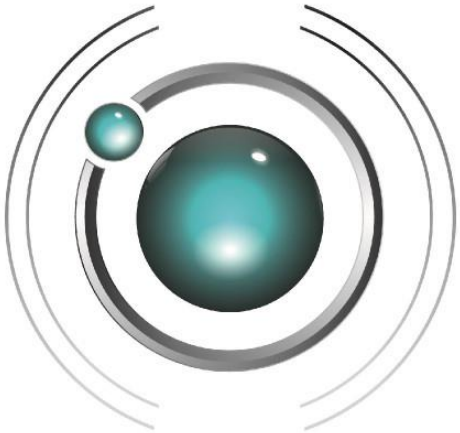
3rd Pilot Training Session, 06 -10 June 2016,
ENSOSP, Aix-en-Provence, France



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Strategies and Intervention tactics - FC stationary installations

Franck Verbecke, AREVA Energy Storage

AREVA
forward-looking energy

Agenda

- Hydrogen behavior and properties
- Fuel Cell and hydrogen stationary applications
- Basic safety design
- Hazard identification and typical scenarios
- Example of deployment of a hydrogen-based green public building in France
- Example of a hydrogen-based energy storage system: MYRTE platform (Corsica)

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Hydrogen behaviour and properties

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Hydrogen properties

- Low density: a safety attribute

Combustibles	Density	Stagnation
Hydrogen	0.07	No
Methane	0.65	No
Propane	1.88	Yes
Gasoline (vapors)	4.4	Yes

Outdoor, no stagnation

Indoor, risk of accumulation

- Low activation energy - **at high concentration**

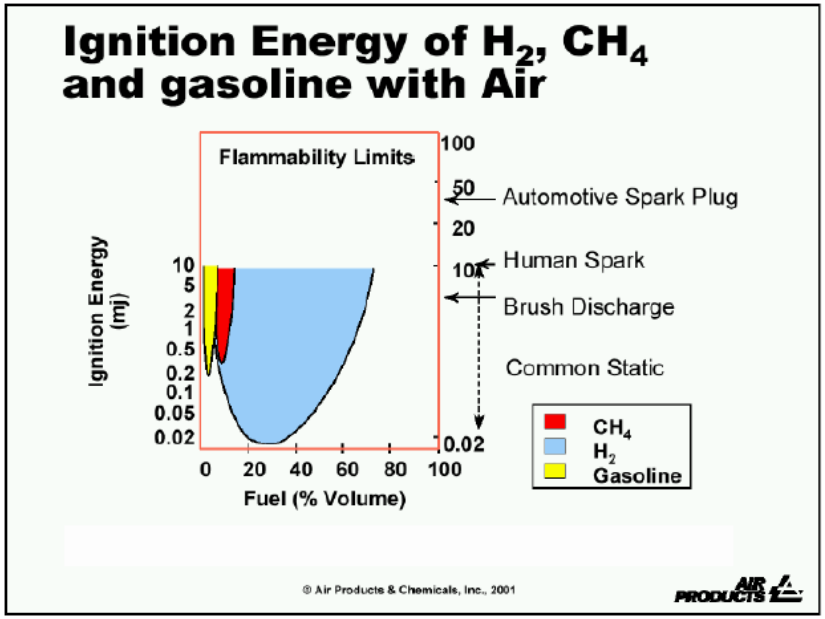

Figure 1: Flammability Limits vs. Ignition Energy of H_2, CH_4 and Gasoline in Air

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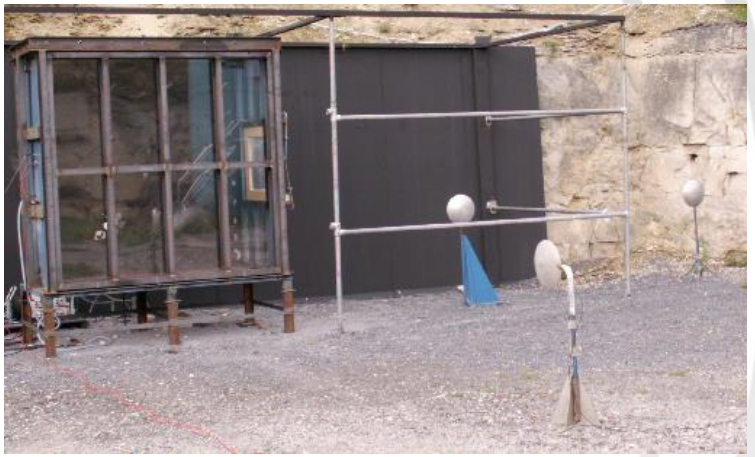
Combustion characteristics in confined geometry

- **A large flammability range**

Combustibles	LFL % vol in air	UFL % vol in air
Hydrogen	4.0	75.0
Methane	5.3	17.0
Propane	1.7	10.9
Gasoline (vapors)	1.0	6.0



- **Deflagration of homogeneous mixture:**

7,3 % H2

10,5 % H2

16,5 % H2

28.7 % H2

Insignificant pressure effects for combustion of lean H_2-air mixtures (<10 % H_2 in air)

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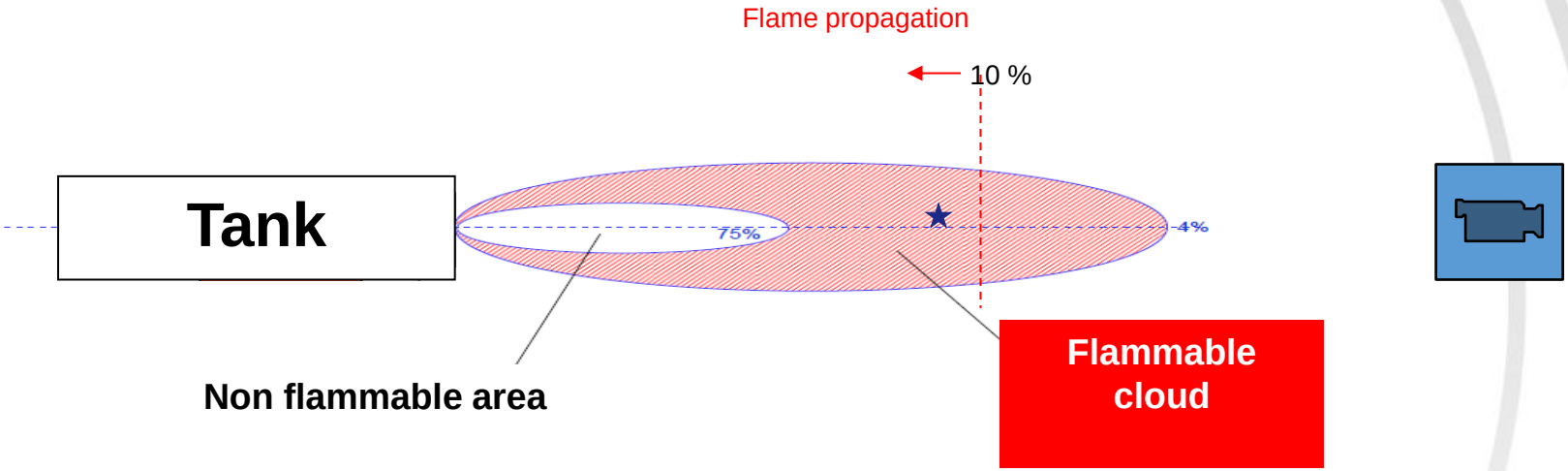
Ignition of hydrogen jets



Ignition of a hydrogen jet may produce pressure effects in surroundings

More experiments required to adjust classical blast model to better estimate overpressure effects

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Fuel Cell and hydrogen stationary applications

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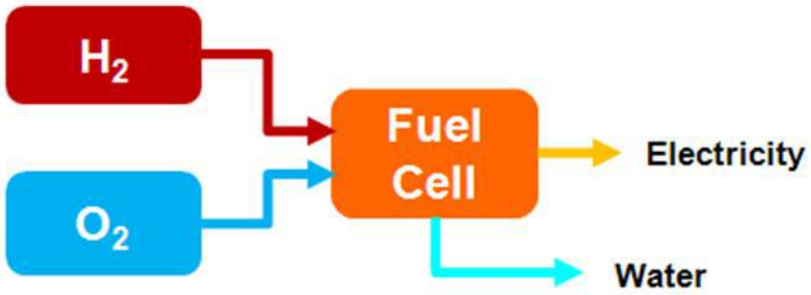
Back up system coupled with a data center



Power capacity	16 - 80 kW (20 -100 kVA) up to 6 systems in parallel
Startup time	Instantaneous
Autonomy (example)	80 kW at full load with 9 standard H2 cylinders: 1 hour 25 min

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Example of hydrogen generator : 10-20 Nm^3 H_2 / h HP PEM Electrolyser

Production flow rates	**10-20 Nm^3 H_2 / h | 5-10 Nm^3 O_2 / h**
Working pressure (without additional mechanical compression)	**35 barg**
Specific consumption	**5,0 kWh/Nm^3**
Operating Range	**10 .. 100 %**
H_2 dewpoint	**< - 70°C**
O_2 in H_2	**< 5 ppmv**
O_2 dewpoint	**< - 70°C**
H_2 in O_2	**< 5 ppmv**

- Increased capacity
- Lowering specific consumption through power conversion higher efficiency and system optimization
- Extended operating range (RES coupling) at high pressure 35 barg
- Fabrication costs breakdown through design to cost conception
- Optimized footprint (SKID integration)
- Optional low consumption purification

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Hydrogen-based energy storage system

Photovoltaic
panels
560 kWc

Electricity

Hydrogen-energy chain

Gas

ELECTROLYSER

Storage tanks
(H2/O2)

Fuel Cell

+

Thermal storage

Electricity
network
Corse

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Integrated hydrogen storage solution

- Increased building autonomy when coupled with RES
- Cogeneration: electricity + heat (water temperature 70-90°C)
- A backup solution
- Modularity:

  from 50 kW to several MW
- Electrical energy stored: > 2 MWh
- Thermal energy available:

  up to 2.5 MW_{th}/h /day @ 70-90°C

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Basic safety design

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CE certification for FCH stationary installations

- CE certification required for commercialisation of FCH systems throughout Europe

- Mainly five directives to be compliant with:
  - Machinery Directive - 2006/42/CE
  - Pressure Equipment Directive (PED) - 97/23/CE
  - Low Voltage Directive - 2006/95/CE
  - Electromagnetic Compatibility Directive - 2004/108/EC
  - ATEX directive

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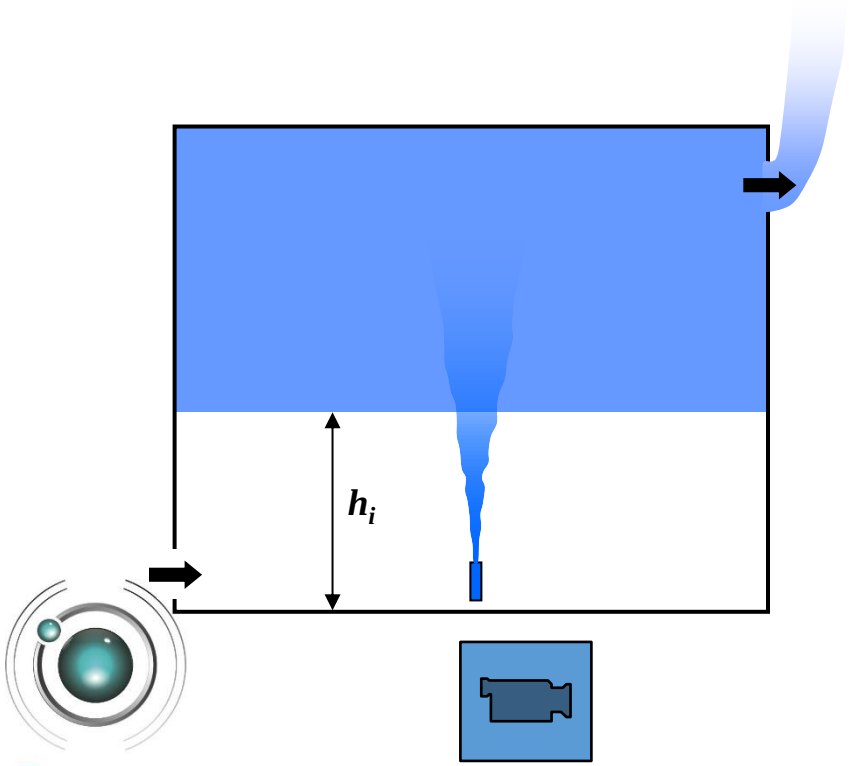
Overall safety strategy

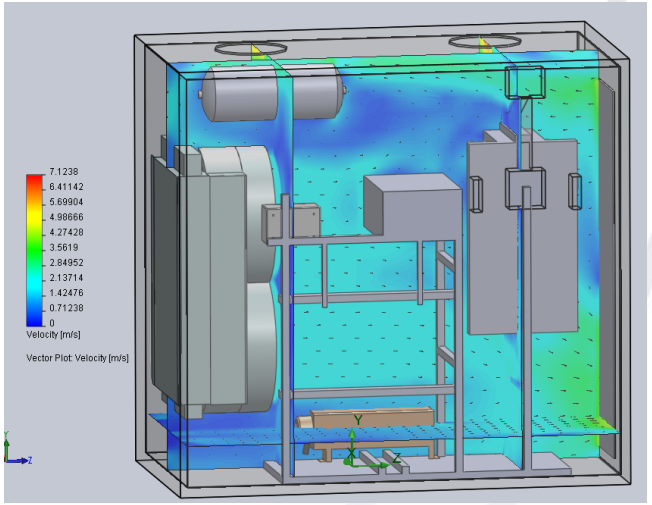
- Safety taken into conception stage :
  - Gas leak prevention
  - Prevention of H2 accumulation in containment
  - Reduction/limitation of ignition sources (e.g. EX zone)
  - Overpressure process prevention
- Secured installation:
  - Rules of installation
  - Limited access to authorized and trained employees
- Ensure an instantaneous and automatic continous :
  - Instantaneous measure of process parameters
  - In case of deviation above the defined threshold, the system stops automatically to reach a safe state
- Maintaining the system in safe operational conditions:
  - Periodic maintenance and inspections

Avoiding hydrogen accumulation in containers/enclosures

- Natural ventilation



- Mechanical ventilation
  - Activated at max speed if H2 is detected above 0,4-1 % H2 in air (vol.)



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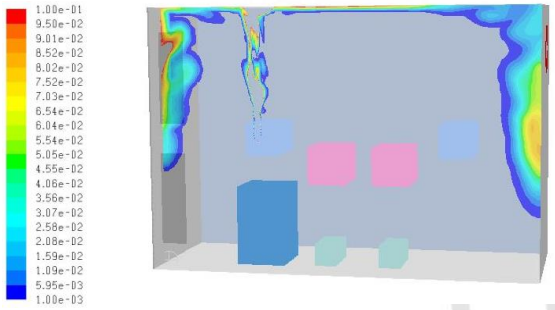
Containment issues

- Context:
  - If failure of high-pressure pipes, fittings or components in confined and obstructed enclosures, may lead to the rapid formation of a turbulent flammable hydrogen-air mixture
  - If ignited, risk from deflagration and DDT

➢ **Challenges: minimize the amount of H_2 potentially releasable in the container**

- Passive safety barriers such as
  - Restrictors, excess flow valves, etc.
- Instrumented safety barriers
  - Dedicated safety control command
  - Fast response time
  - High reliability components to achieve SIL classification (Safety Integrity Level)



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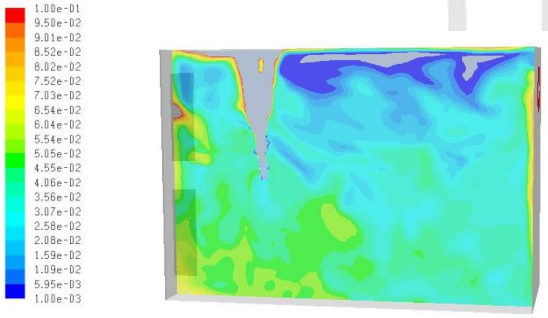

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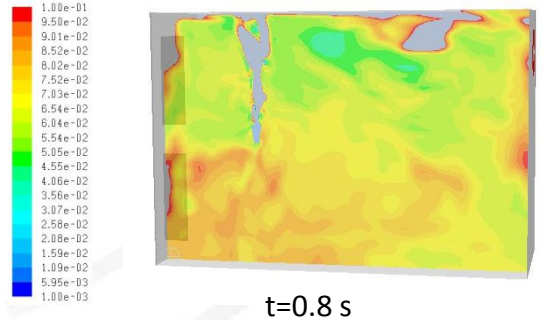

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Example of automatic sequence in case of hydrogen leak detection in a container

- Automatic activation of several safety barriers :
  - Detection of P drop in the hydrogen line
  - Detection Delta P between the hydrogen and air/oxygen lines e.g. for electrolysers, fuel cell systems
  - Hydrogen detection in enclosure/container

- Typical safety sequence :
  - Process, power conditioning stopped
  - Mitigation of the leak by isolating the hydrogen storage
  - Activation of the mechanical ventilation of the container
  - Major safety event triggered transmitted to the plant manager, project and safety managers and safety intervention teams

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Example of safety devices for a FCH system

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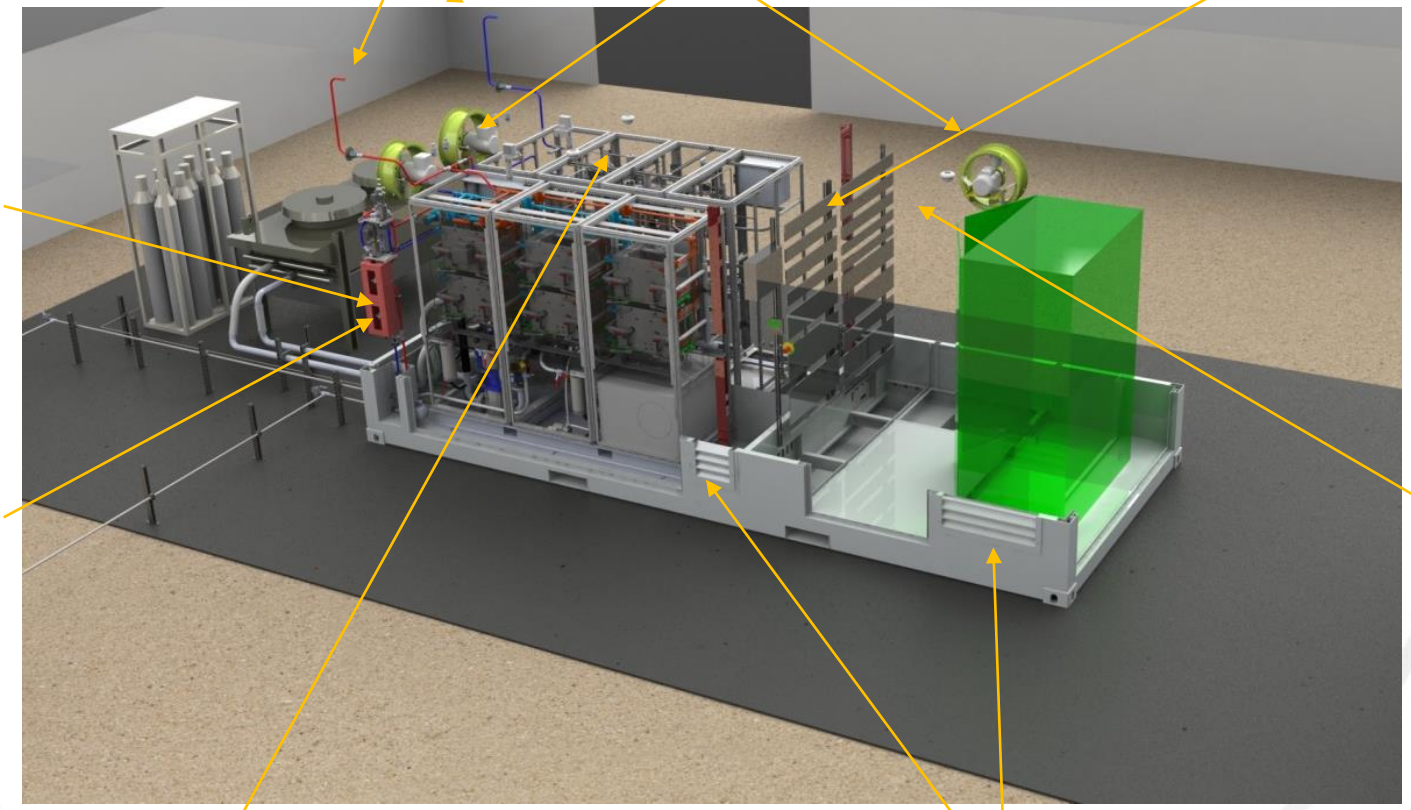
Example of safety devices for a FC system



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Hazard identification and typical scenarios

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Hazardous phenomena for FC stationary application

Hazardous phenomena for electrolysers

Products	Equipment of hazards	Potential hazard
Hydrogen	Container	Container explosion Jet fire
Hydrogen	Gas separators (electrolyser systems)	Burst
Hydrogen	Pipes	UVCE VCE Jet Fire
Electricity	Cable/cabinets	Electrocution

Hazardous phenomena for FC systems

Products	Equipment of hazards	Potential of Hazard
Hydrogen	Container	Container explosion Jet fire
Hydrogen	Pipes	UVCE VCE Jet Fire
Electricity	Cable	Electrocution

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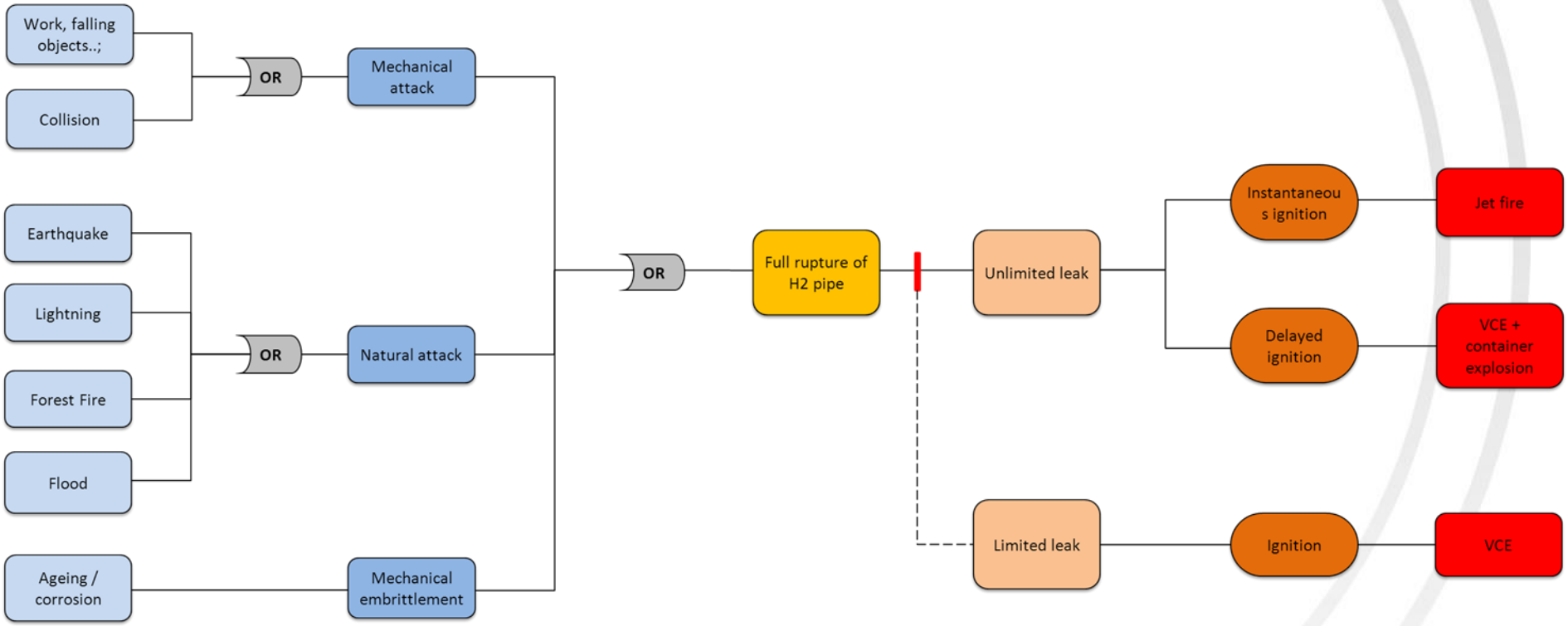
Typical scenario inside a container



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Hydrogen accumulation followed by container explosion

Hazardous phenomena	Volume, m^3	Free volume 70%	Significant lethal effects – Domino effects 200 mbar (m)	Lethal effects 140 mbar (m)	Irreversible effects 50 mbar (m)	Indirect effects : broken glass 20 mbar (m)
Explosion of container 10 feet L x l x H (m): 3 x 2.4 x 2.4	17	12	14	17	40	80
Explosion container 20 feet L x l x H (m): 6 x 2.4 x 2.4	34	24	17	21	51	102
Explosion container 40 feet L x l x H (m): 12 x 2.4 x 2.4	68	48	22	27	64	128

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Example of deployment of a hydrogen-based green public building in France

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Hydrogen-based energy storage system: installation in a public building

- Context:
  - Increase of population by a factor 10 in summer
  - End line location on the electrical grid network
- Deploying hydrogen-based energy storage solution coupled with photovoltaic panels to:
  - Insure the green production of electrical and thermal energy
  - Ensure the partial energy autonomy of the buildings
  - Backup system in case of power cut
  - Decrease the energy bill of the city while promoting sustainable development
  - Develop a reliable and safe solution
- The first Greenergy Box™ in a Kid Leisure Centre (Public Building)

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Integrated hydrogen storage solution : the Green Energy Box™

CERTIFIED CE

- Increased building autonomy when coupled with RES
- Cogeneration: electricity + heat (water temperature 70-90°C)
- A backup solution
- Modularity:

  from 50 kW to several MW
- Electrical energy stored:

  > 2 MWh
- Thermal energy available:

  up to 2.5 MW_{th}/h /day @ 70-90°C

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Challenges

1. No hydrogen-related installation rules in Public Building Codes

Define the rules for the first installation of a hydrogen-energy storage system

2. Hydrogen safety and public acceptance

Convince the population that the Greenergy Box™ is a safe hydrogen solution

3. Designated installation location with limited surface

Offer a solution respecting the client's constrains

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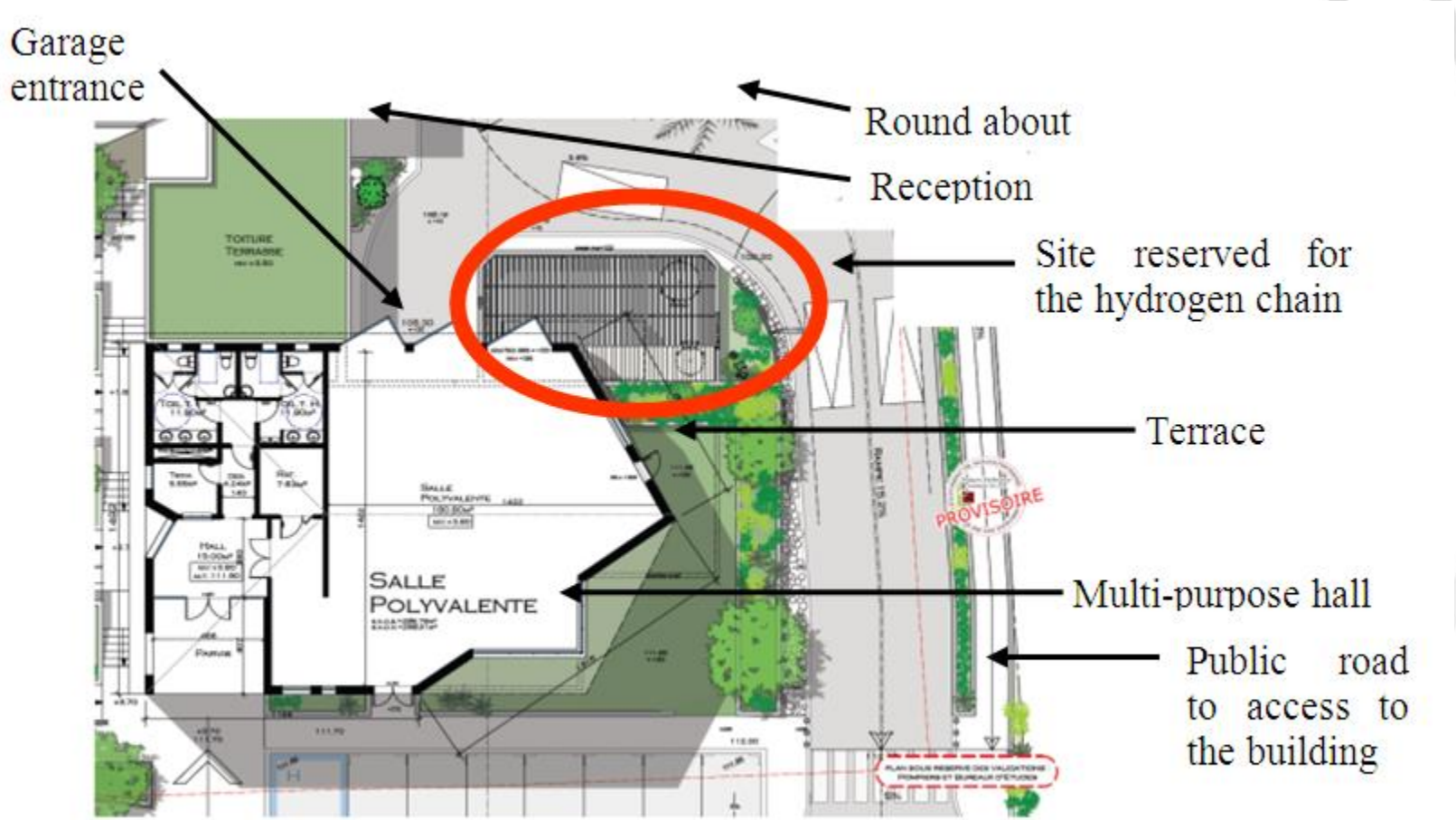
Site allocated for the hydrogen chain



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Hydrogen-based energy storage system: installation in a public building

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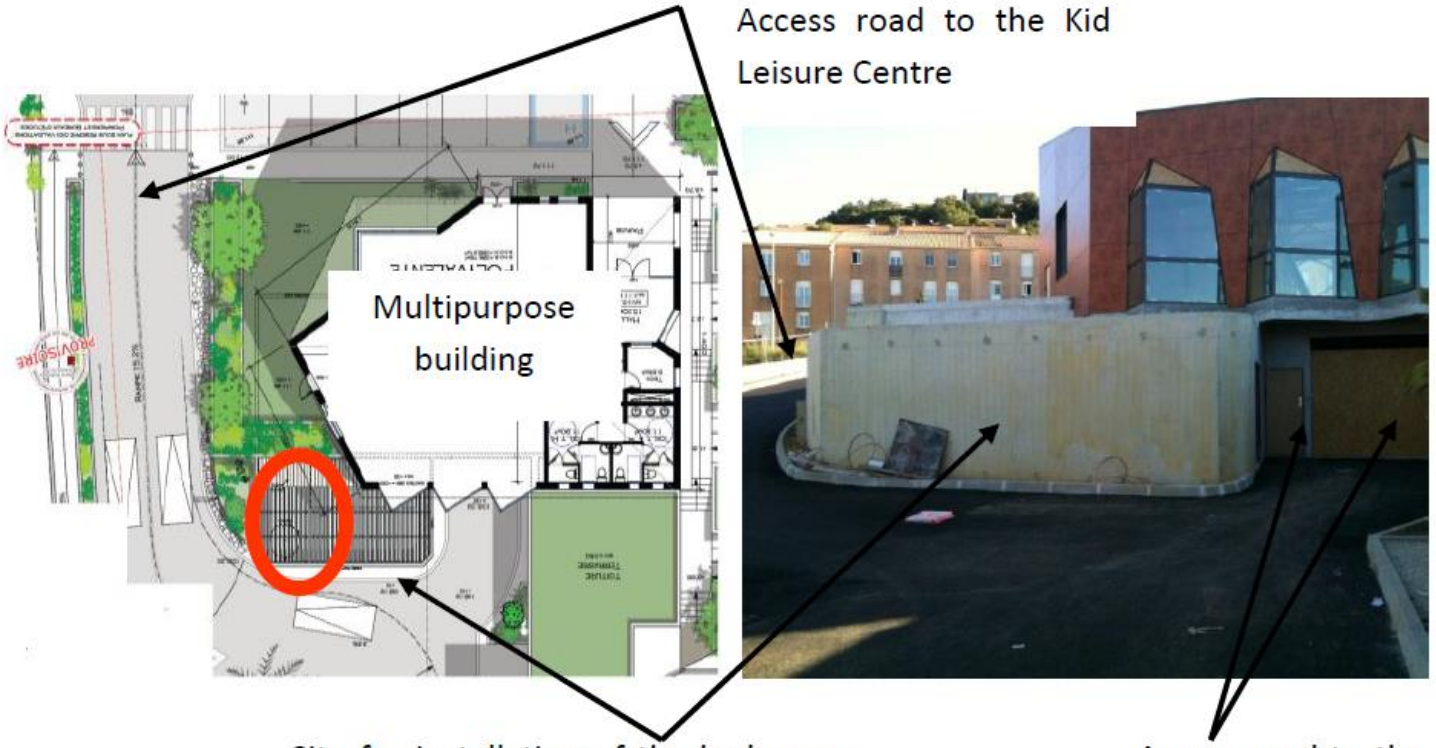
Hydrogen-based energy storage system: installation in a public building



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French Public Building Regulation

- In France, a local Safety Commission checks the conformity of architectural plans of a new building with Public Building Code
  - No competent to authorize the installation of a hydrogen system
  - Authorization delivered by a National Public Building Safety Commission
- Analogy with cogeneration system in Public Building Code
  - Greenergy Box™ similar to a cogeneration module system
  - Installation guidelines defined for combustion heating systems
  - Prescriptive approach

Installation location	Total power of the system (heat + electricity)		
	<30 kW	>30 kW & < 70 kW	>70 kW
Inside			
Outside			
Terrace			

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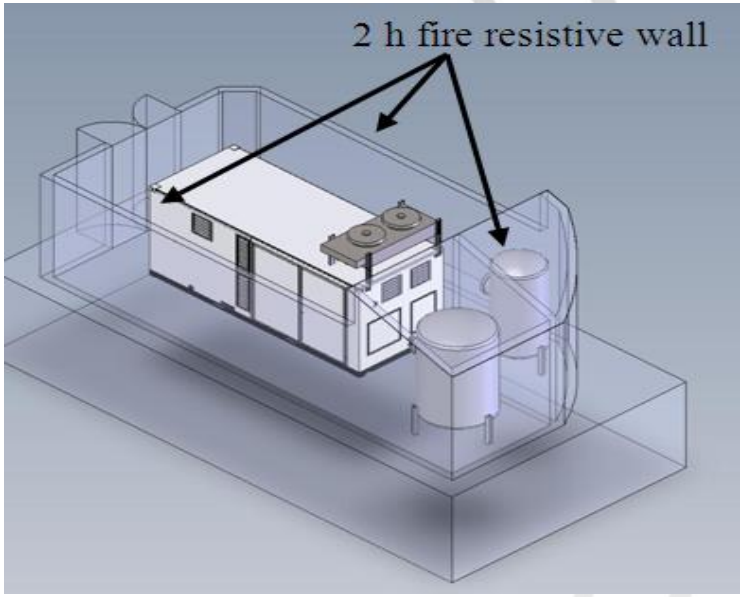
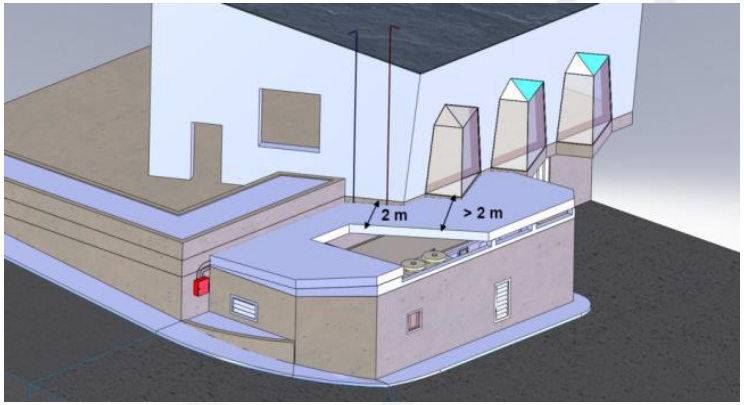
Solution of implantation

- System installation :
  - Non flammable system envelop
  - Inaccessible to public or made inaccessible by the use of a wall or a fence of at least 2 m high
  - 10 m distance from highway, private property limit or other buildings. IF NOT, protective wall of fire resistance of 2 hours and of 2m minimum height
  - 2h fire resistant canopy to protect the system and the storage and/or the façade of the multi-purpose from thermal effects in case of fire





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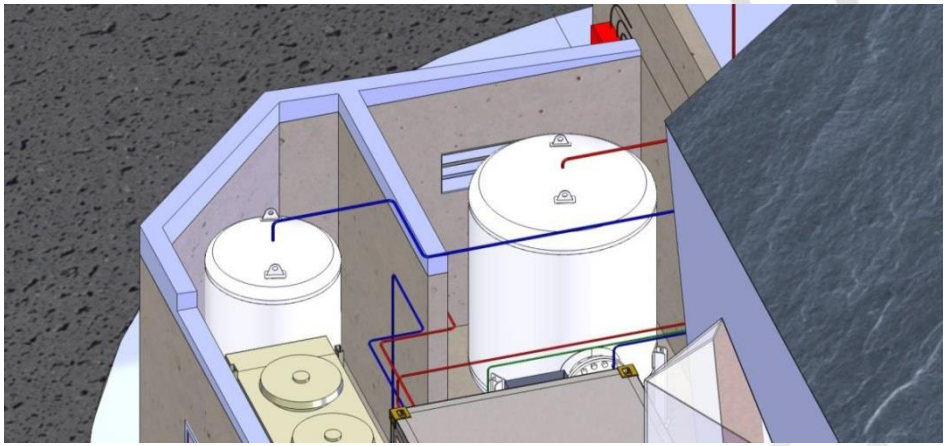
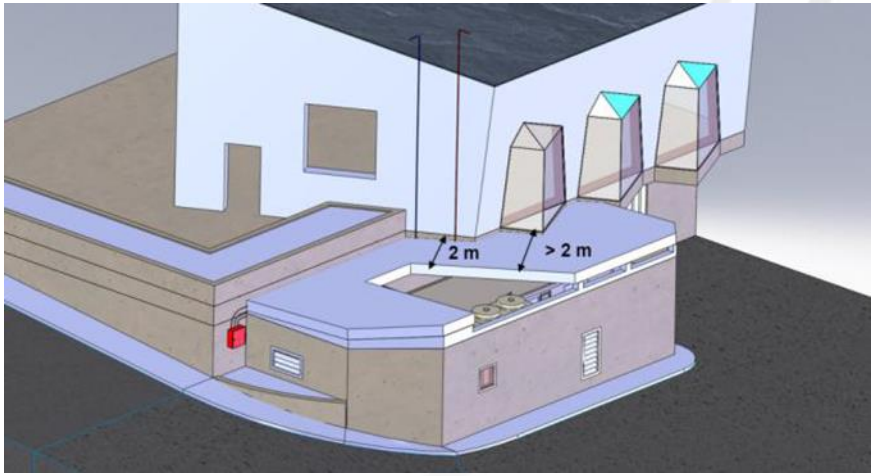
Solution of implantation

- Storage installation :
  - Zone inaccessible to public and surrounded by a protective wall of fire resistance of 2 hours and of minimum height of 2 m
  - Storage tanks separated by a 2 h fire resistance wall
  - 2h fire resistant canopy above the storage tanks
  - PED certification for the tanks
  - Manual safety valve for each tank
  - Electro-valve close to each tank
  - In case of power cut or activation of a safety function, both the storage tank and the Greenergy Box are isolated by the electro-valves





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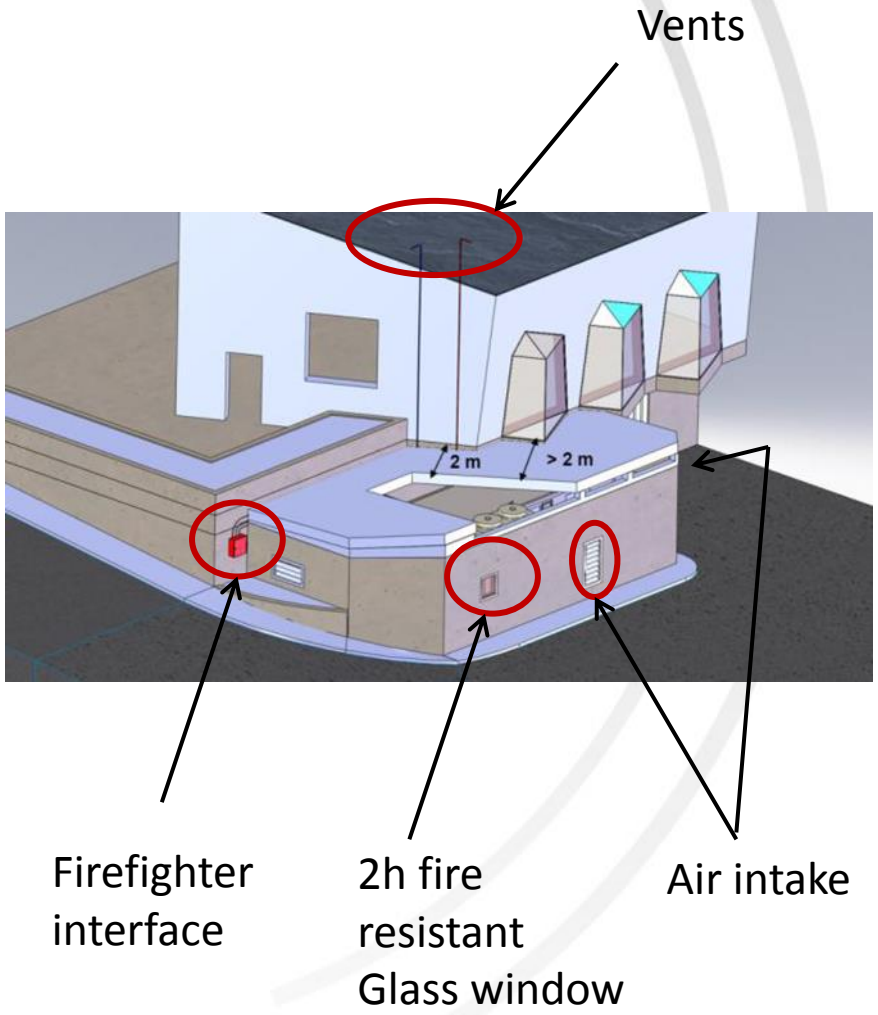
Solution of implantation

- Emergency safety devices
  - An "Emergency Discharge Device of the tanks, positioned outside of the technical premise in a protected access, enables to discharge the storage tanks in about 10 minutes through the vent
  - Several emergency shut-down bottoms located enables to:
    - isolate the gas supply at the tank and the container,
    - disconnect the Greenergy Box™ from the electrical grid up to the electrical cabinet,
    - which implies the depressurization of the system through the vents installed on the roof of the building.
    - Residual amount of hydrogen will subsist in the process.



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Example of a hydrogen-based energy storage system: MYRTE platform (Corsica)

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Indoor process system installation

- High building with large openings for natural ventilation
  - Sizing for limiting H2 accidental leaks
- Leak and fire detection
  - H2 detectors
  - ΔP
  - Thermal camera
- Reduction of electrical sources
  - ATEX components (H2, smoke detectors)
  - Electrical switch off at low H2 concentration
- Emergency discharge bottom
- Safety distances or fire resistance wall

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Example of hydrogen-based energy storage system: MYRTE platform

Photovoltaic
panels
560 kWc

Electricity

Hydrogen-energy chain

Gas

ELECTROLYSER

Storage tanks
(H2/O2)

Fuel Cell

+

Thermal storage

Electricity
network
Corse

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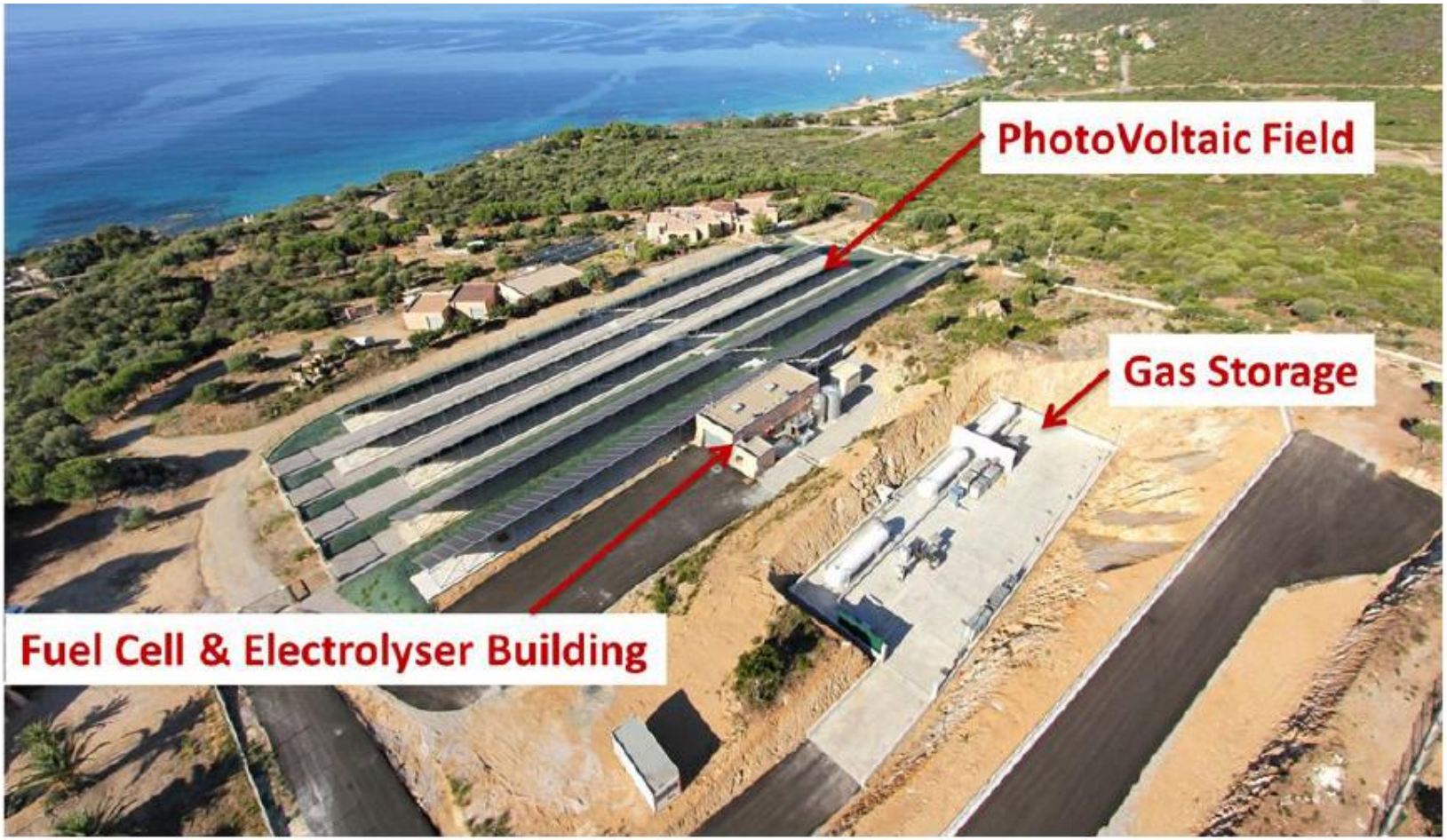
Hydrogen-based energy storage system: MYRTE platform (Corsica)



Hydrogen-based energy storage system: MYRTE platform

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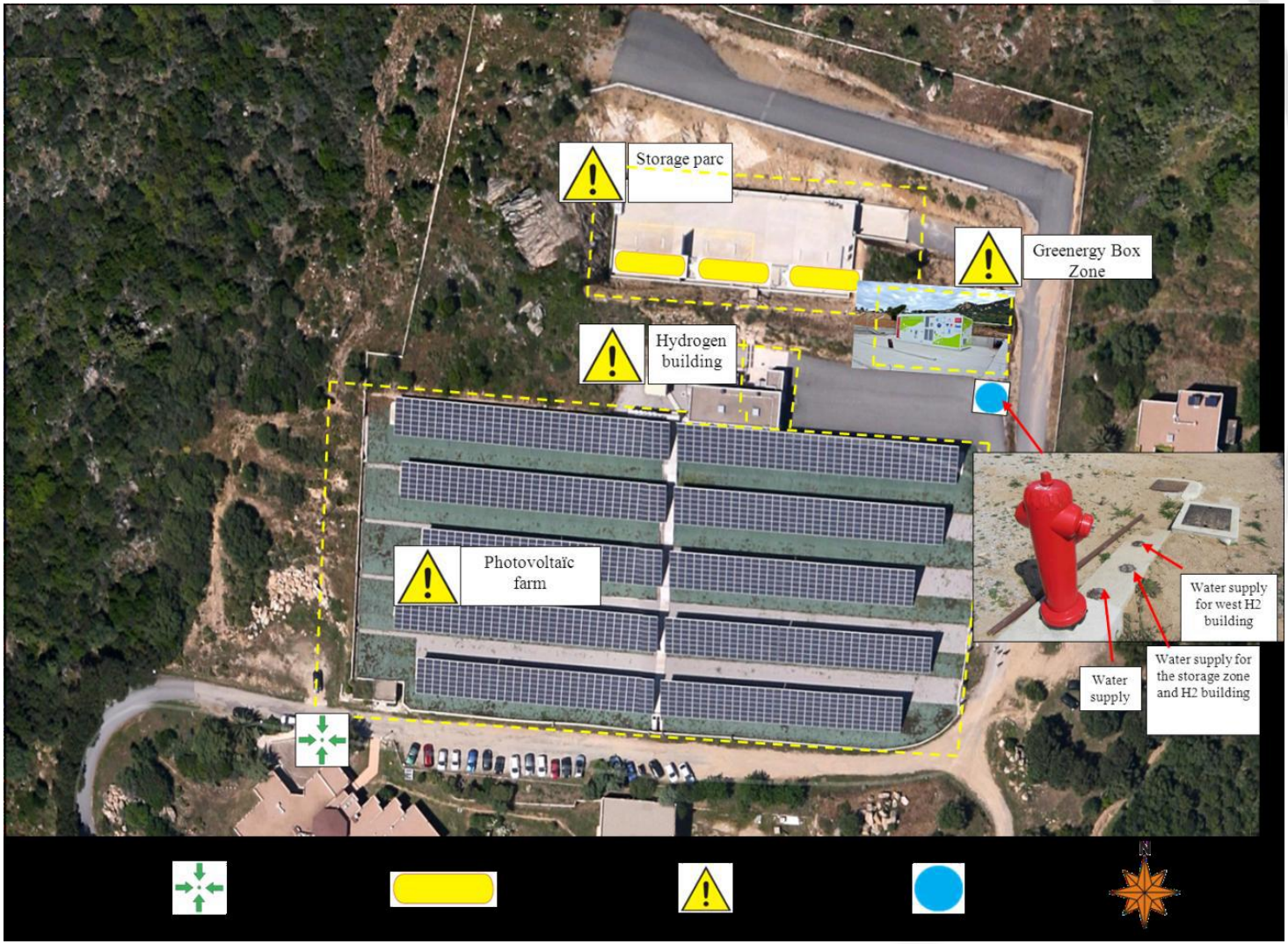
Hydrogen-based energy storage system: MYRTE platform



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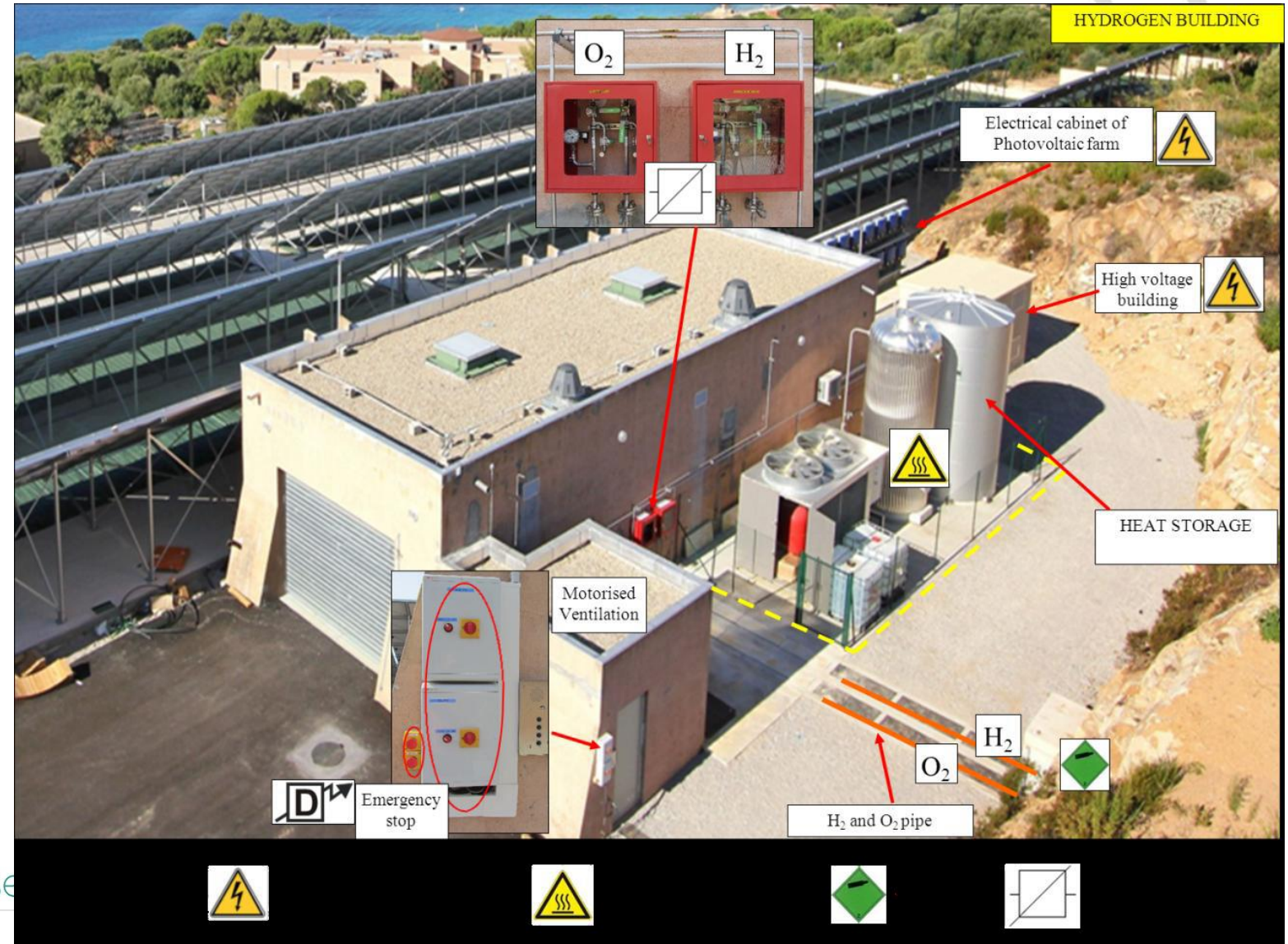
Hydrogen-based energy storage system: MYRTE platform



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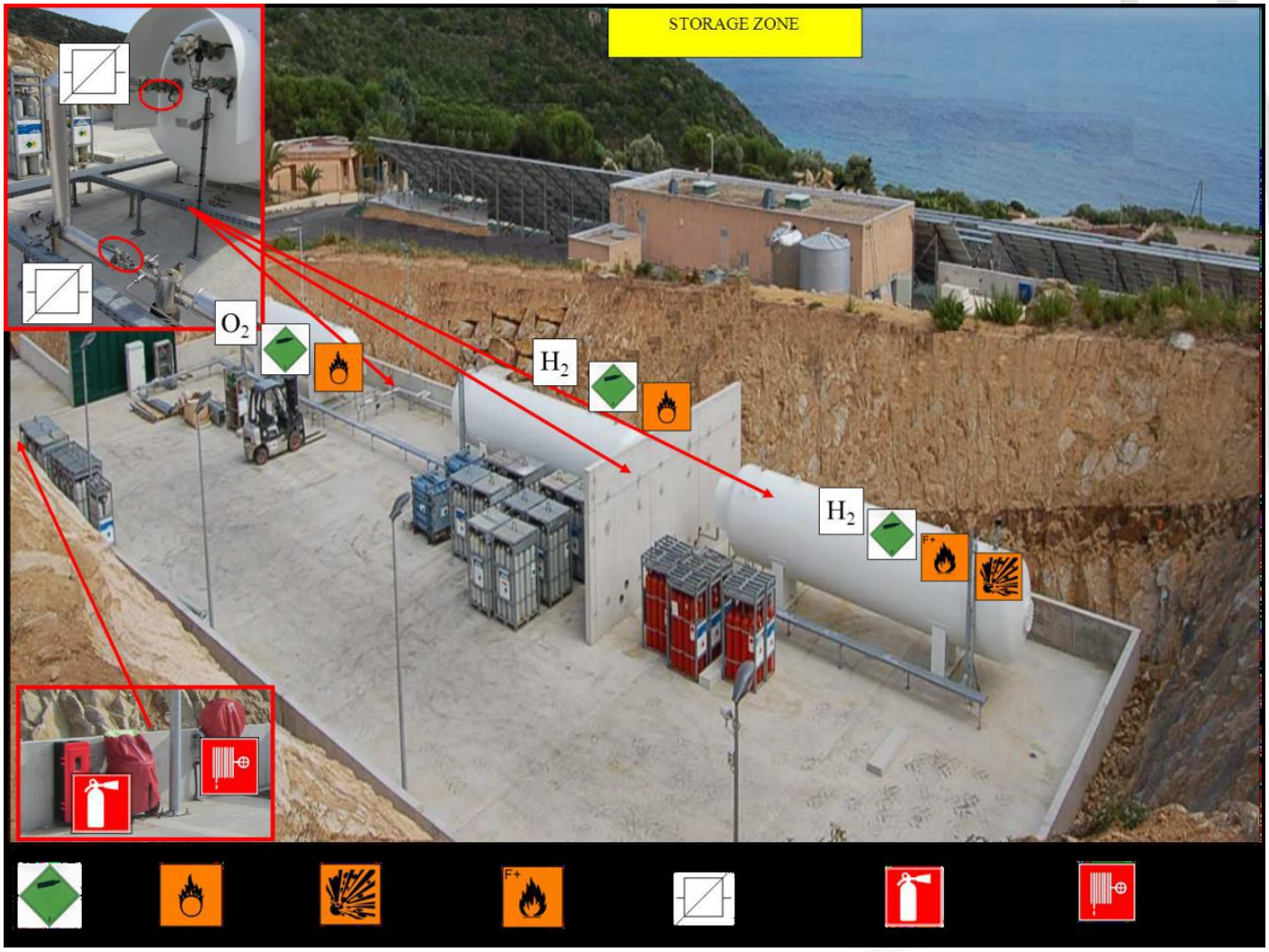
Hydrogen-based energy storage system: MYRTE platform



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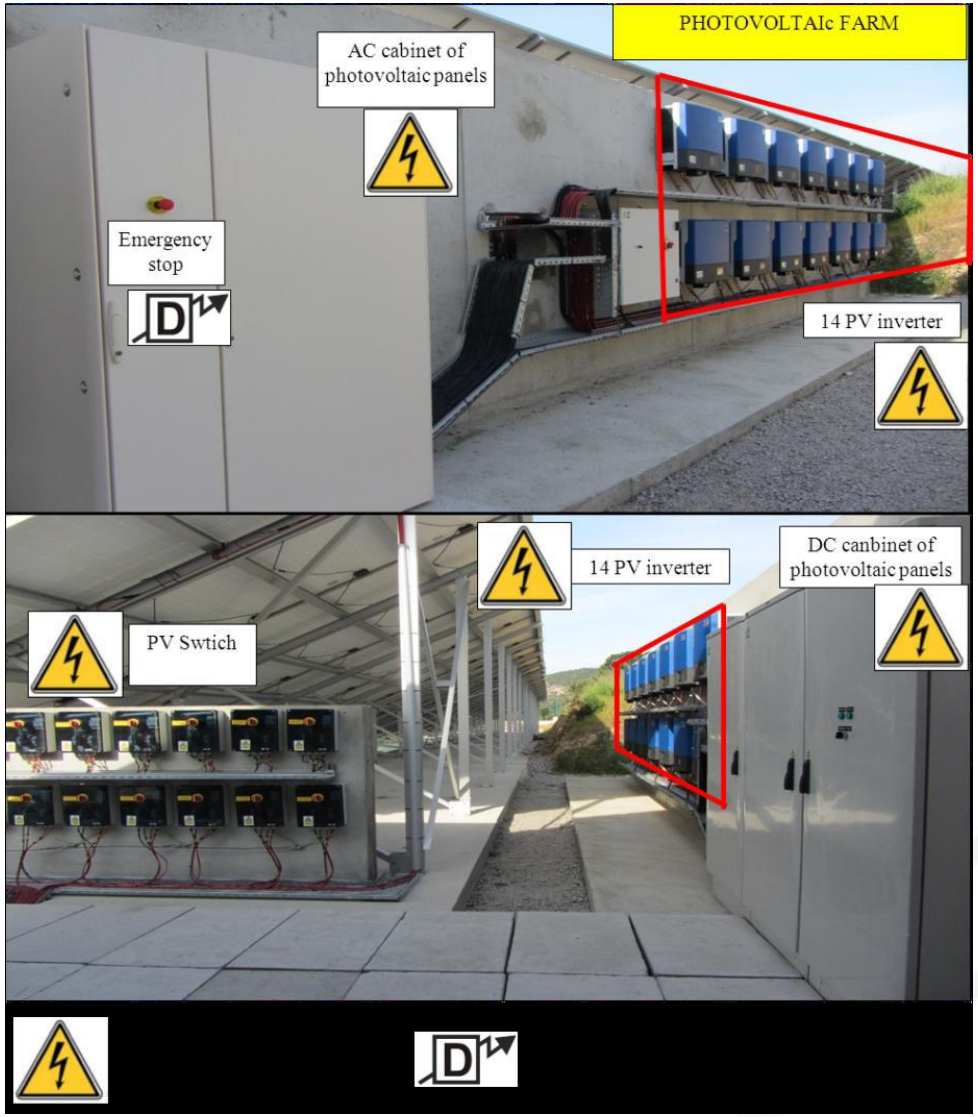
Hydrogen-based energy storage system: MYRTE platform



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Thank you for your attention

http://www.hyresponse.eu/

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