Risks: Activities & Development of Guidelines

- Methods & Tools
  - Provide support in the development of internal rules, general specifications, guides, tools and methods
  - Ensure the centralization of documentation on methods, standards and tools in the area of major risk management related to new energies
- Competence and Training
  - Contribute to the development of a knowledge database
  - Distribute the know-how and ensure a technology watch
- Networking and Communication
  - Develop an internal network (One HSE, One Tech,….)
  - Develop an external network (academic environment, professional organizations)
- Assistance
  - Provide or search for assistance for the realization of PHA studies at the request of all entities of TotalEnergies and by projects. It concerns more in particular support in the selection of methodologies, tools, training, interpretation/derogation of applicable specifications and selection of subcontractors
- Other
  - Identify, in collaboration with research teams, necessary actions and programs by R&D
  - Ensure the interface with research teams
  - Give support to management (and if necessary, alert) in specific files

Guidelines

1. Relevant Hazards
2. Experience Feedback
3. Codes and Standards
   a. Internal to TotalEnergies
   b. External to TotalEnergies
4. Networking
   a. Internal network
   b. Professional Associations
5. Methods & Tools
   a. Probabilities
   b. Consequence modelling
6. Generic Major Accident Scenarios
7. Prevention and Mitigation Barriers
8. Environmental Aspects
9. Intervention Strategies
10. Development Areas
11. Training Materials
12. Bibliography
13. Studies and Projects
    a. Internal to TotalEnergies
    b. External to TotalEnergies

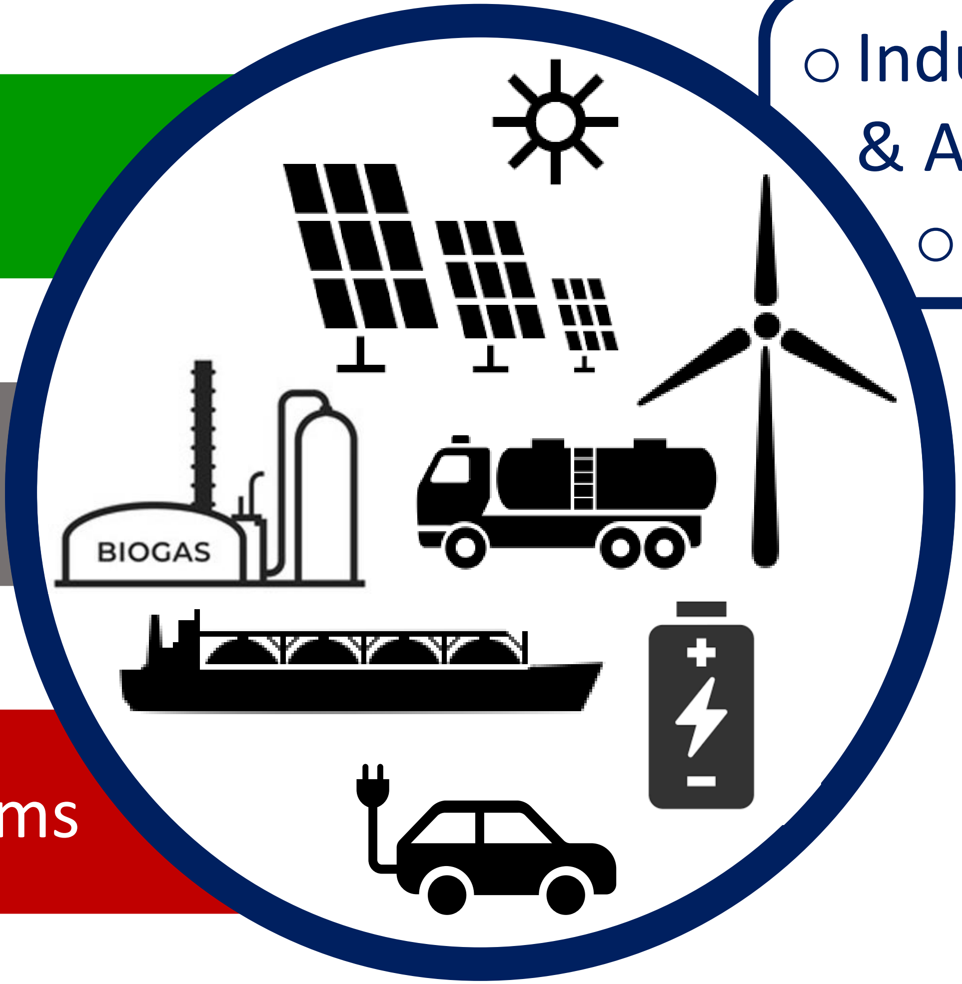
New Energies and Major Risks: Support Organization

Networking / Communication

One HSE
(> 200 HSE experts at corporate level)

One Tech
(> 3000 technical experts at corporate level)

Business Development Teams



- Industrial Sites & Activities
- Projects

Thanks for your attention

