Impact of Energy Transition on Process Safety

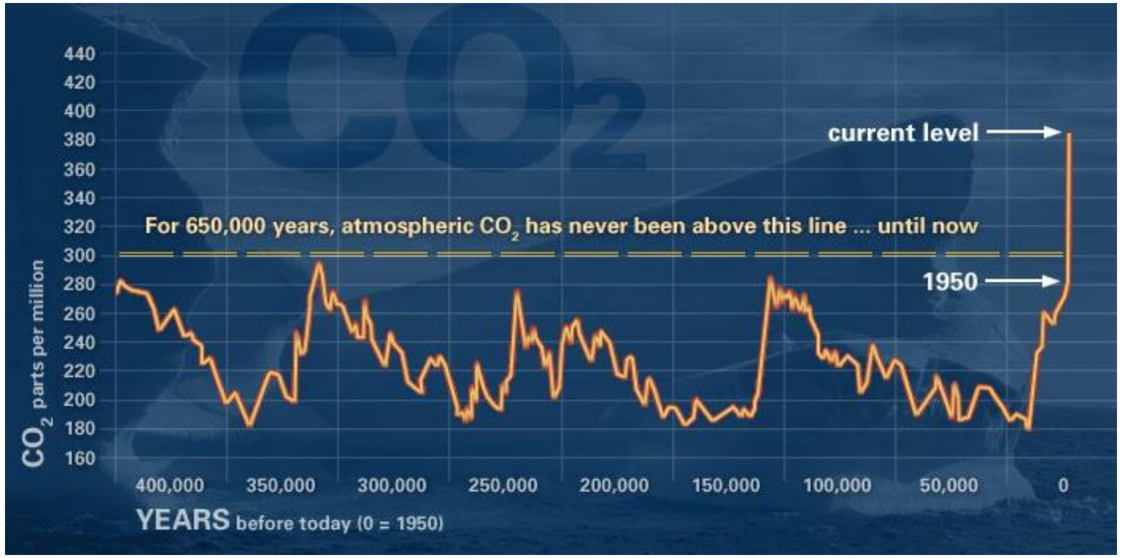
PSR/HSE/RM/SPI©
August 2022

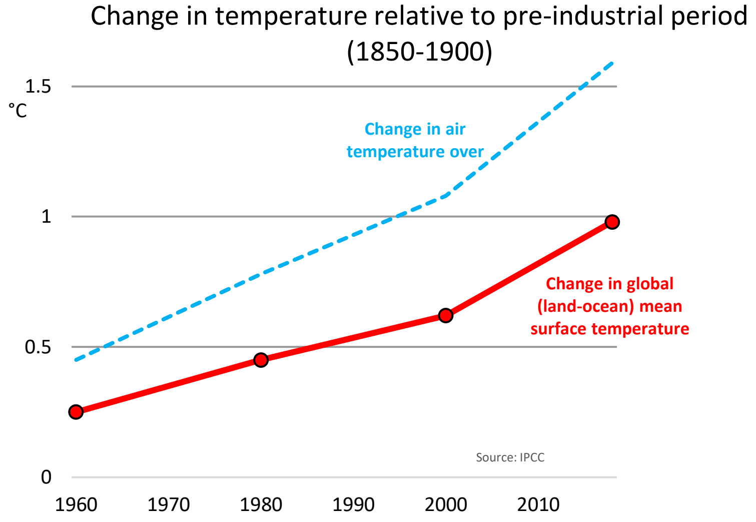
The Need for Energy Transition

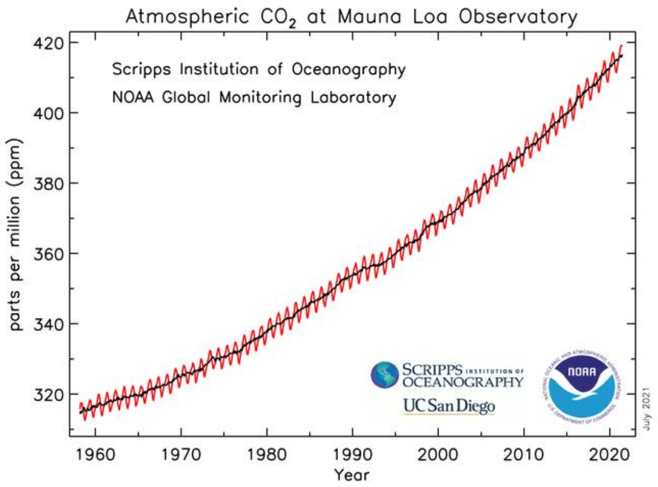
- Why do we need renewable energy resources?
- Why can't we just continue to use non-renewable resources?

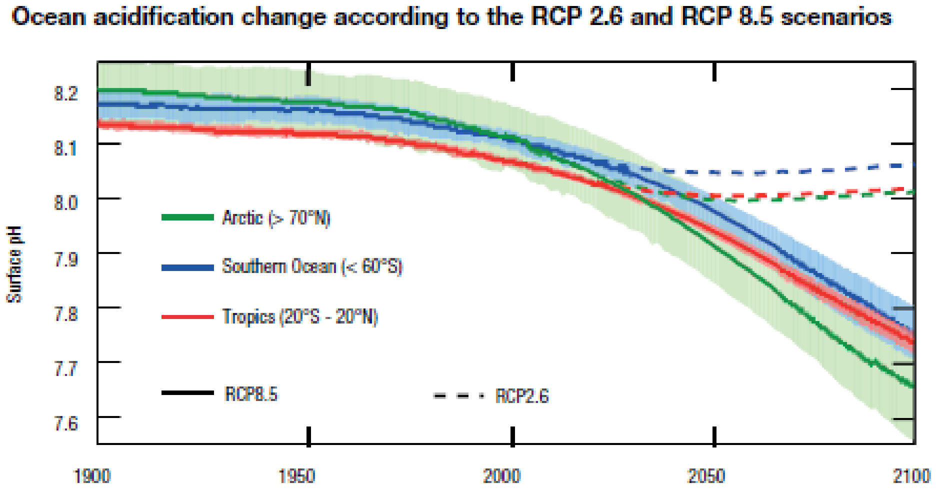
The Need for Energy Transition: Climate Change

- 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

AR6 Report of IPCC (2021)

- Prepared by 234 authors during the last 4 years, report endorsed by 195 countries
- Based on 14.000 scientific papers

Conclusions

- Code red for humanity !
- Global surface temperature was 1.09C higher in the decade between 2011-2020 than between 1850-1900.
- The past five years have been the hottest on record since 1850
- The recent rate of sea level rise has nearly tripled compared with 1901-1971
- Human influence is "very likely" (90%) the main driver of the global retreat of glaciers since the 1990s and the decrease in Arctic sea-ice
- It is "virtually certain" that hot extremes including heatwaves have become more frequent and more intense since the 1950s, while cold events have become less frequent and less severe

> - The Intergovernmental Panel on Climate Change (IPCC) is an intergovernmental body of the United Nations that is dedicated to providing the world with objective, scientific information relevant to understanding the scientific basis of the risk of human-induced climate change, its natural, political, and economic impacts and risks, and possible response options.
> - The IPCC was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) and was later endorsed by the United Nations General Assembly. Membership is open to all members of the WMO and UN.

Five future impacts (AR6 IPCC)

- Temperatures will reach 1.5°C above 1850-1900 levels by 2040 under all emissions scenarios
- The Arctic is likely to be practically ice-free in September at least once before 2050 in all scenarios assessed
- There will be an increasing occurrence of some extreme events "unprecedented in the historical record" even at warming of 1.5°C
- Extreme sea level events that occurred once a century in the recent past are projected to occur at least annually at more than half of tidal gauge locations by 2100
- There will be likely increases in fire weather in many regions

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

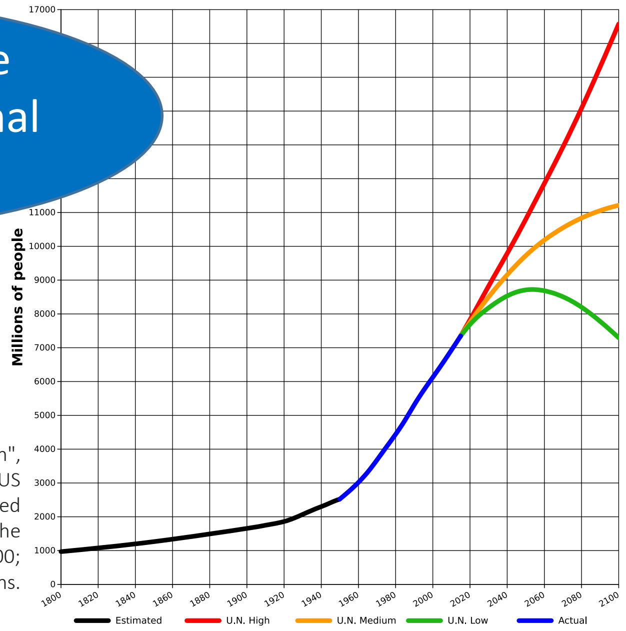
- Sustainable lifestyle
- Energy efficiency
- Responsible consumption

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



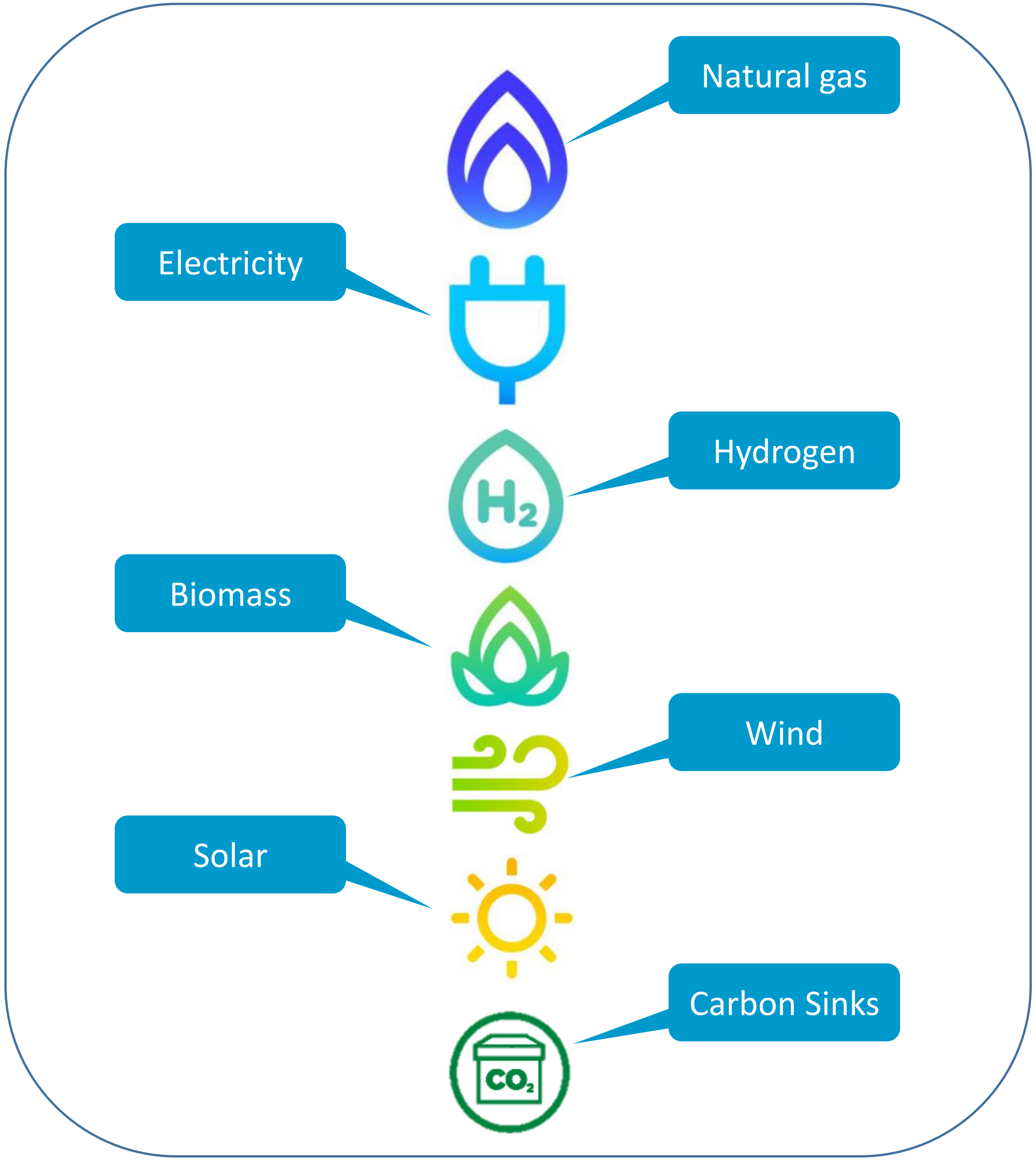
World population estimates from 1800 to 2100, based on "high", "medium" and "low" United Nations projections in 2010 and US Census Bureau historical estimates (in black). Actual recorded population figures (as of 2010) are colored in blue. According to the highest estimate, the world population may rise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

Climate: Activity Areas

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

TOTAL

TotalEnergies



Main Hazards related to New Energies

Solar
- Electrocution
- Fire

Wind Turbines
- Fire in nacelle
- Turbine blade ejection
- Fall of mast/nacelle
- Ship collision (offshore)

Battery Energy Storage
- Thermal runaway of batteries
  - ✓ Heat radiation due to fire inside BESS
  - ✓ Blast wave due to explosion of flammable gas inside BESS
  - ✓ Ejection of fragments upon explosion of flammable gas inside BESS
  - ✓ Dispersion of toxic smoke
  - ✓ Electric fire

CO2 Capture/Transport/ Storage
- Intoxication upon large CO_2 release (pipelines, ships, reservoirs)
- Blast wave upon pneumatic explosion of lines/vessels

Biofuels/Biogas
- Dispersion of toxic H_2S upon leakage
- Heat radiation due to jet fire or flash fire upon large release of flammable gas
- Heat radiation due to pool fire upon large release of flammable liquids
- Blast wave due to deflagration upon large release of flammable gases in a congested/confined environment (biofuels)
- Blast wave/ejection of fragments due to deflagration of flammable gas inside a building/vessel (biogas)
- Damage to environment in case of large spill of feedstock/digestat (biogas)
- Heat radiation due to storage tank boilover for some feedstocks (biofuels)

LNG/CNG
- Heat radiation due to jet fire or flash fire upon large release of CNG of LNG
- Heat radiation due to pool fire upon large release of LNG
- Blast wave due to deflagration upon large release of LNG or CNG in a congested/confined environment
- Blast wave due to RPT (rapid phase transition) when mixing LNG with water
- BLEVE of vessel filled with LNG

Hydrogen
- Blast wave/ejection of fragments due to explosion in electrolyzer or electrolyzer hall
- Blast wave due to deflagration or detonation upon large release of hydrogen in line/vessel
- Heat radiation due to jet fire or flash fire upon large release of hydrogen in line/vessel
- Dispersion of toxic gas when using ammonia as hydrogen carrier

Severity of Potential Consequences of Accidents →

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

Accidents related to Hydrogen

Hydrogen accidents marking the public opinion

Properties of Hydrogen: Flammability Characteristics

Property	
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

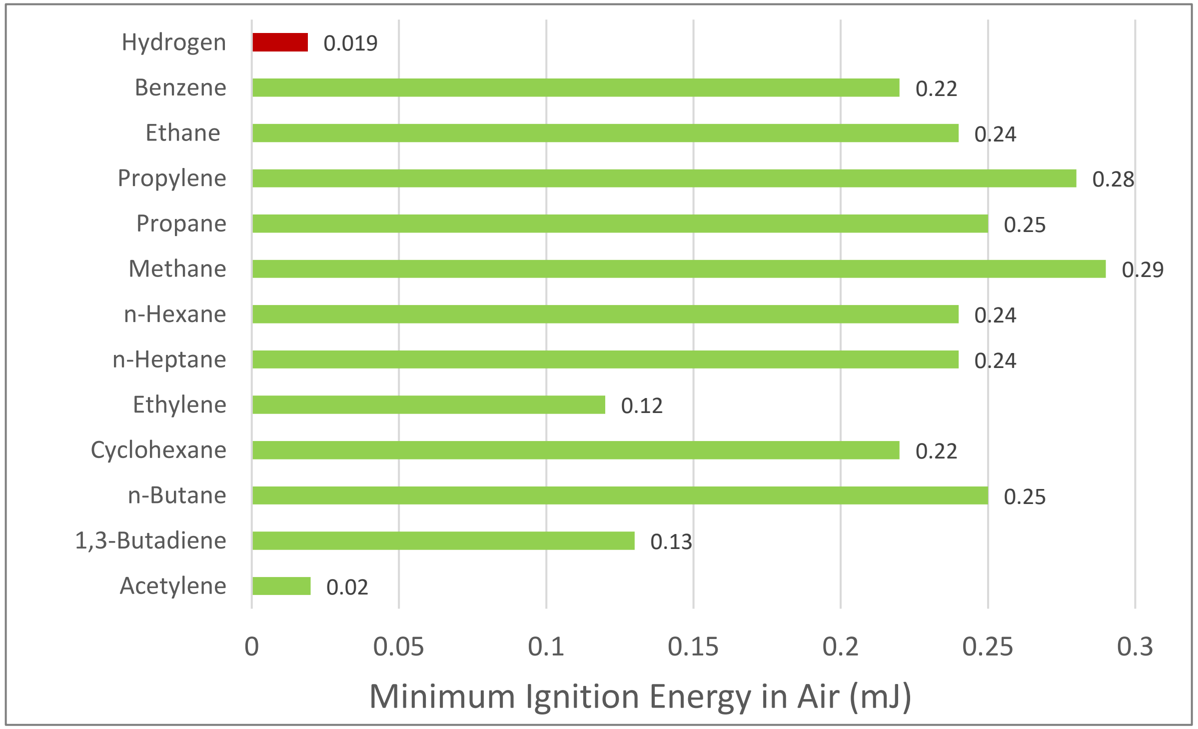
Flammable in very wide concentration range

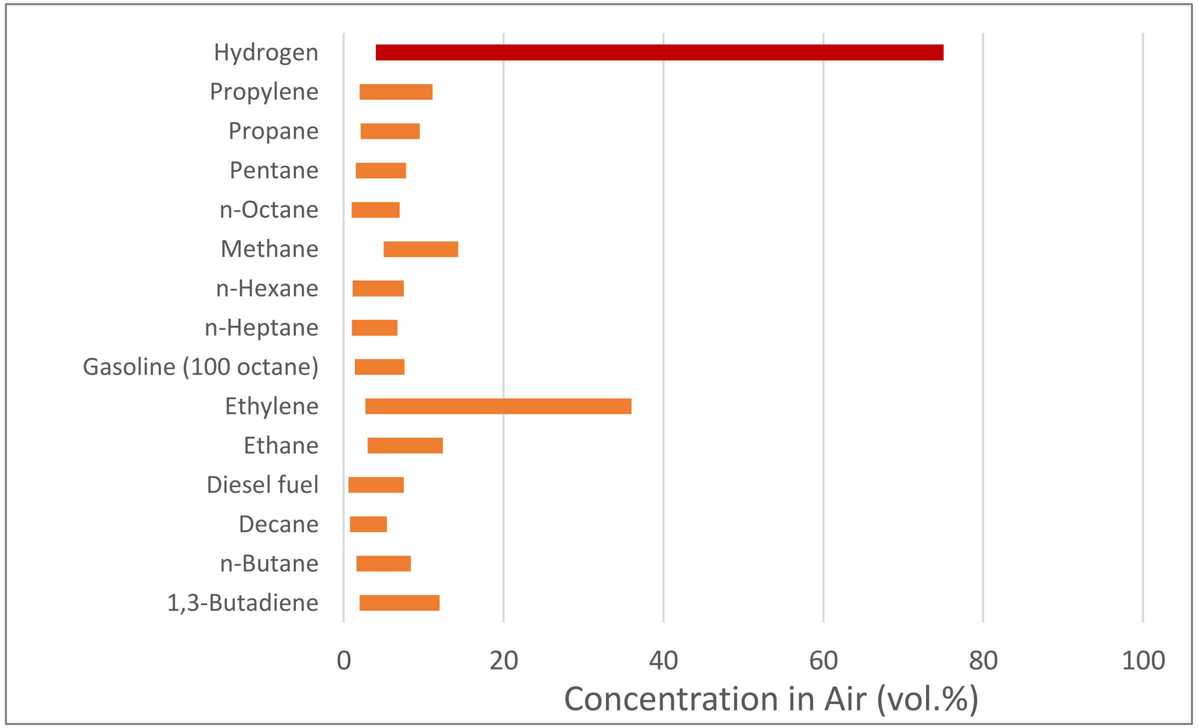
Ignites very easily

Stored electrical energies $\frac{1}{2}CU^2$ in non-earthed items of different capacitances C, charged to different voltages U

Charged object	Capacitance (pF)	Potential (kV)	Energy (mJ)[a]
Single screw	1	5	0.01
Flange, nominal width = 100 mm	10	10	0.5
Shovel	20	15	2
Small container (~50 l)	50	8	2
Funnel	50	15	6
Person	300	10	15
Drum (200 l)	200	20	40
Road tanker	1000	15	100

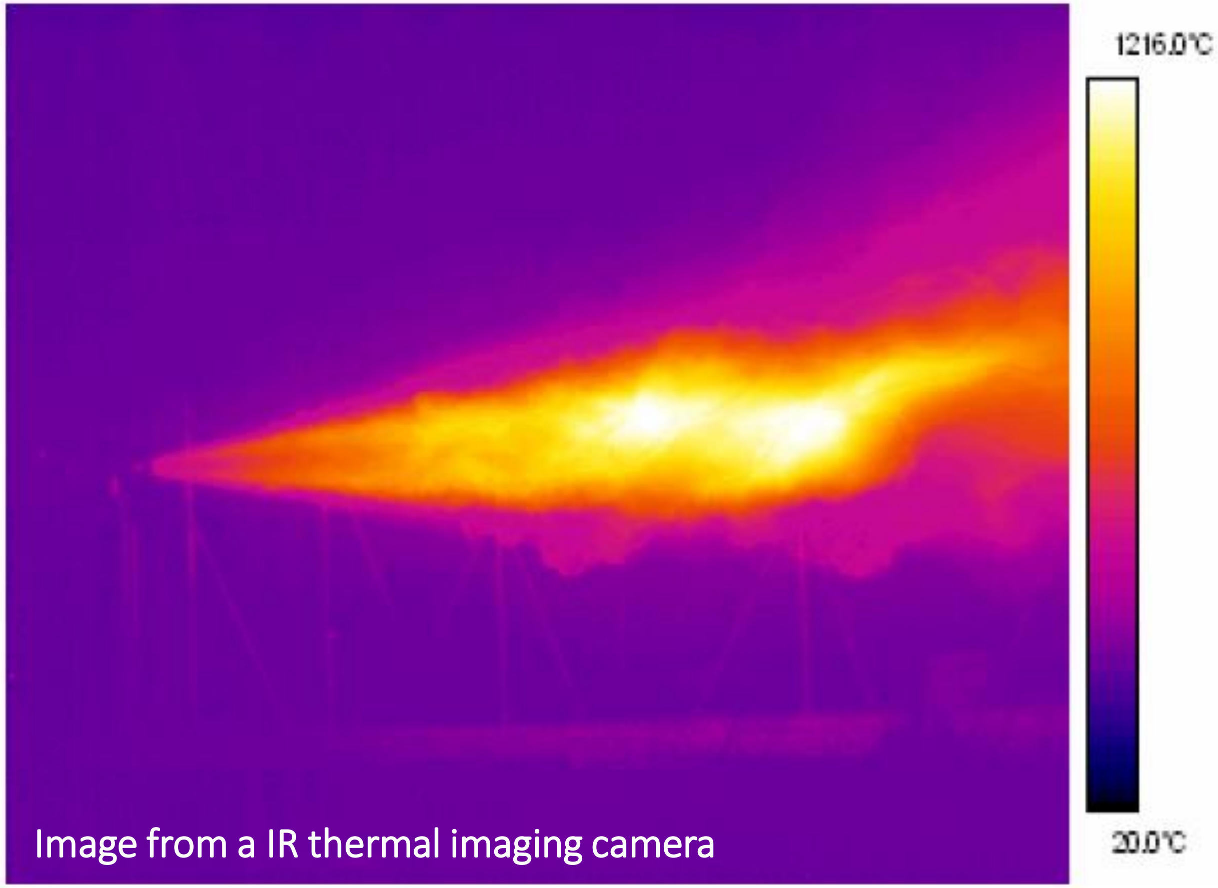
From Lüttgens and Glor (1989).
[a]Approximate values.





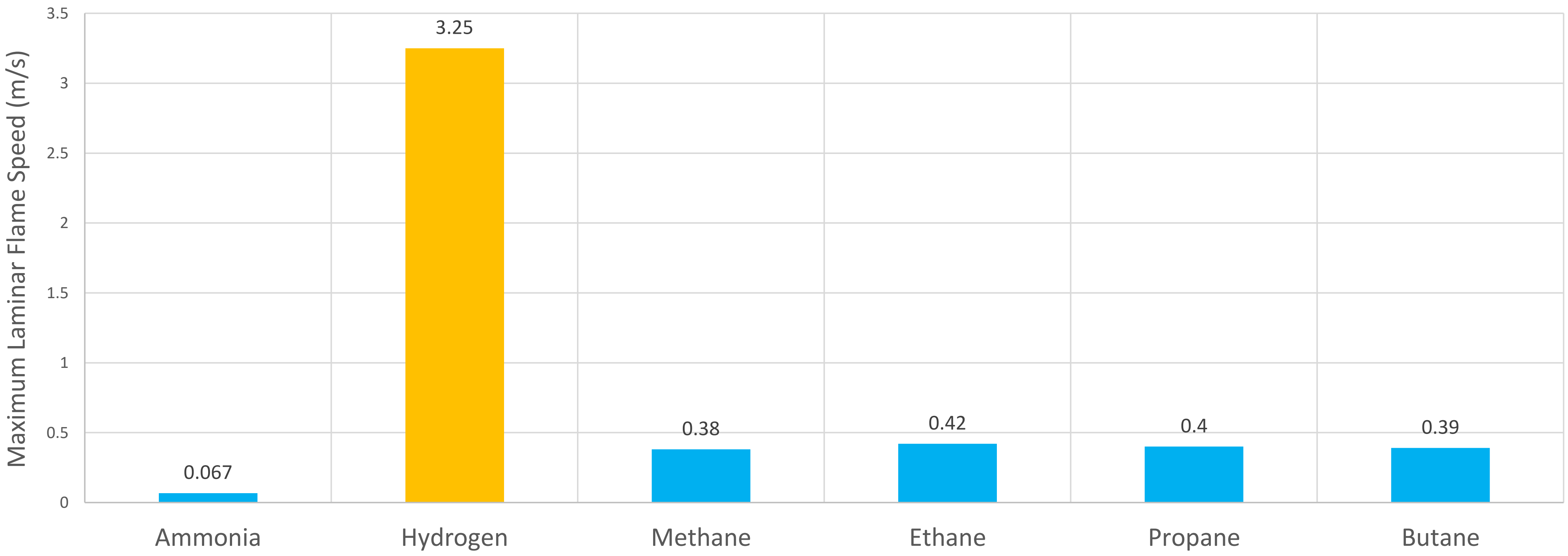
Properties of Hydrogen: Flame Visibility

- 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.



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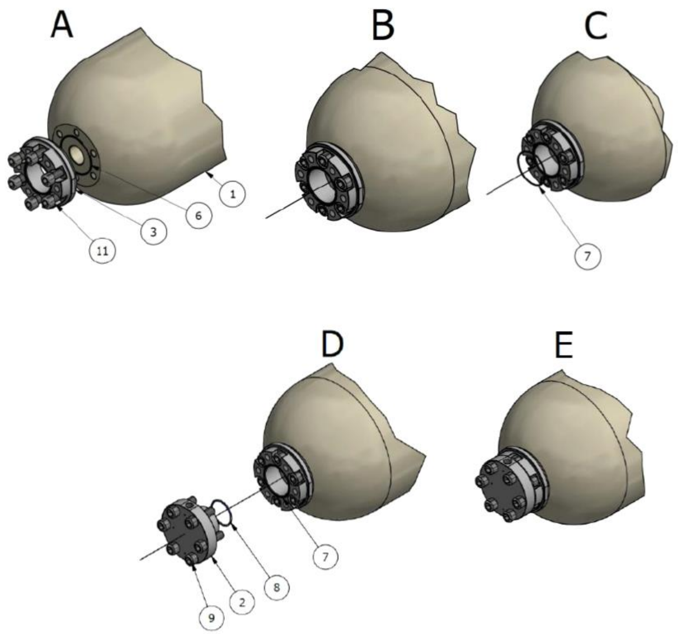
Hydrogen: Accidents

Hydrogen explosion in hydrogen fueling station (Kjorbo (N), 2019)



1. Starting condition

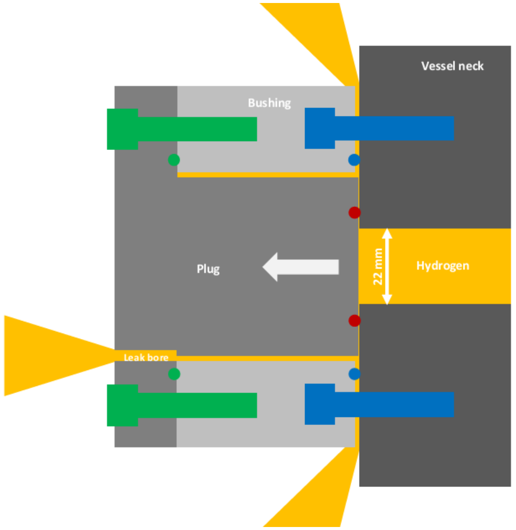
- Green bolts torqued properly
- Blue bolts not torqued properly

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 l sealings fail immediately
- Spread of Hydrogen leaks out in uncontrolled way



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Hydrogen: Accidents

Hydrogen explosion in dome of sulfuric acid tank

- Hydrogen explosion in empty 97% H_2SO_4 storage tank during inspection.
- 3 people were injured, of which 2 severely. At the time of the accident, the workers 3 were standing on the roof of the tank cutting the bolts of the manhole on the dome of the tank using a grinder.
- The hydrogen was formed in the tank upon cleaning of the tank with water prior to its inspection.

Natural Gas (CNG, LNG)

- The use of natural gas (compressed or liquefied) will play a critical role in the transition towards renewable energy sources
- Application as fuel for electricity generation (CCGT,….)
- New application as fuel for transport applications (cars, ships, trucks,…)


LNG bunkering (ship to ship)


LNG : 400l #; 170 kg ; 8 bar

CNG : 7 to 12 bottles ; 200 bar

Natural Gas (CNG): Hazards

Natural Gas (CNG, LNG): Hazards

Catastrophic rupture of cryogenic storage tank

Natural Gas (LNG): LNG Bunkering

June 2021: First cruise ship to bunker LNG in North America
With 180,000-gross-ton, the ship can accommodate more than 5,200 guests and a crew of 2,000.

Li-Ion Batteries

Electricity Storage Systems

Mechanical
- Pumped storage
- Compressed air
- Liquid air storage
- Flywheels

Thermal
- Thermo-chemical
- Sensible thermal
- Latent thermal

Chemical
- Hydrogen storage
- Synthetic natural gas (SNG)

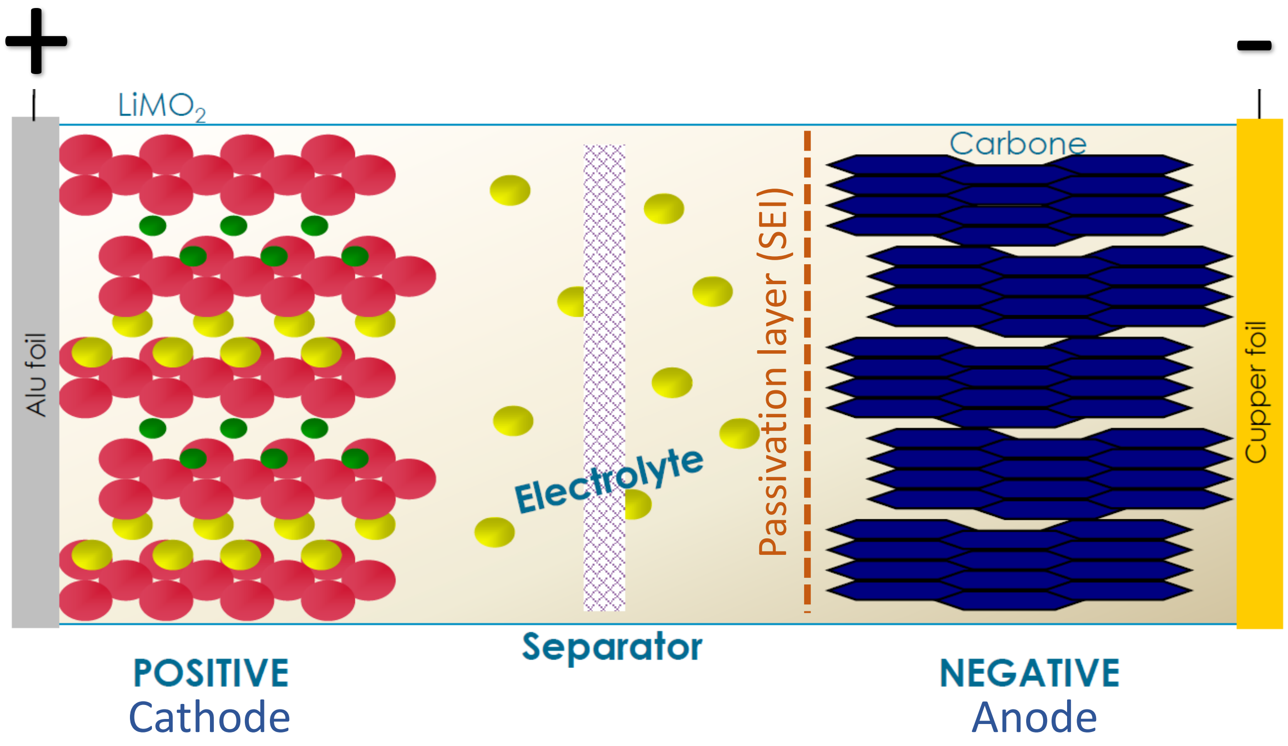
Electro-chemical
- Lithium-Ion battery
- Lead-acid battery
- NaS battery
- Redox flow battery

Electrical
- Super capacitators

Source: World Energy Council, 2016

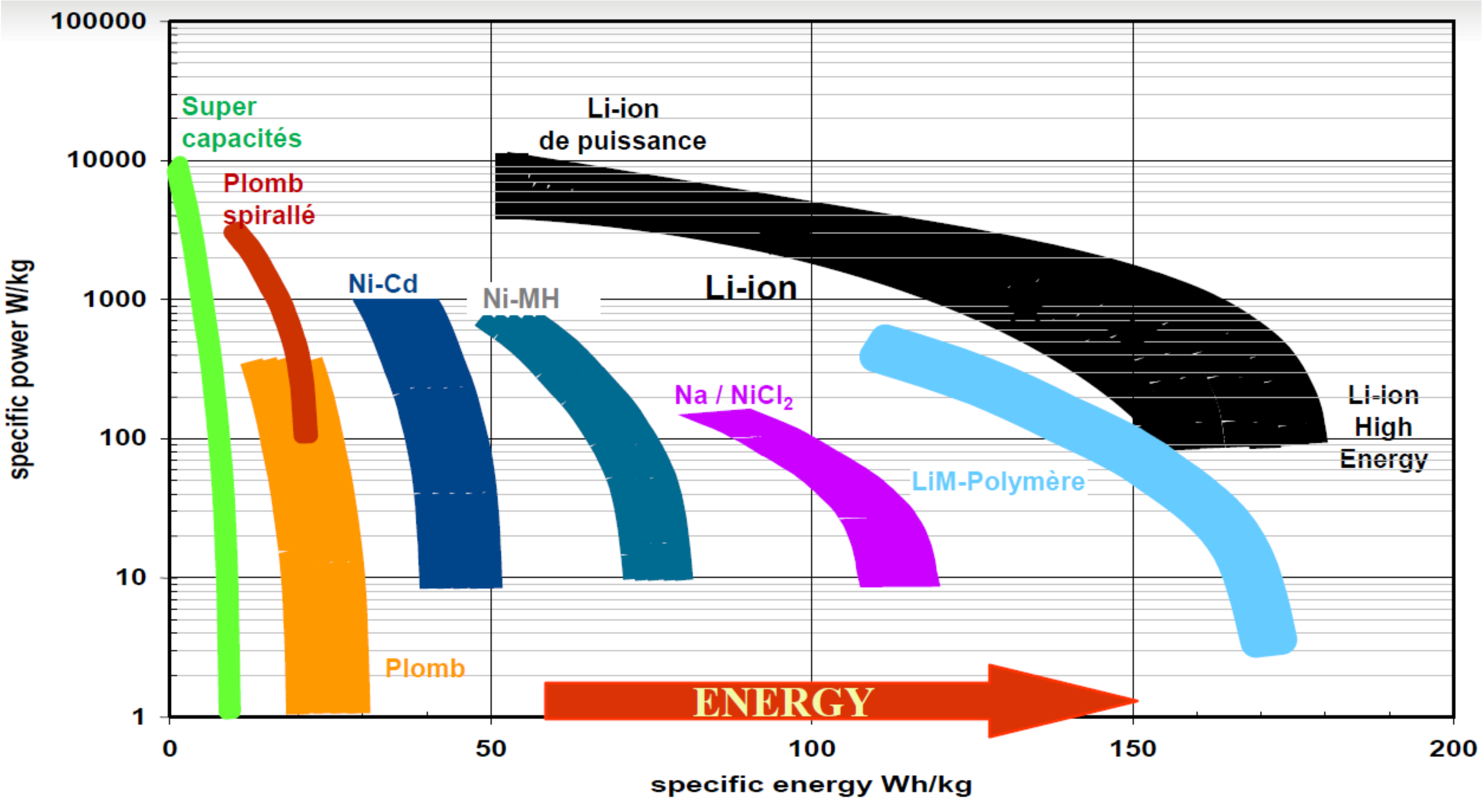
Li-Ion Batteries

- Electrodes
  - ✓ Primary function: determine the voltage, capacity.
  - ✓ Can be solid, liquid, gas.
- Electrolyte
  - ✓ Primary function: assure the ionic path /transportation
  - ✓ Must have conduction properties : solvent + salt
- Separator
  - ✓ Primary function: physical barrier to avoid electric contact between both electrodes
  - ✓ Paper, microporous polymer.
- Passivation layer (SEI: Solid Electrolyte Interface)
  - ✓ Formation during 1st charge with a small ratio of electrolyte reduction on the anode electrode surface
  - ✓ To protect the anode against corrosion (oxidation) by electrolyte
  - ✓ Cycling stability thanks to electrodes volumes stability



Li-Ion Batteries

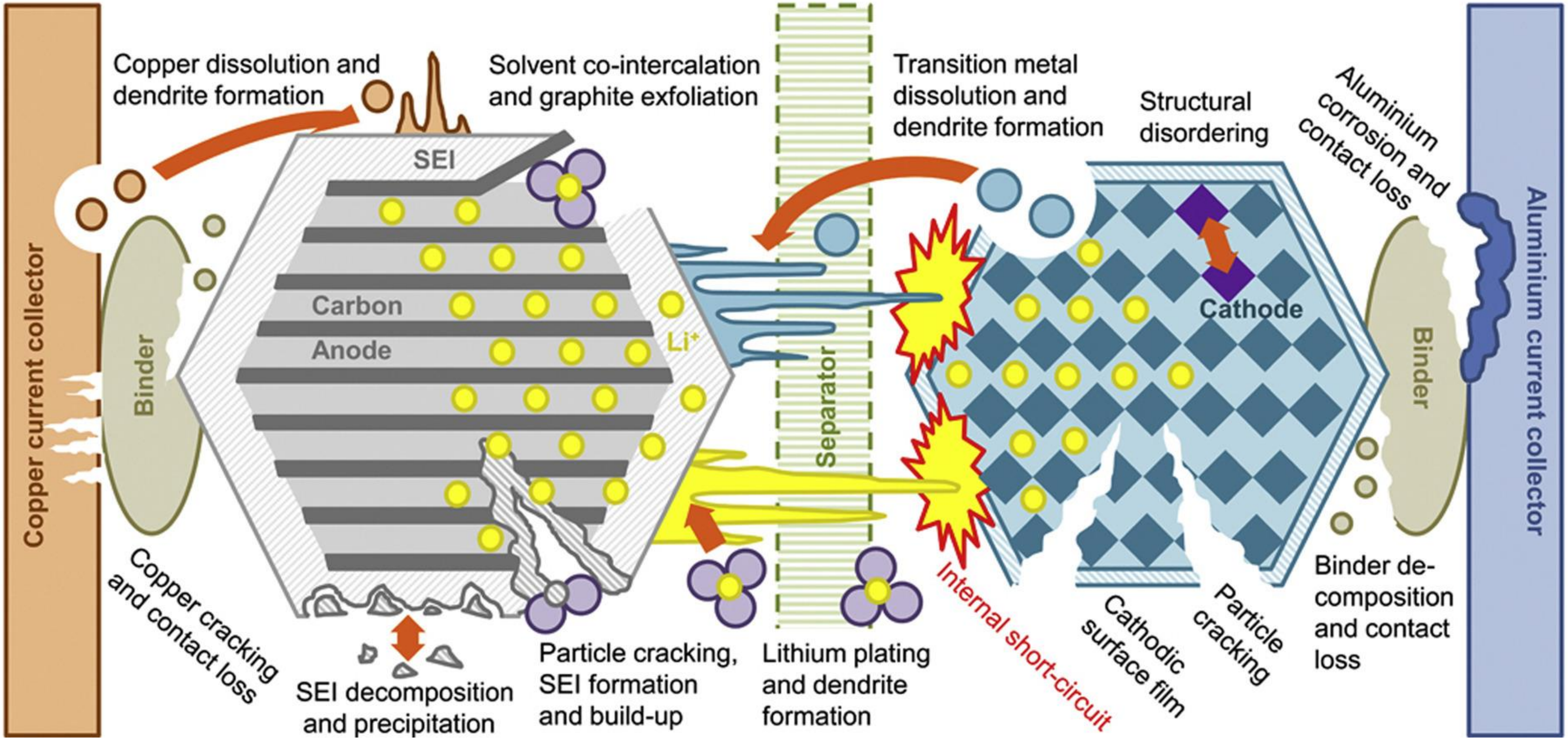
- Benefits
  - ✓ High average voltage (3,3 3,8 V)
  - ✓ High specific energy (>180 Wh/kg
  - ✓ Huge volumic energy (> 500 Wh/l)
  - ✓ Good cyclability (> 1000 cycles)
  - ✓ Small self discharge during storage
  - ✓ Coulometric efficiency close to 100% and energy efficiency > 90
  - ✓ Fast charge compliancy
  - ✓ No memory effect like Ni/Cd or Ni/MH
  - ✓ Better safety behavior than lithium metal



- Drawbacks
  - ✓ Lithium, LiCx reacts with water
    - ➢ Use of organic electrolytes
  - ✓ No involvement of the electrolyte in the reactions (no recombination reactions, like e.g. water on Lead and NI/Cd batteries)
    - ➢ Strict control of the charging voltage needed (protection circuits) to prevent overloading of the electrolyte

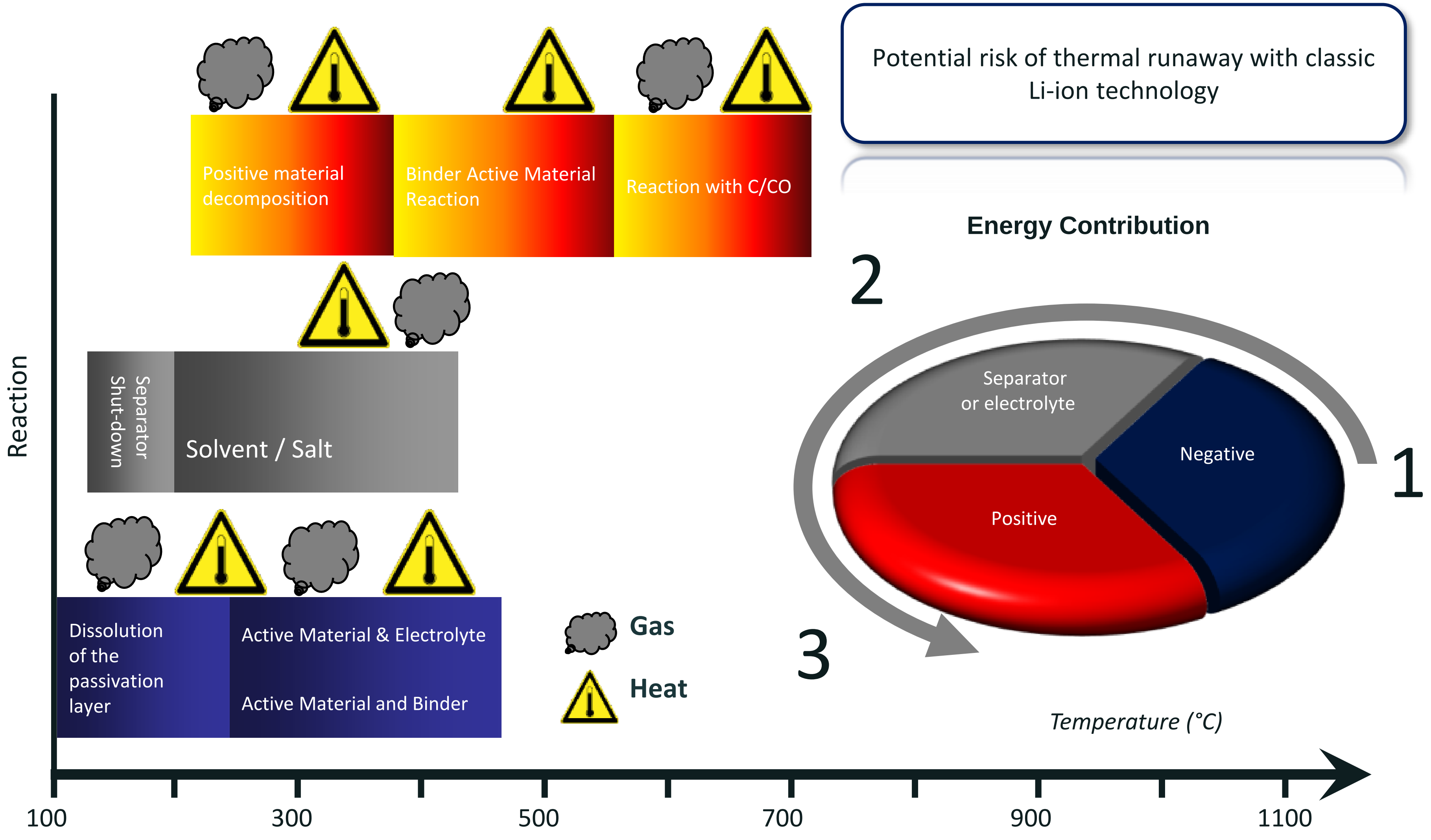
Li-Ion Batteries: Hazards

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

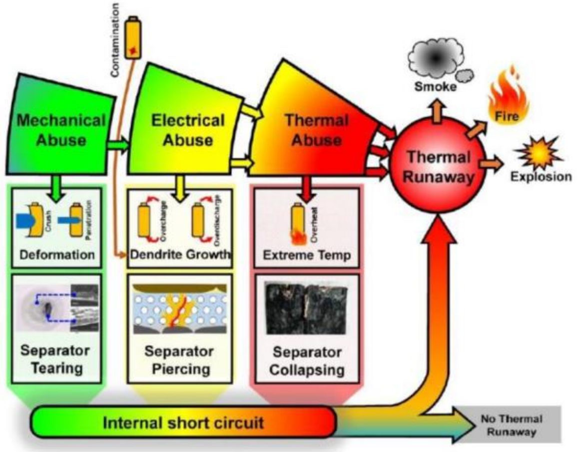


Li-Ion Batteries: Hazards

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

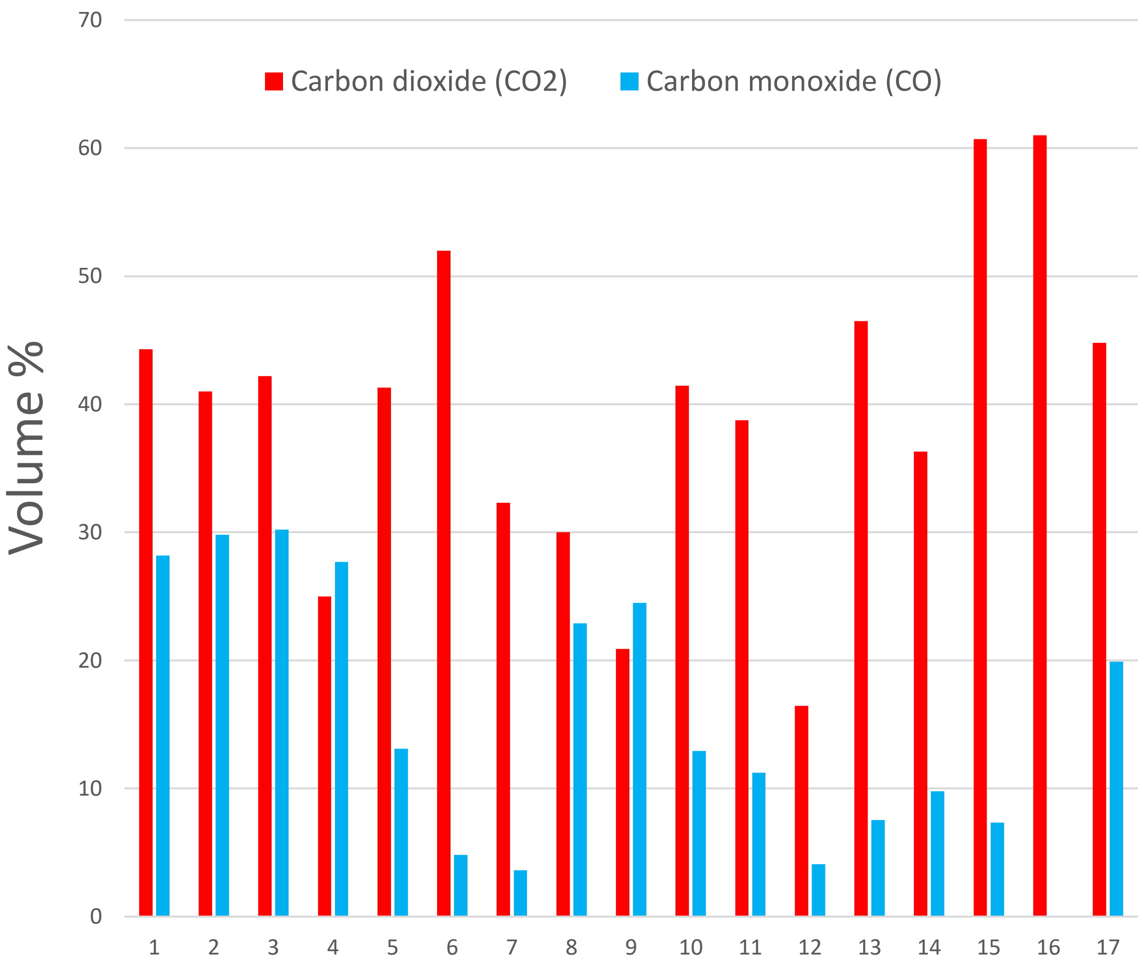


- Thermal runaway is a phenomenon which consists in a melting of the separator of the Lithium-Ion cell at high temperature.
- This non-mastered action results to put in contact the positive and negative electrodes of the cell.
- It is followed by a high increase of the internal temperature & pressure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

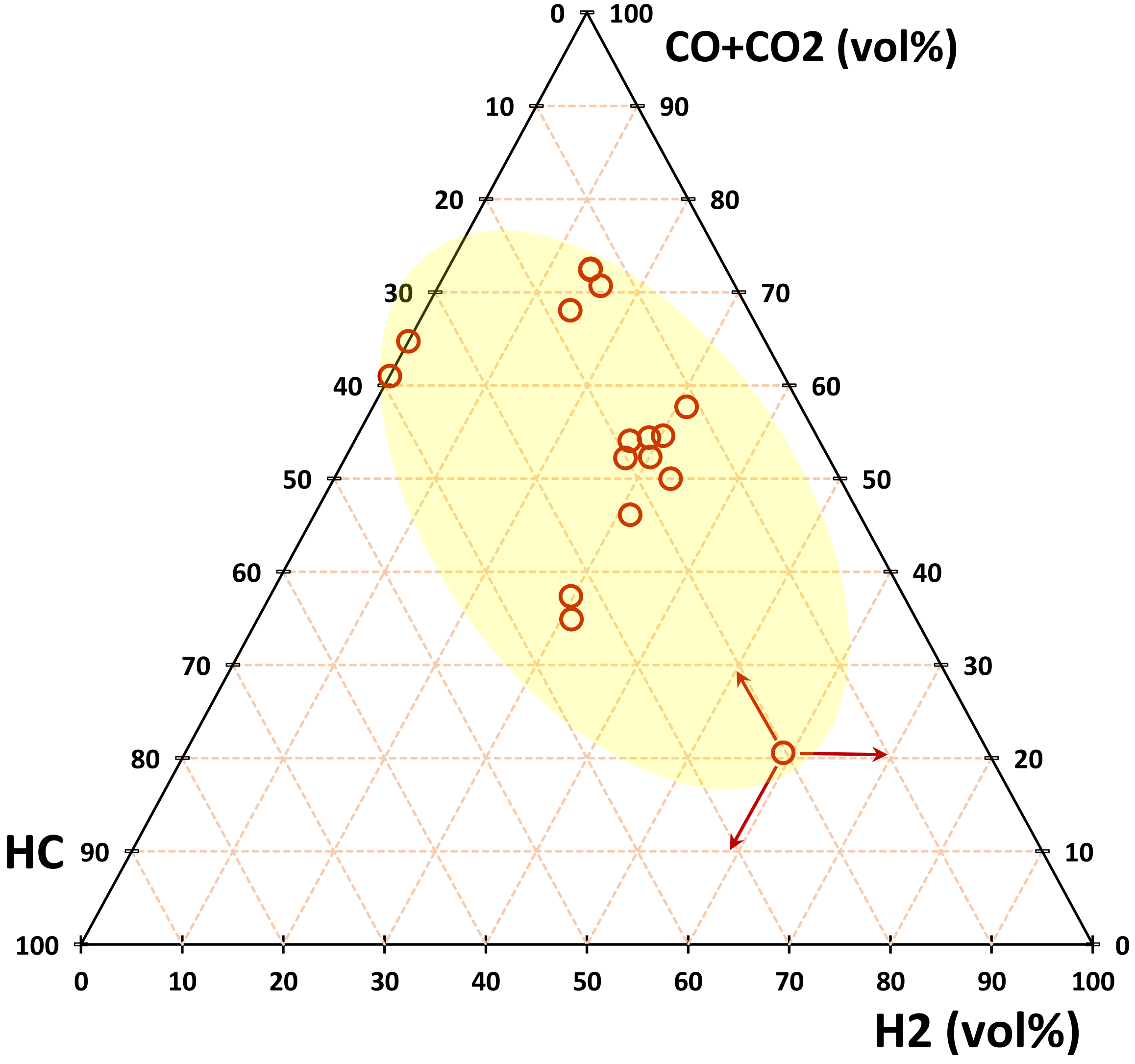


Li-Ion Batteries: Hazards

- The gases discharged during thermal runaway of Li-Ion batteries contain large amounts of hydrogen (flammable) and carbon monoxide (toxic)



Source: Arora et al. (2018), Barry et al. (2020a, 2020b), Golubkov et al. (2014), Somandepalli et al. (2014)

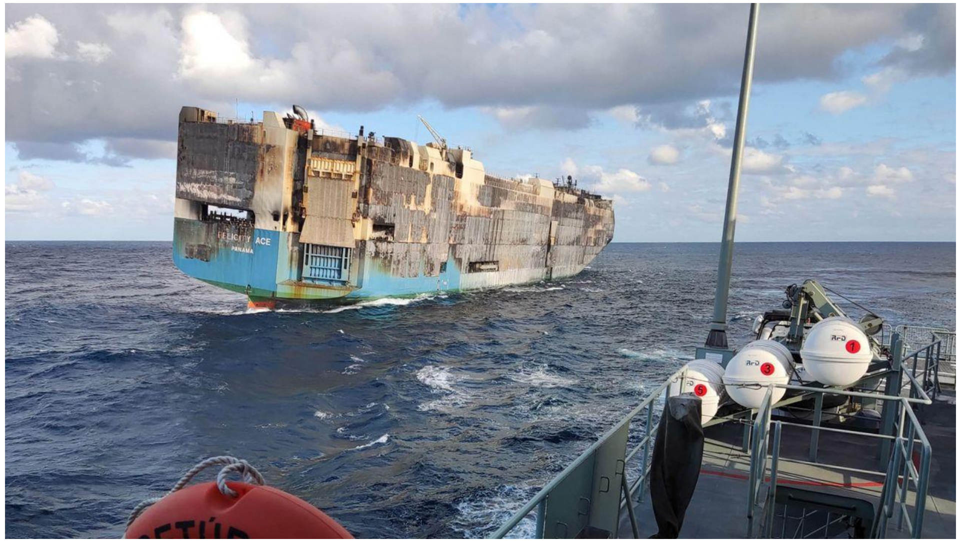


Li-Ion Batteries: Experience Feedback

Video

Li-Ion Battery Fires: Recent Events

- A huge cargo ship carrying thousands of luxury vehicles from Germany to the United States, including 4000 luxury cars (Porsche, Bentley, Audi), caught fire in February 2022, forcing all 22 crew members to abandon ship and leave the vessel adrift in the middle of the Atlantic Ocean.
- A fire broke out Wednesday morning (16/02/2022) on the Felicity Ace, a ship about 650 feet long, near Portugal’s Azores Islands, according to the Portuguese navy. The ship had departed from Emden, Germany, on Feb. 10 and was scheduled to complete its 13-day trip and arrive in Davisville, R.I., next week. The Volkswagen Group estimated that nearly 4,000 cars were aboard the Felicity Ace (1100 Porsches, 2000 Audi's, 189 Bentleys and 100 Lamborghini’s).
- The Portuguese navy said it rescued all 22 crew members via helicopter
- The fire was still burning on the ship as of Friday, according to the Portuguese navy, and photos showed white smoke billowing out of the vessel. Joao Mendes Cabecas, a captain of the nearby port of Hortas, told Reuters that lithium-ion batteries in the electric cars on the Felicity Ace caught fire, but it was unclear whether that is what started the blaze.
- The ship sank on March 1st 2022



Li-Ion Battery Fires: Recent Events

- Monday 4 April 2022
- Electric bus of RATP on the Boulevard Saint-Germain in Paris
- The driver had the time to evacuate all passengers
- It took 1 hour to extinguish the fire (3 fire hoses)

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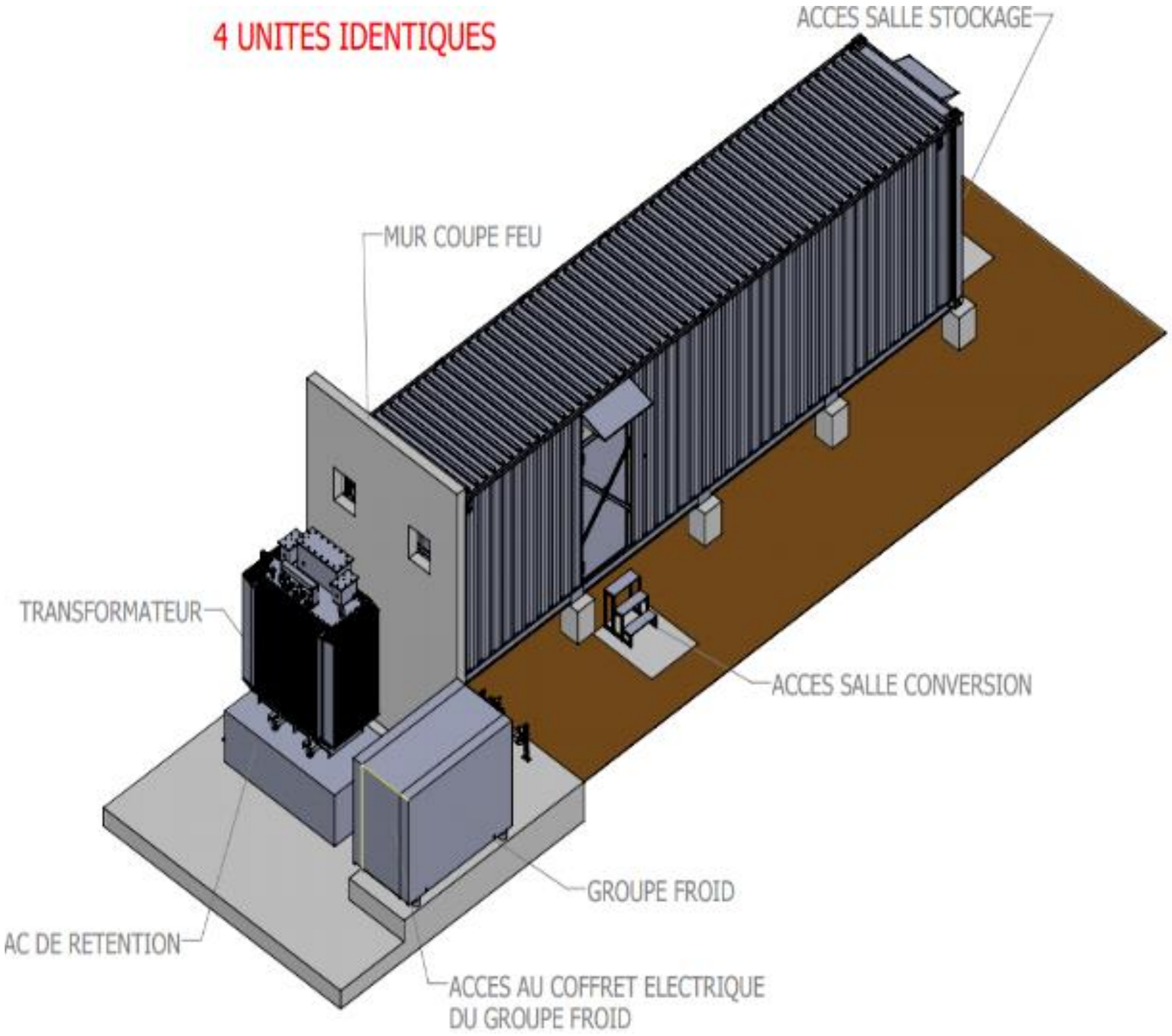
Battery Energy Storage Systems



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Battery Energy Storage Systems

Toxic smoke

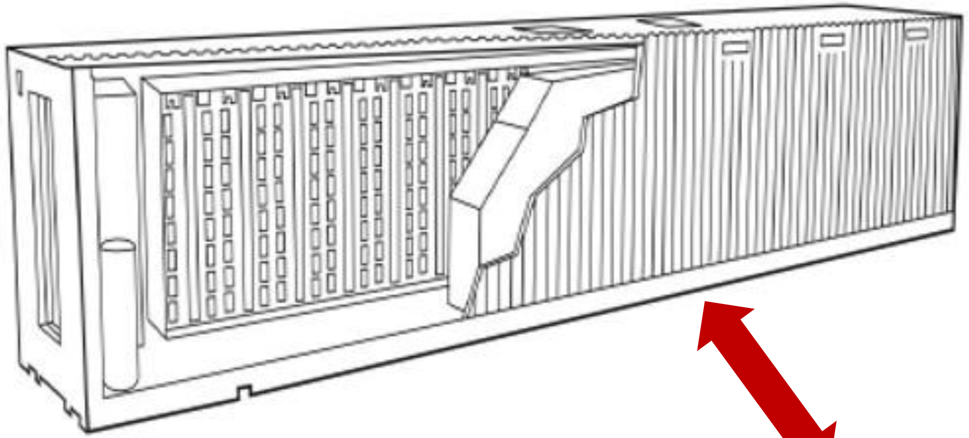
Generation of toxic gases upon thermal runaway of the battery.

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.

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.

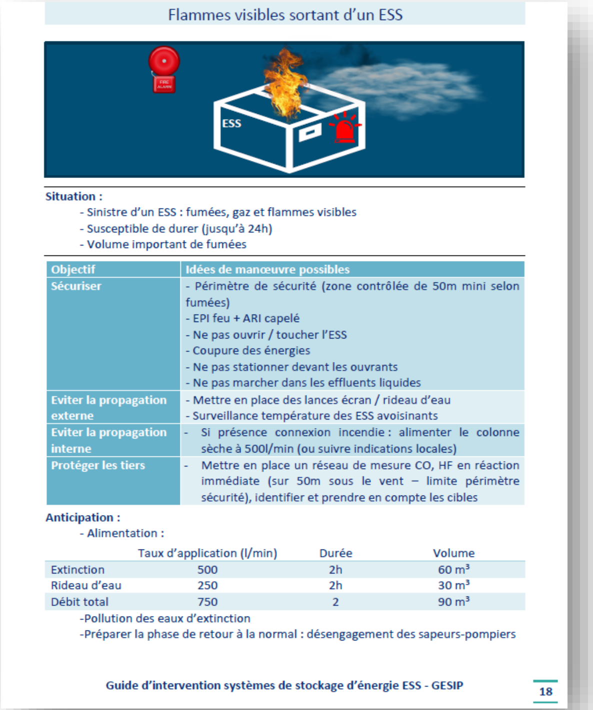
Australia, 2021 (Moorabool)

- 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: 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 the BESS
- Scenario 4: BESS exposed to external thermal impact (forest 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 m^3
Rideau d'eau	250	2h	30 m^3
Débit total	750	2	90 m^3

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

Guide d'intervention systèmes de stockage d'énergie ESS - GESIP 18

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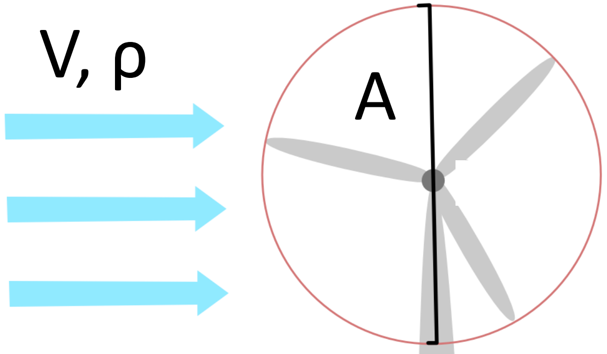
Wind Turbines

- 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.

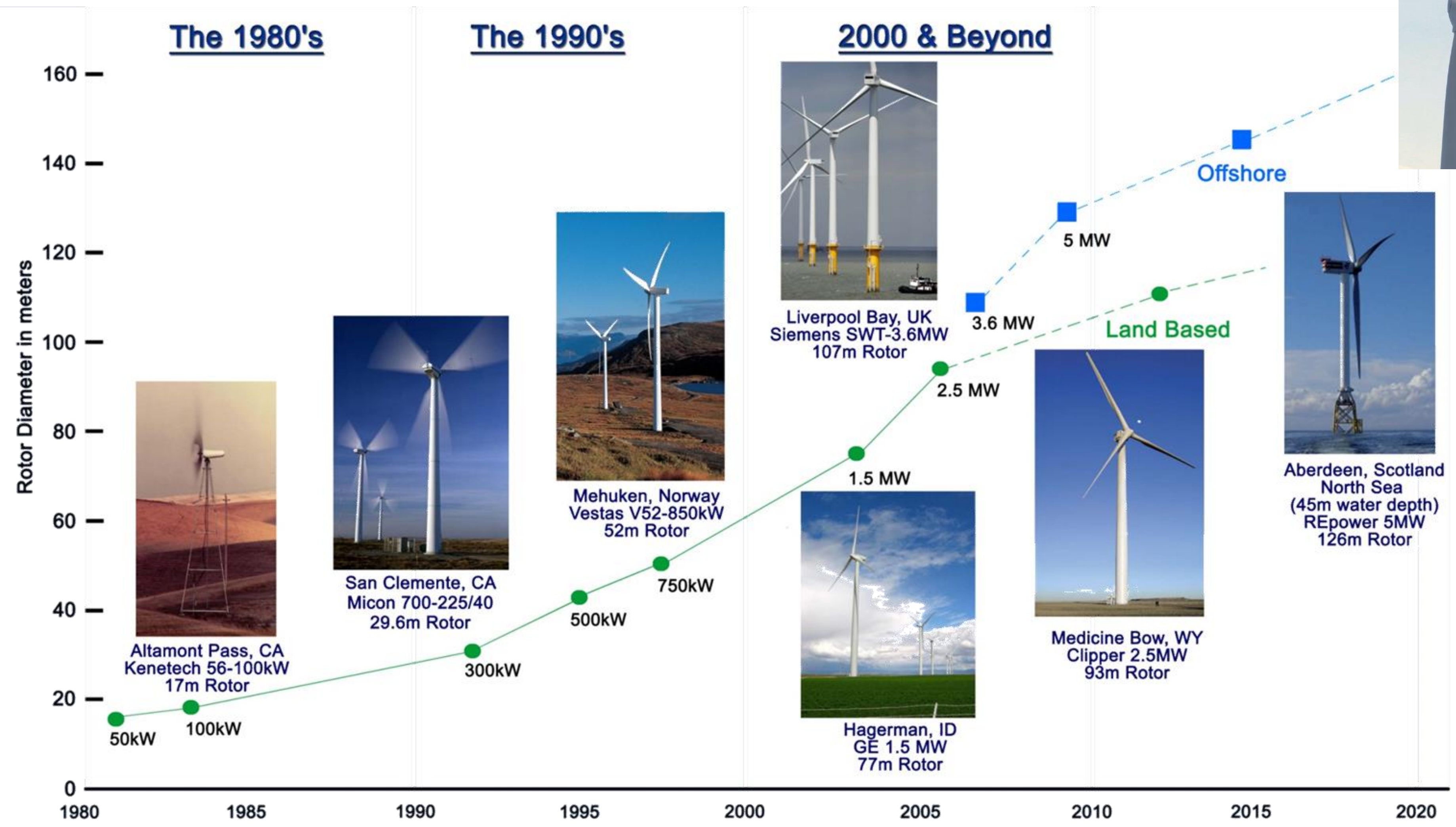


Power (W)= ½ ρAV^3

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



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Wind Turbines

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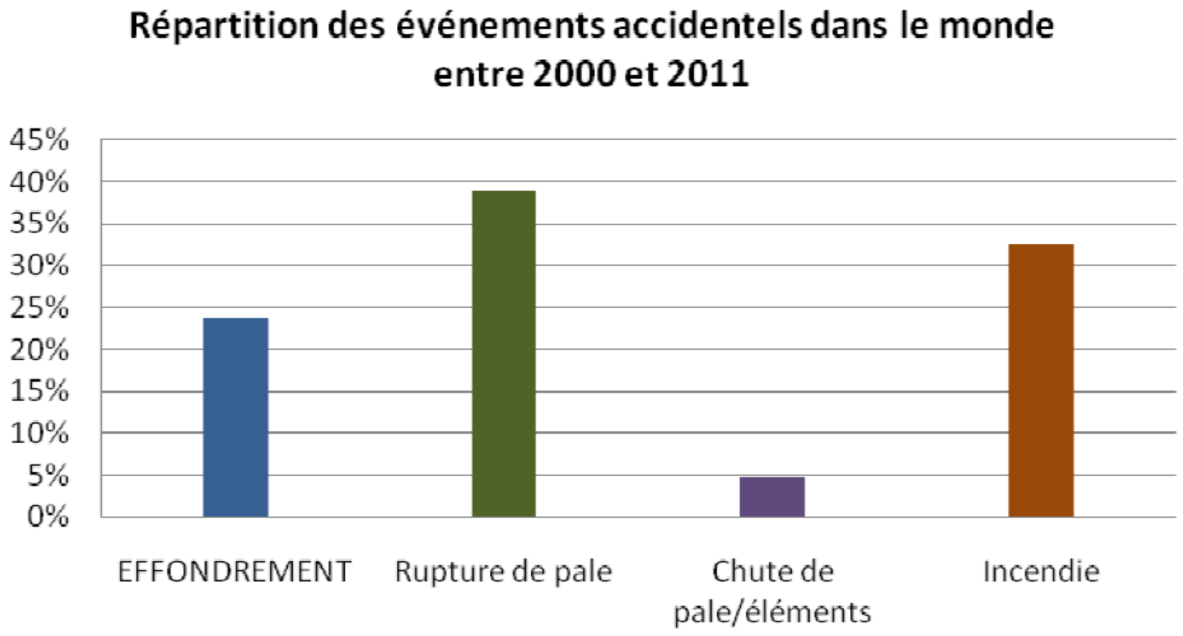
Wind Turbines: Hazards

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)



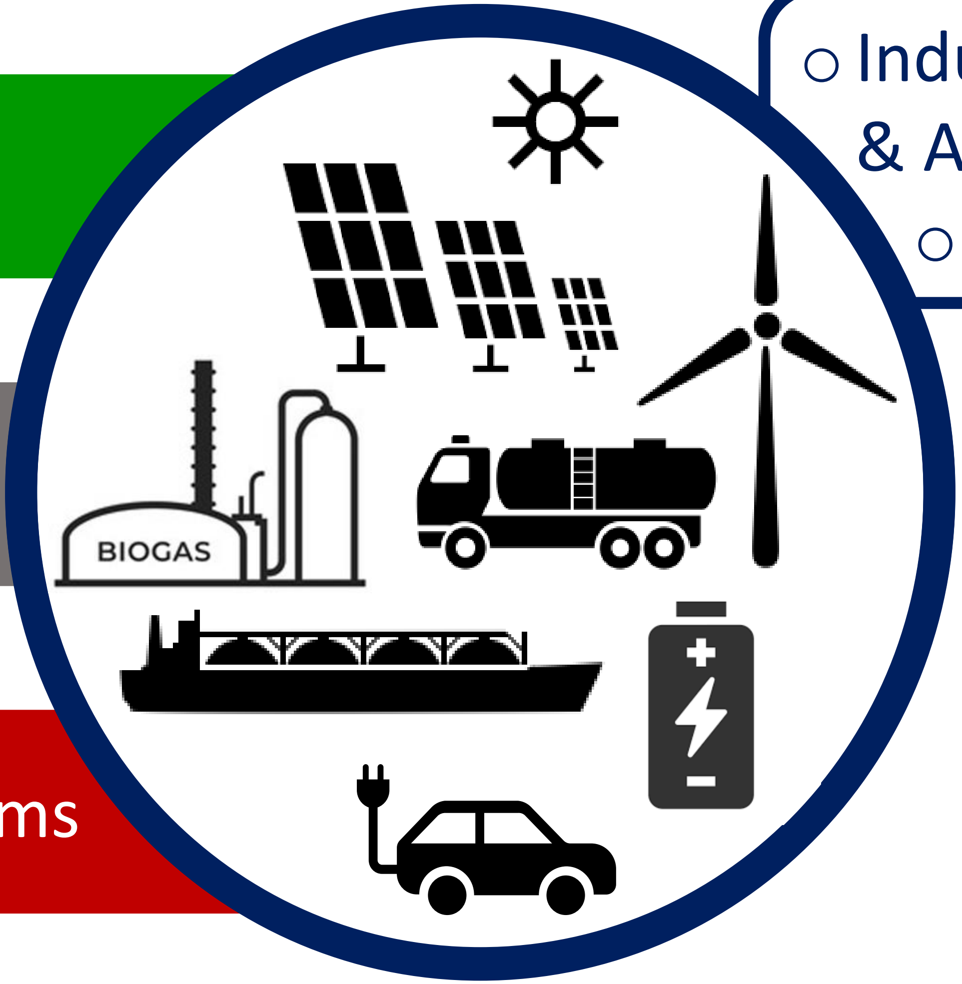
New Energies and Major Risks: Support Organization

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