PLACE DE L'HYDROGENE ET IMPORTANCE DE LA SECURITE COMBUSTION DANS NOTRE MIX ENERGETIQUE: LE CAS PARTICULIER DES TRANSPORTS ET DE L'AERONAUTIQUE

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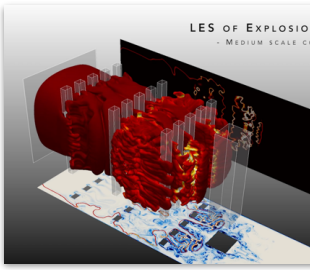

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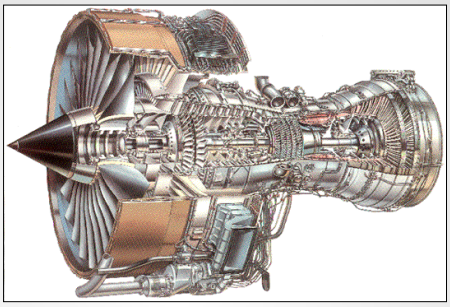
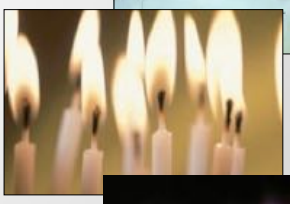
ENERGY ON EARTH TODAY = COMBUSTION

Combustion: approx. 90 percent of the energy produced on earth





Why do we burn things ?

The he of fuel burnt is

One kg of hydrogen
=
100 kg of batteries

Fuel + Oxidizer → Products + ***Heat***

For mo he heat re n) is of the order of 50 MJ/kg (120 for H2).

One kg of kerosene
=
40 kg of batteries

COP28: we MUST stop (minimize?) fossil fuel combustion… but how ?

We MUST go to renewable energies

Problem: renewable energies are intermittent

ENERGY STORAGE IS A MAJOR ISSUE

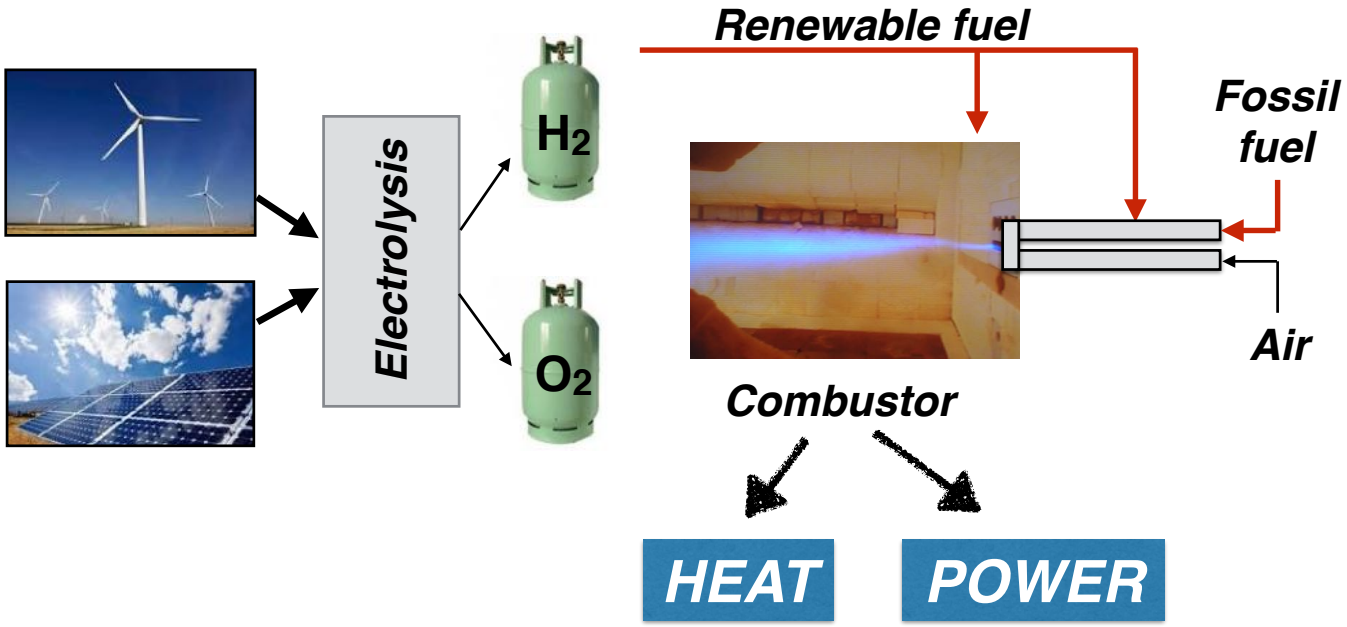
HOW CAN WE STORE ENERGY ?

★ **SURPRISE: WITH COMBUSTION AGAIN !**

★ **STRATEGIES CALLED POWER TO X TO POWER:**

- Use renewable energy to produce gas (H2 for ex)
- Use H2 later to produce power when needed

WHAT IS POWER TO GAS ? One example:



ONCE WE HAVE H2 SAFELY STORED….

★ USE IT IN A FUEL CELL IN A CAR OR AN AIRCRAFT

★CONVERT IT TO CH4 OR NH3 (EASIER FOR STORAGE)

ONCE WE HAVE H2….

WE CAN ALSO BURN IT ! :

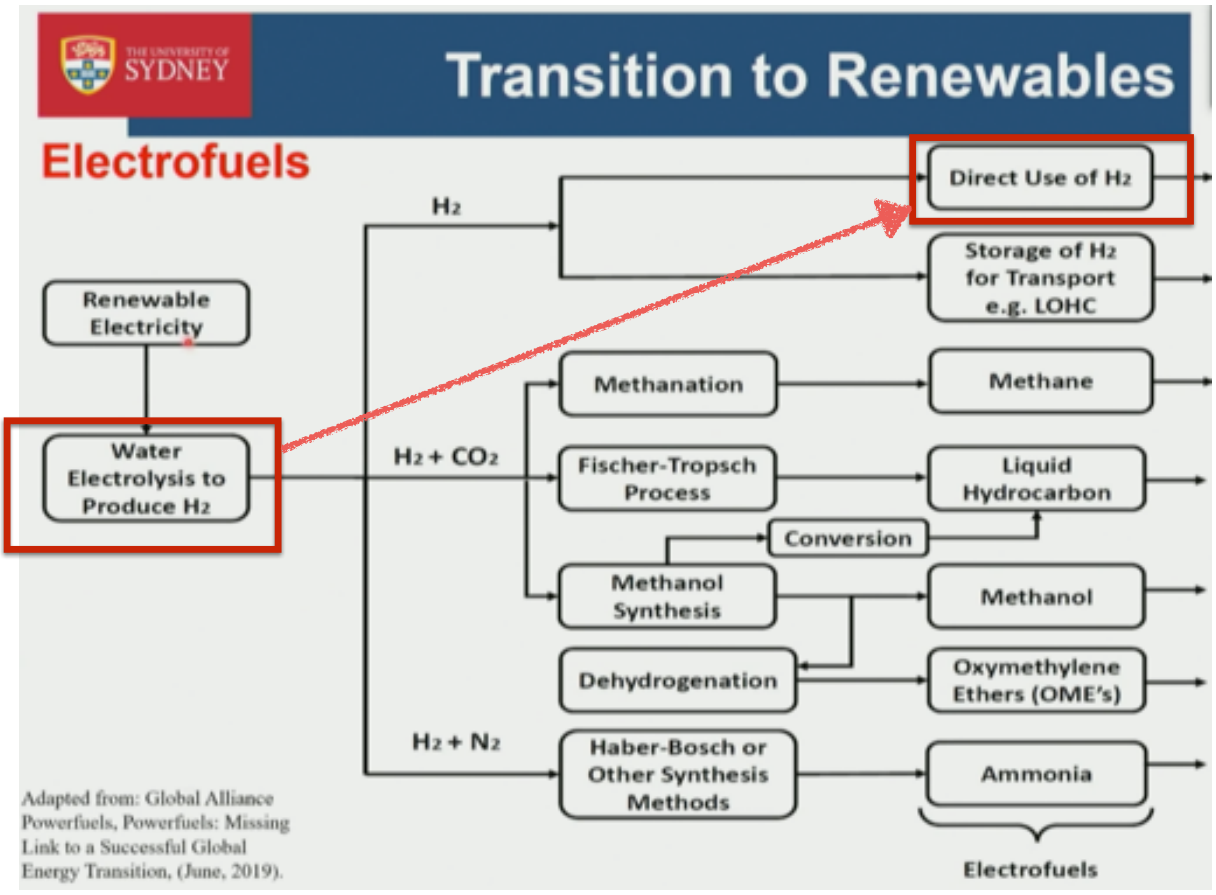
★ IN A PISTON ENGINE (TEN TIMES CHEAPER THAN A FUEL CELL) FOR CARS OR BUSES

★IN A TURBINE FOR POWER GENERATION IN AIRCRAFT, HELICOPTERS OR FOR ELECTRICITY

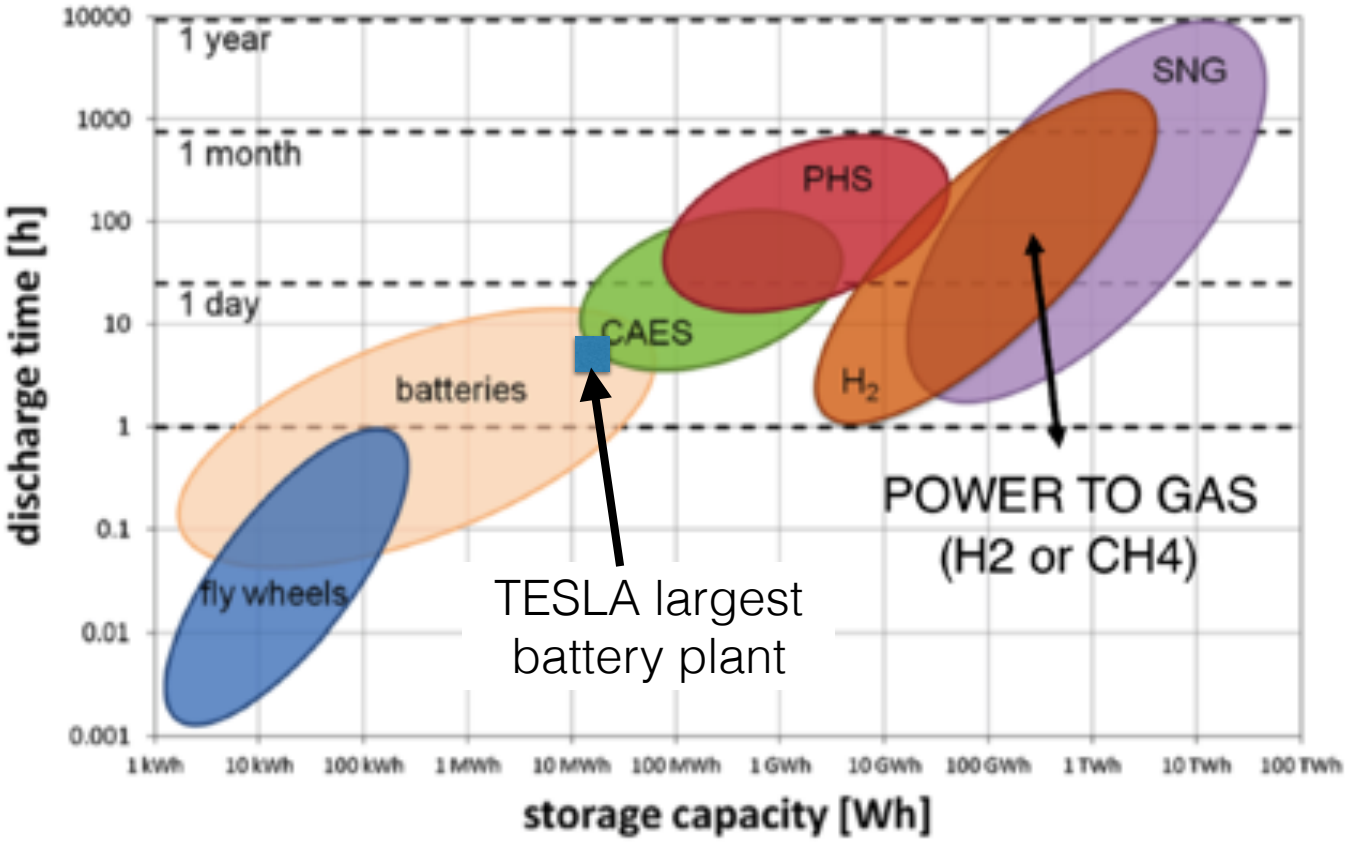
★IN A FURNACE

★TO MAKE YOUR COFFEE OR YOUR BBQ

H2 IS ONLY THE ENTRY GAS:….



FUELS CAN STORE A LOT OF ENERGY:



H2 CAN BE USED FOR MOBILITY:

INNOVATION

La Région Occitanie lance son plan hydrogène vert

Par Pierrick Merlet | 22/05/2019, 16:03 | 618 mots

© Frédéric MALIGNE/LAPLACE/CNRS Photothèque

Inauguration de la Plateforme Hydrogène à Toulouse

10 octobre 2019 INSTITUTIONNEL

La Plateforme Hydrogène, dont la vocation est de réaliser des travaux de recherche sur les utilisations et la production de l'hydrogène et d'accompagner les industriels dans ce domaine, est inaugurée le 10 octobre 2019 à Toulouse.

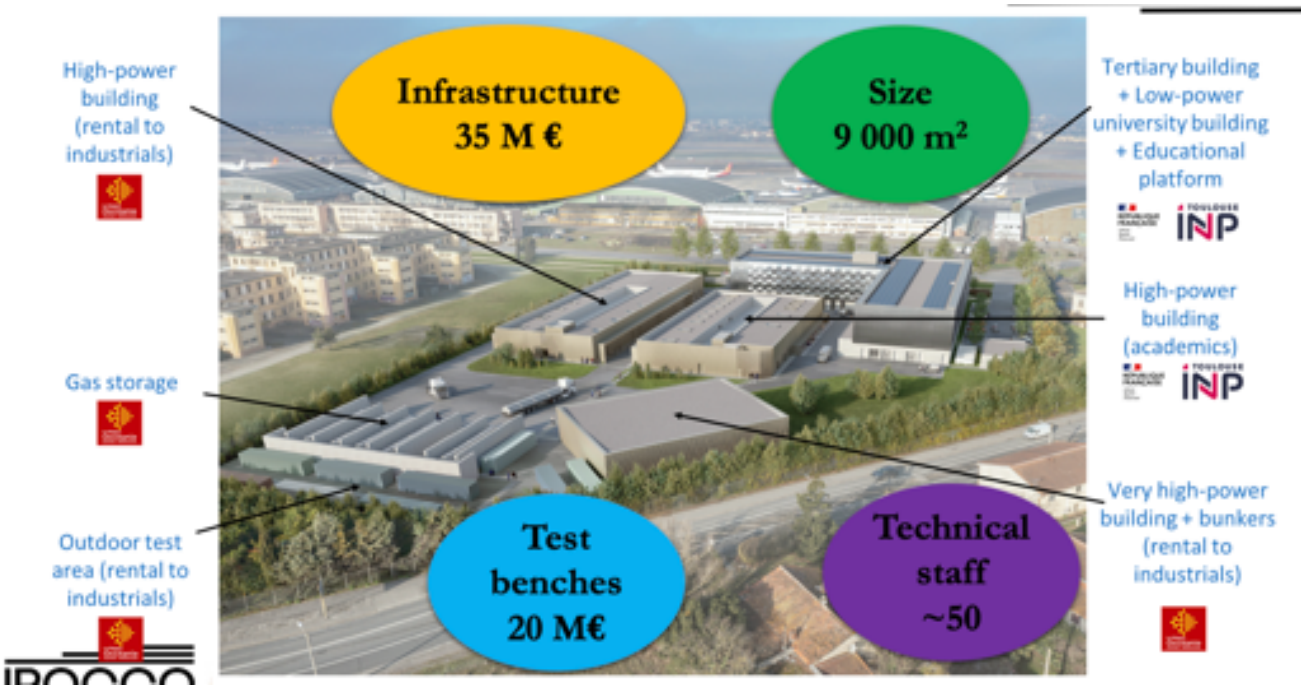
A - / A+

Contact(s)

Communication INSIS

L'hydrogène-énergie au service de la transition énergétique

Et Francazal en 2024:



ASSUME THAT H2 WILL BE HERE AND ACCEPTED AS ‘GREEN’. THEN TWO MAIN QUESTIONS:

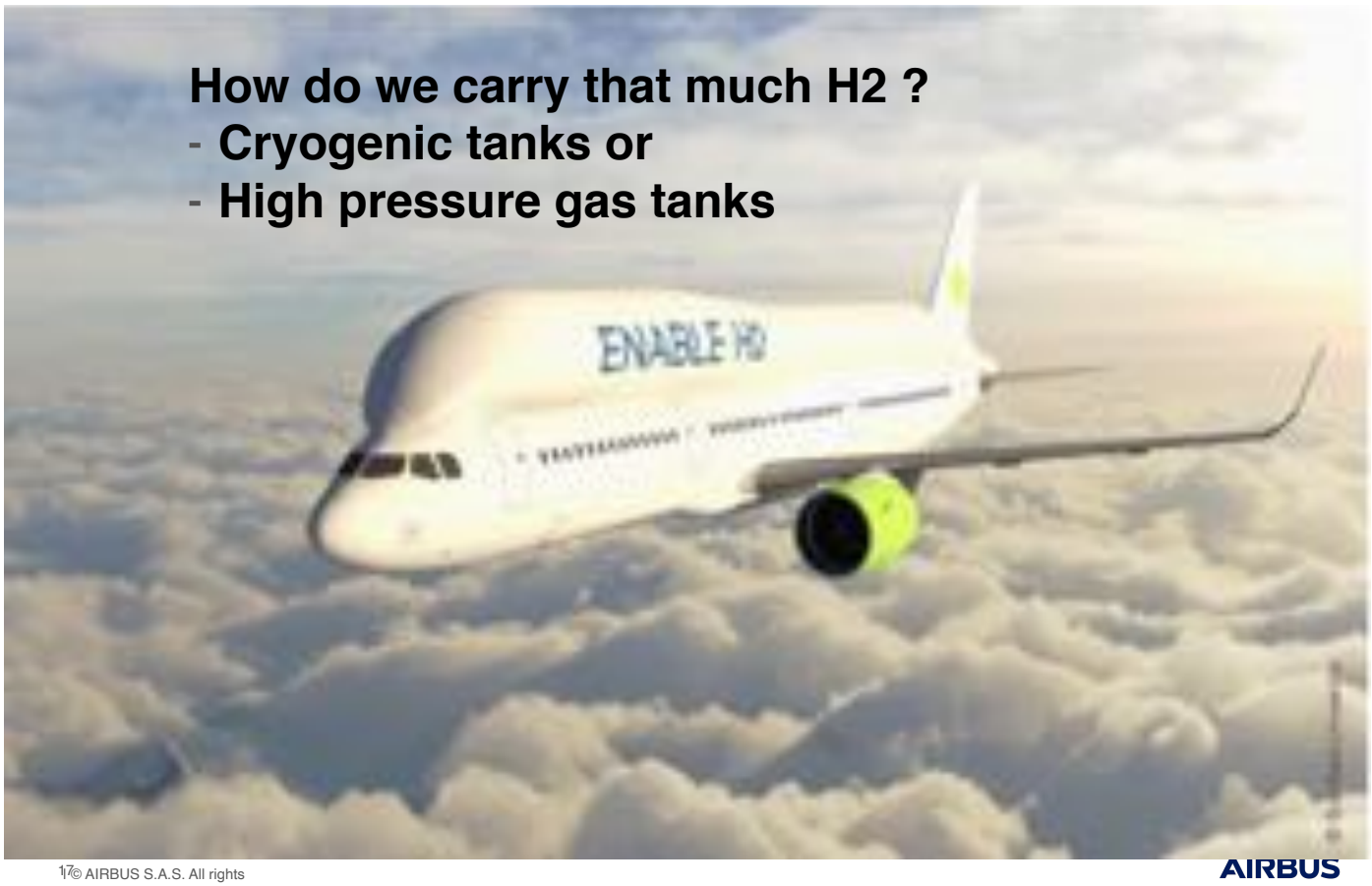
★Can I use H2 for my applications ?

Can we use H2 for aircraft (in Toulouse !)

-> H2 in GAS TURBINES ? (I will not discuss fuel cells here -> cant be used for big planes)

★Is it safe ?

INDUSTRIE ET TECHNOLOGIE JUILLET 2021



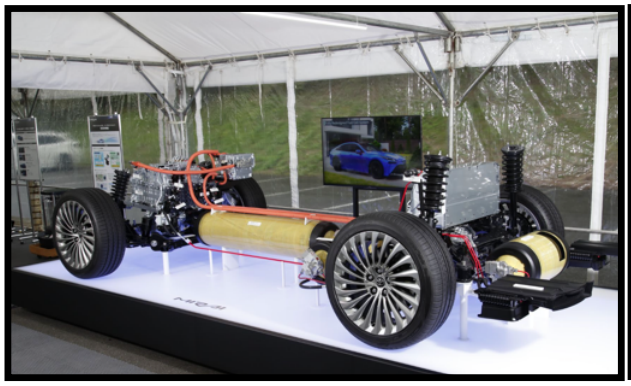
AIRBUS

Cryogenic tanks: even cryogenic, H2 is not very dense

Density of liquid, cryogenic H2 = 70 kg/m3

Density of liquid kerosene = 800 kg/m3

Even if the heat of reaction PCI of H2/kg = 2.2 PCI of kerosene/kg, replacing 200 tons of kerosene (220 m3) by H2 will lead to 80 tons of H2 (1100 m3 … at 20 K)

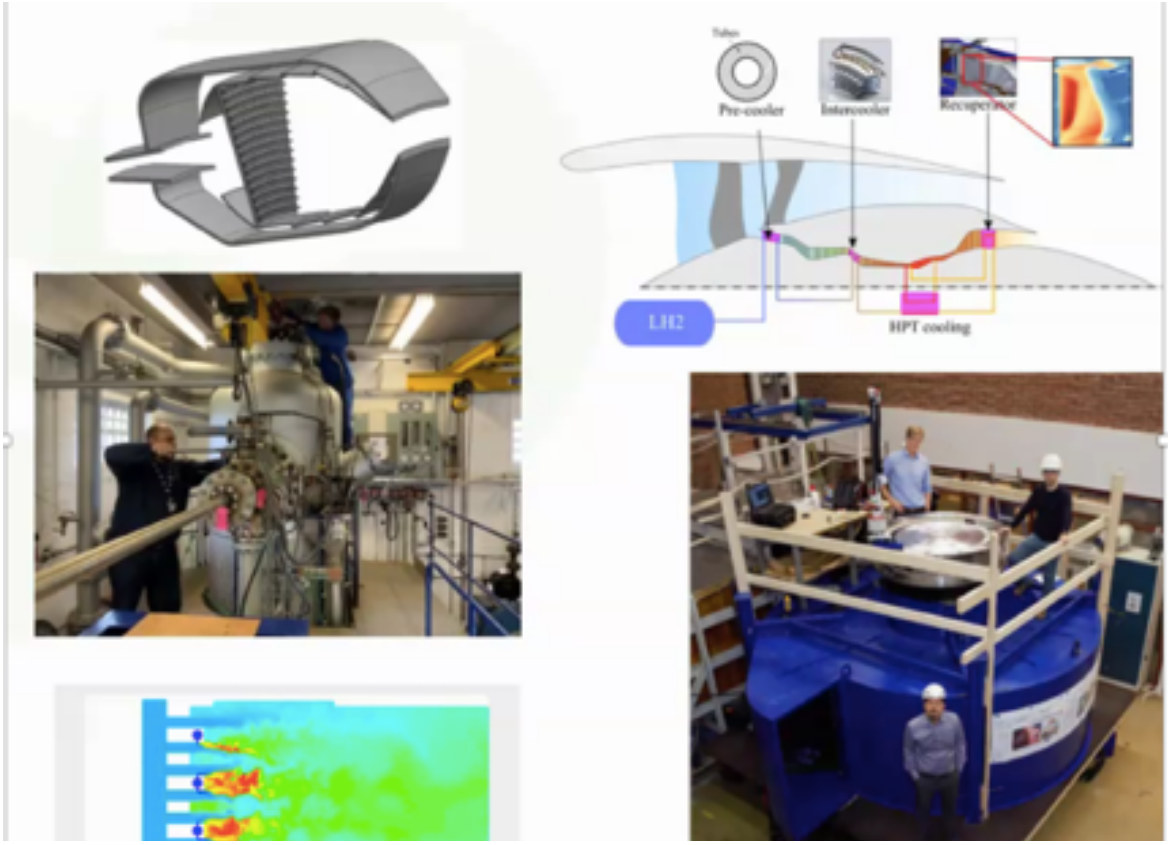


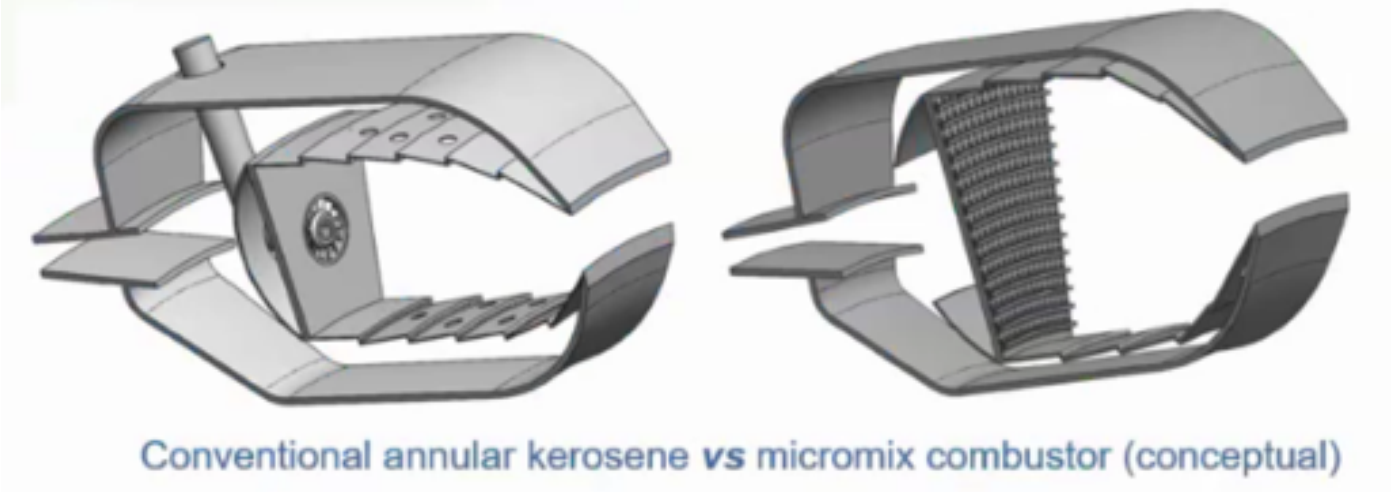
High pressure (700 bars) tanks:

- **High pressure gas tanks can't fly…They are too heavy. In a H2 car like the TOYOTA, the tank weight is 130 kgs for 5 kgs of H2 which provide as much autonomy as 13 kgs of gasoline**

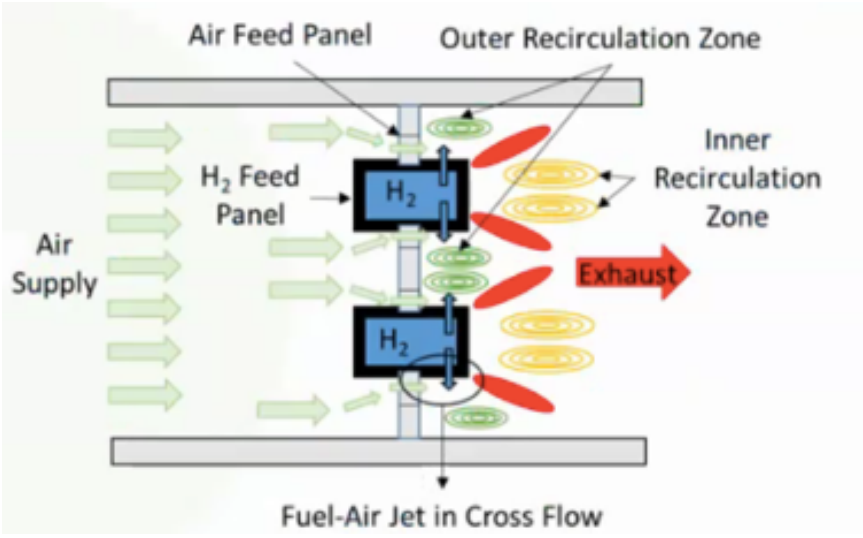
- **So it will have to be cryogenic…**

GOING TO FULL H2 - RADICAL DESIGNS: THE MICROMIX ENGINE OF CRANFIELD

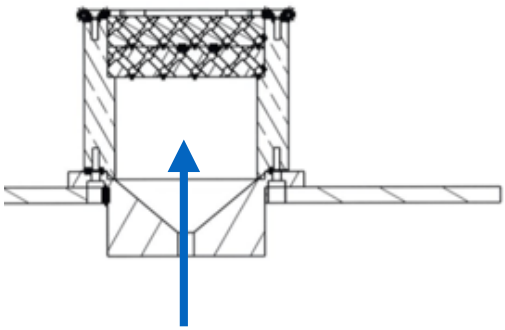




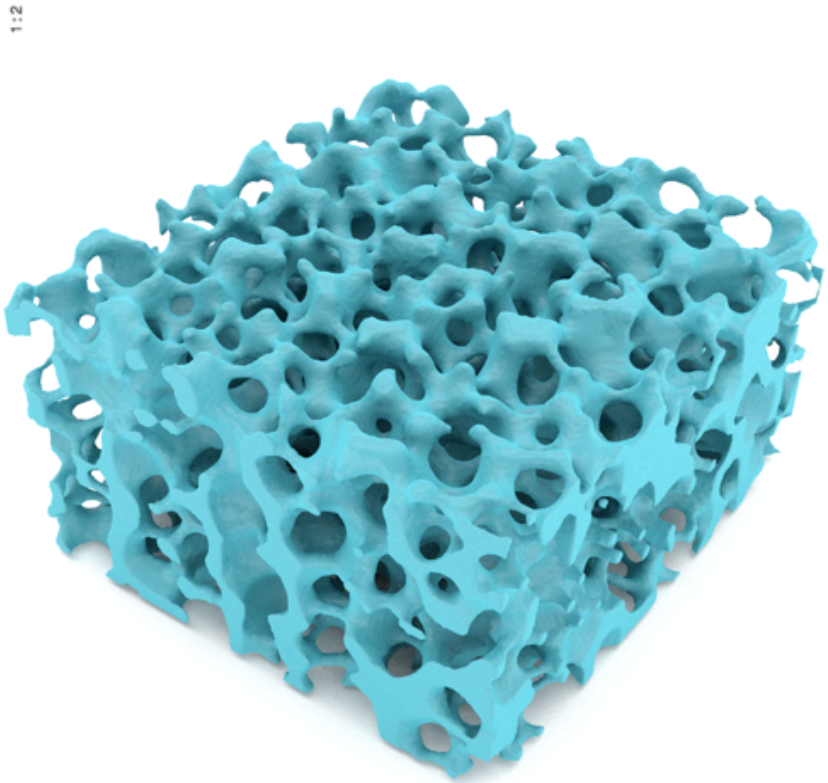
Conventional annular kerosene ***vs*** micromix combustor (conceptual)



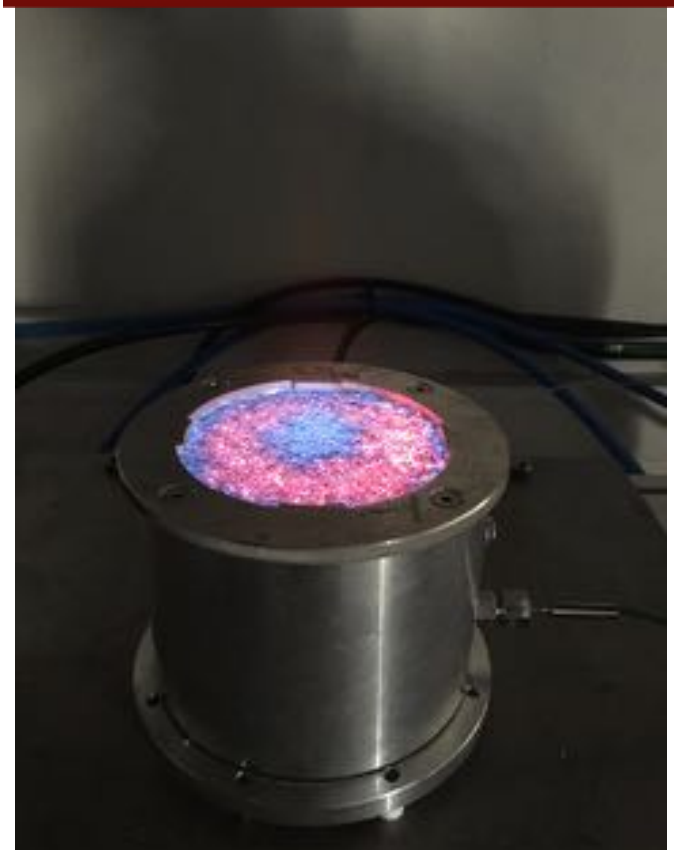
MORE RADICAL DESIGNS: H2 COMBUSTION IN POROUS MEDIA

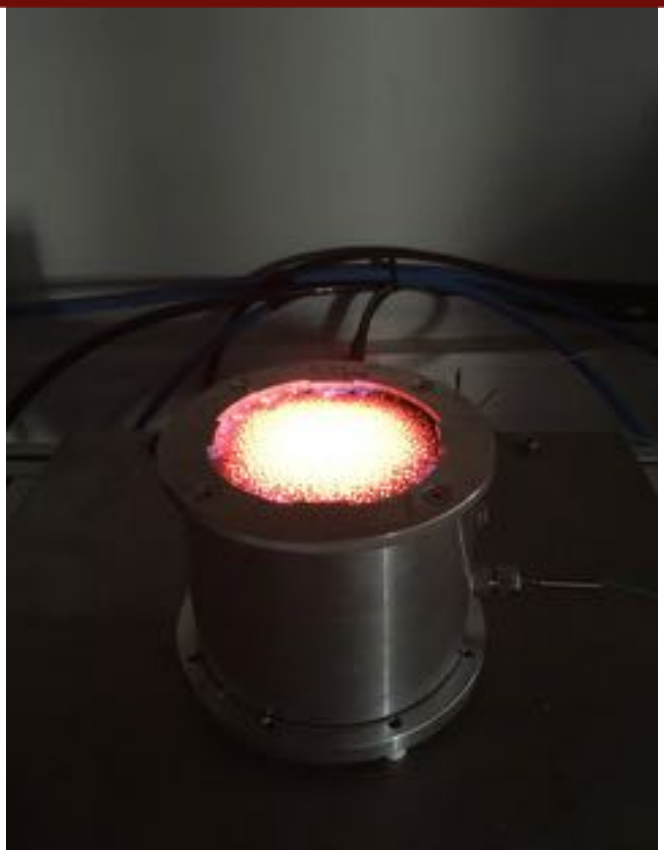


Gaz + air

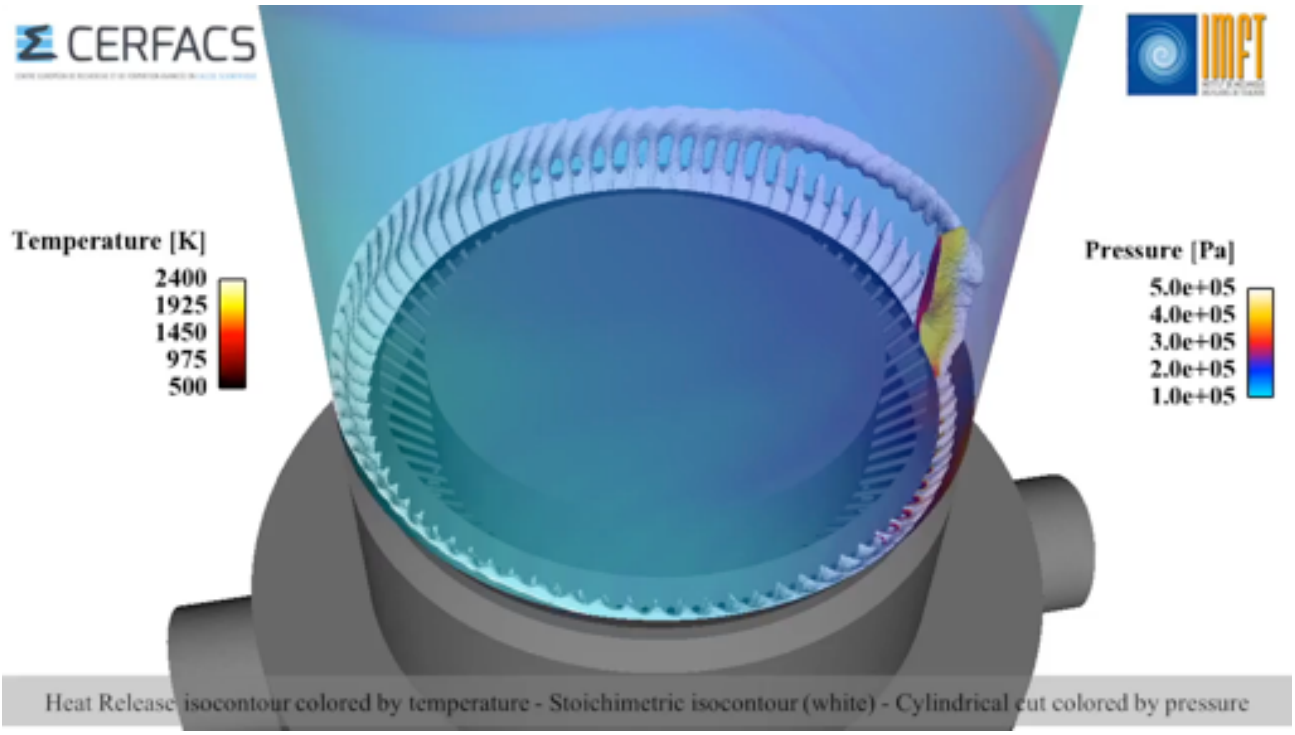


EXAMPLE OF SCIROCCO: H2 COMBUSTION IN POROUS MEDIA





OR EVEN MORE RADICAL: ROTATING DETONATION ENGINES



BACK TO THE AIRCRAFT

- Suppose that we can build the engine itself as well as its hydrogen tanks at 20 K
- What about the rest of the aircraft and of the whole airport ?
- Need to discuss safety issues
  - Filling H2 tanks at 20 K
  - Transporting and storing large quantities of H2
  - Leaks of H2: detection and protection
  - Public relations in case of accidents

BACK TO SCIENCE: H2 IS VERY DIFFERENT FROM OTHER FUELS

★ Hydrogen leaks…

★ Hydrogen ignites much more easily

★ Hydrogen burns much faster than all other fuels

★Hydrogen explodes…

WHY TALK ABOUT SAFETY ?

- **SAFETY AND ACCEPTABILITY BY SOCIETY GO TOGETHER**
- **THIS IS WHERE PHYSICS AND SOCIOLOGY MEET**
- **FOR A COMBUSTION EXPERT, HYDROGEN IS NOT A 'NORMAL' PRODUCT**
- **OF COURSE, HYDROGEN IS USED TODAY BY INDUSTRY, SAFELY, IN MANY PLACES**
- **THE CLASSIC EXAMPLE OF ROCKET ENGINES (ARIANEGROUP) VS AIRCRAFT ENGINES (SAFRAN/AIRBUS):**

Comparing H2 in rockets and aircraft (S. Zurbach, SAFRAN)

EVEN IF THERE ARE SIMILAR ELEMENTS, THE TRUTH IS THAT WHAT WORKS FOR ROCKETS WILL NOT APPLY EASILY FOR AIRCRAFT…

AND EVEN LESS FOR:
- HEATERS
- CARS, TRAINS, BUSES
- BBQ
- COFFEE MACHINE…

LET US CONSIDER AN ANALOGY FOCUSING ON SAFETY ISSUES ONLY

CATS or TIGERS ?

CATS IN HOMES

THIS IS SAFE

TIGERS IN ZOOS

THIS IS SAFE, TOO

WANT TO HAVE TIGERS AT HOME ? SERIOUSLY ?

IS THIS SAFE ?

H2 REALLY IS THE TIGER OF FUELS

Le tigre a déjà mordu… Norvège 2019

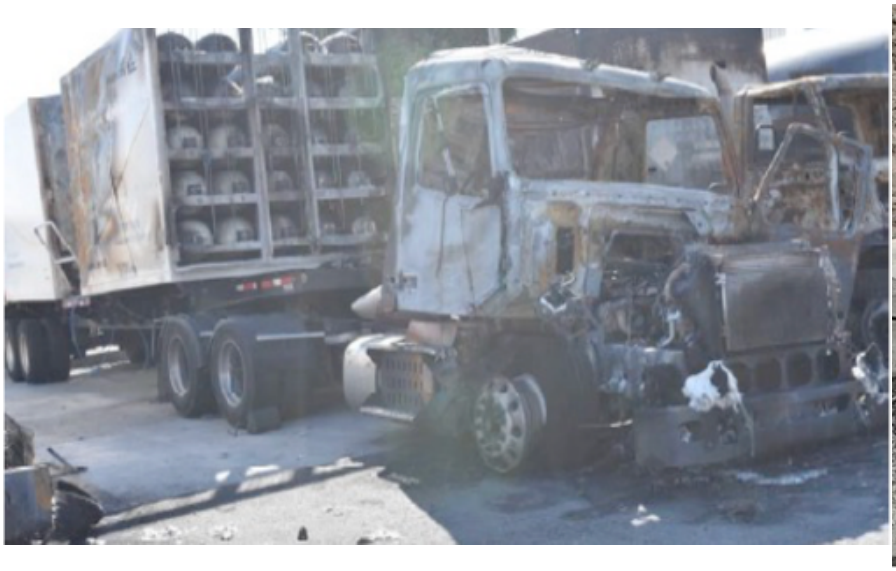
Explosion d'une station d'hydrogène en Norvège : premiers résultats de l'enquête

Bernard DEBOYSER / 20 Juin 2019 3:27 / 97

Hydrogène, Voiture hydrogène

FUITE DE H2 APRES PLUSIEURS MOIS DE SERVICE A CAUSE D'UN JOINT HAUTE PRESSION MONTE A UN COUPLE INADEQUAT

Le tigre a déjà mordu… Santa Clara 2019



FUITE DE H2 SUIVIE D'UN ALLUMAGE IMMEDIAT SUR UNE STATION DE REMPLISSAGE DE CAMION TRANSPORTANT DU H2

HYDROGEN AND SAFETY

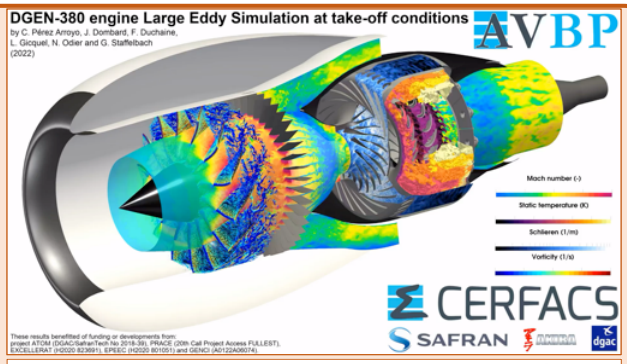
- Many fundamental mechanisms which control combustion safety for H2 are simply unknown
- How do we study combustion safety ? Experiments + simulations ?
  - ★Studying safety scenarios is dangerous and limited: you break the experiment every time you use it !
  - ★Diagnostics are difficult
  - ★Simulations using computers (CFD: Computational Fluid Dynamics) would be very useful
  - ★These codes exist: we take them from the Aerospace community where they have been validated very thoroughly

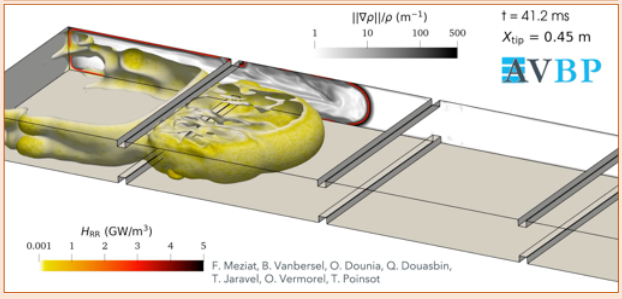
TRANSFERRING AEROSPACE COMBUSTION APPROACHES TO SAFETY:

COMBUSTION RESEARCH METHODS IN AEROSPACE

Simulation methods

- The high tech expertise of the aerospace field has allowed to develop highly advanced simulation methods.
- Combustion in an aircraft engine and in an explosion follow… the same equations and can be solved with the same tools.





SAFETY - NOT TOTALLY RIGHT IDEA 1:

- HYDROGEN IS LIGHT. IT WILL GO UP AND DISAPPEAR IN THE AIR IF THERE IS A LEAK. NO NEED TO WORRY ABOUT IT

- WELL, YES IN CERTAIN CASES

- H2 MIGHT ALSO ‘STAY’, TRAPPED IN MULTIPLE PLACES, WAITING FOR SOME IGNITION SOURCE

- NOT ALL PLACES ARE CONNECTED TO FREE AIR…

SAFETY - NOT TOTALLY RIGHT IDEA 2:

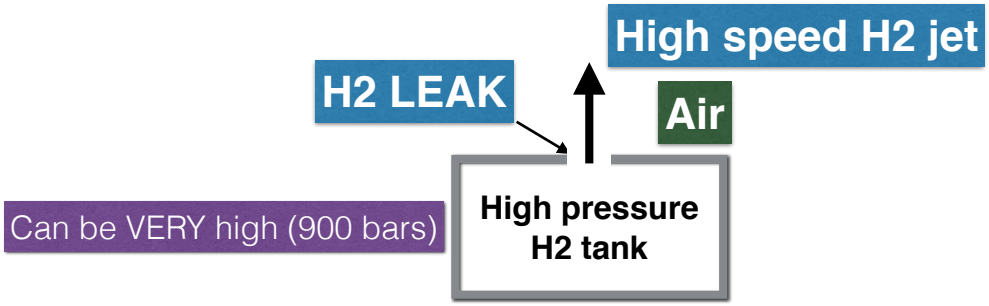
- HYDROGEN MAY LEAK … AND NOT IGNITE

- WELL, HYDROGEN IGNITES MUCH MORE EASILY THAN ALL OTHER FUELS

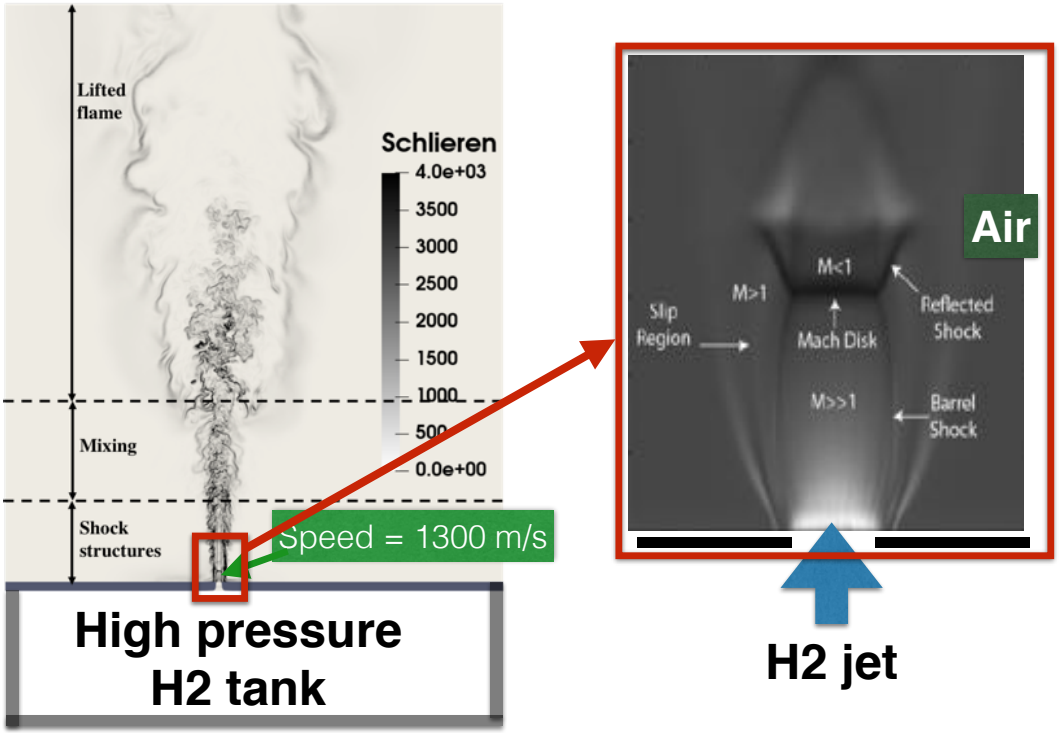
- SAFETY RULE IS TO AVOID ‘FAVORABLE’ GUESSES AND INVESTIGATE ‘WORST’ SCENARIOS: IN OTHER WORDS, WE HAVE TO ASSUME THAT IGNITION WILL TAKE PLACE AS SOON AS THERE IS A LEAK…

- WHICH IGNITION ?

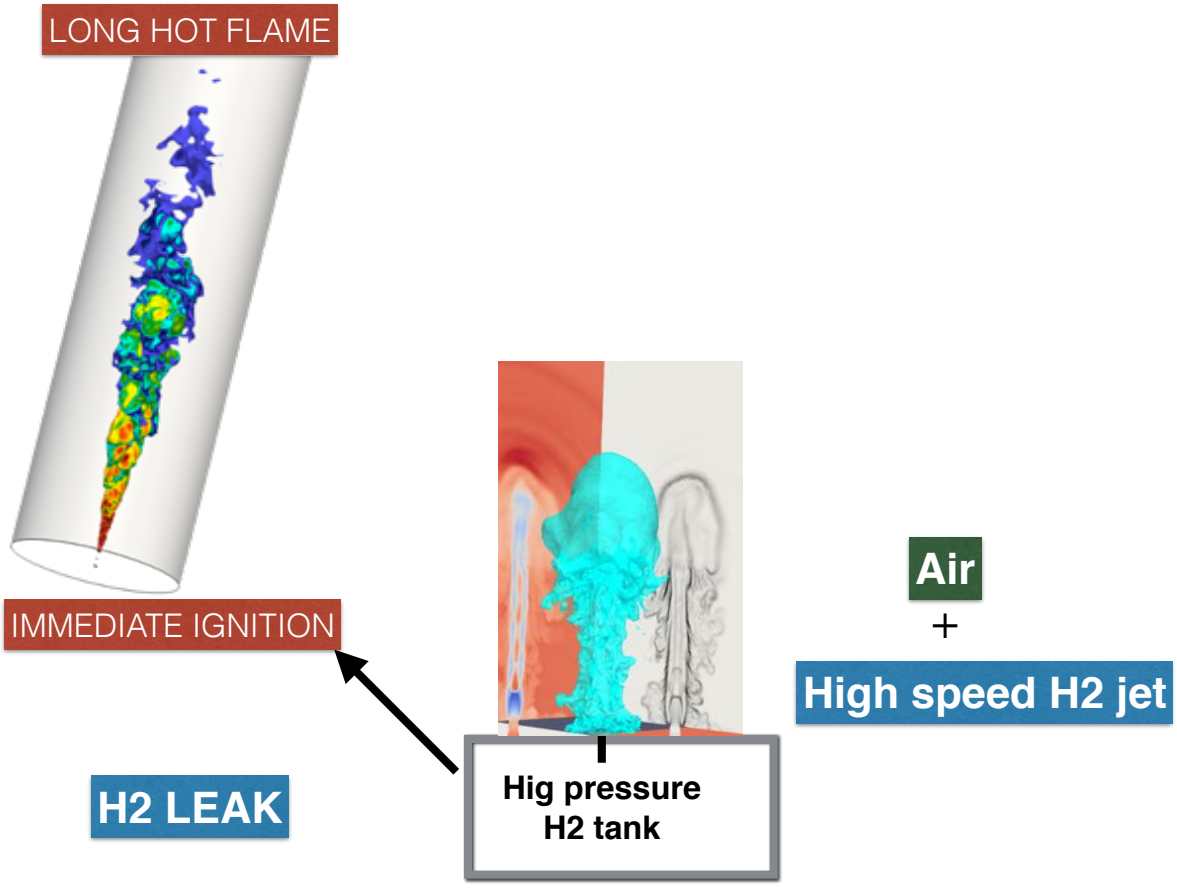
COMBUSTION SAFETY SCENARIOS



H2 TANKS PRESSURES WILL BE VERY LARGE:
- VERY BIG FLAMES
- UNDEREXPANDED JETS AND SHOCKS



COMBUSTION SAFETY SCENARIOS



Firefighters movie: comparing a 'normal' fire (beginning of video) to a H2 fire from a high pressure bottle (end of video):

In some cases we will create our own leak: this is ‘venting’. We may have to ‘vent’ H2 out through a tube if pressure is too high in a tank:

THEN TWO THINGS MAY HAPPEN:

NO IGNITION

IGNITION

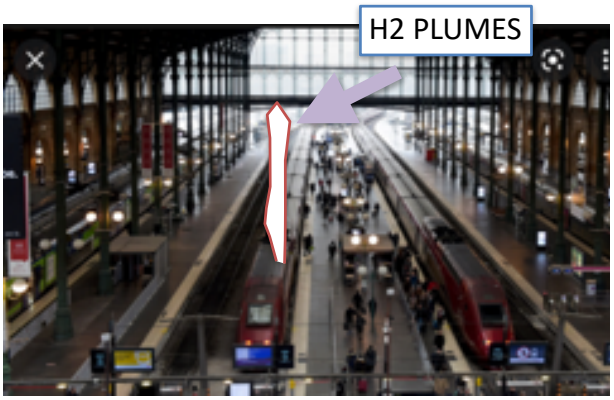
REMEMBER A CASE OF ANCHORED FLAME ON AN AIRCRAFT:

Designing an exhaust pipe for H2 which NEVER allows flame anchoring will require some work

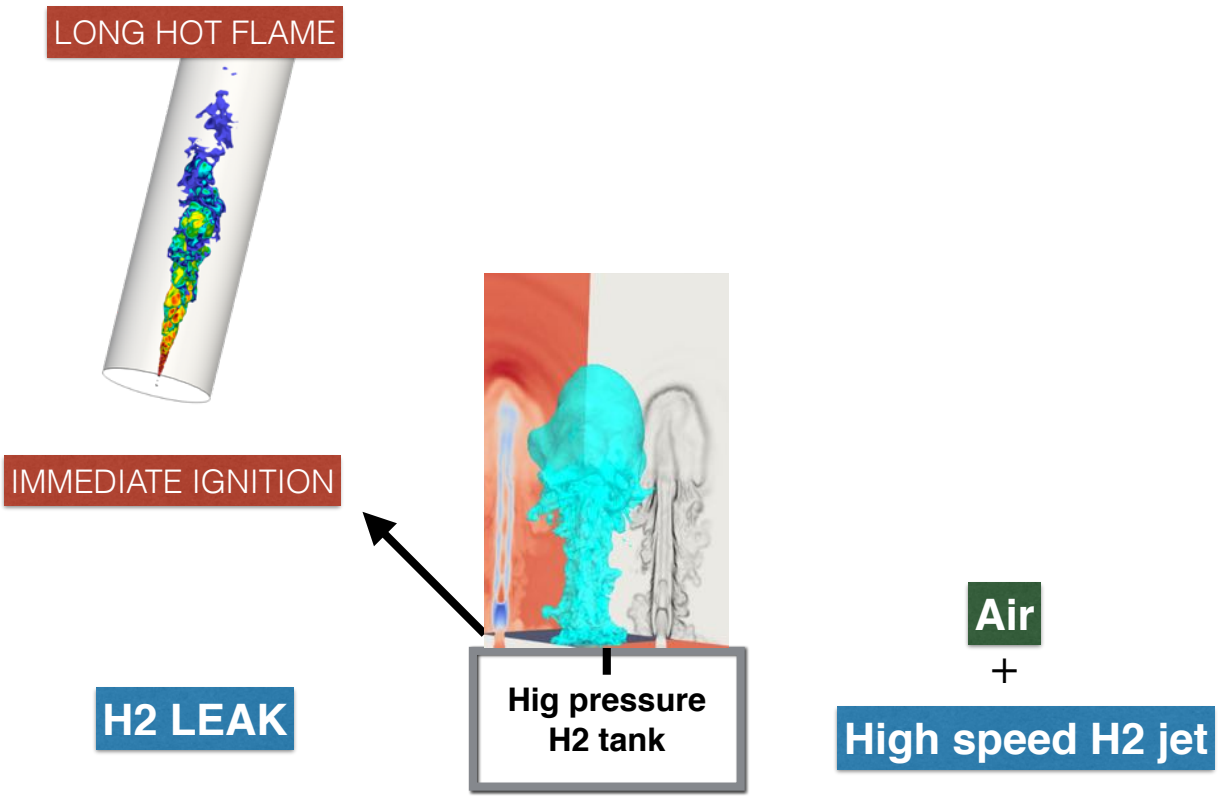
This is for a H2 jet produced at a place WE chose…
If we have a mechanical failure and the leak takes places anywhere in the engine for ex, similar problem… but more complicated to predict and control

What about airliners releasing H2 in an airport or trains in a station (or in a tunnel)?

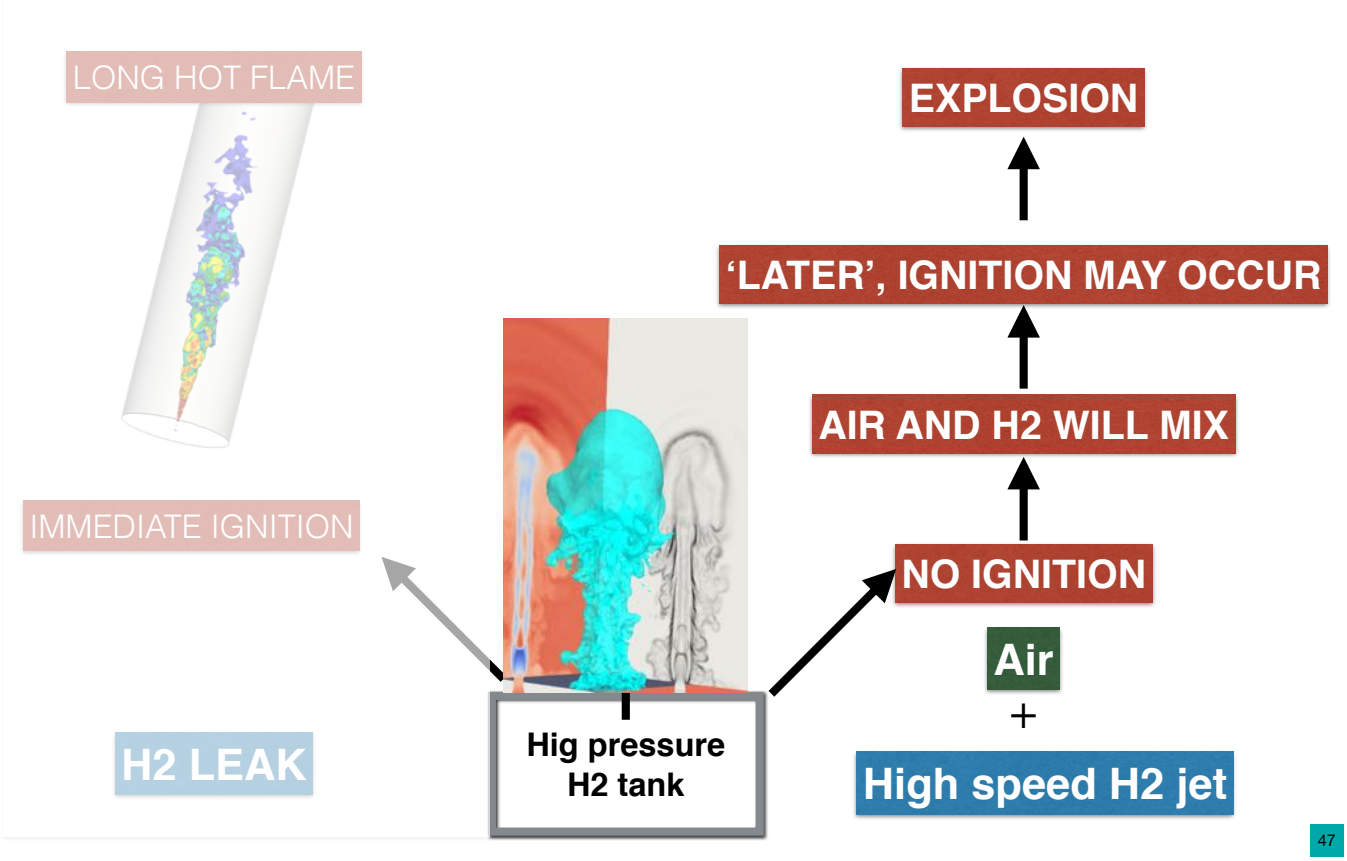
- **Mixing with air will depend on weather and ventilation.**
- **Ignition sources will become an issue**



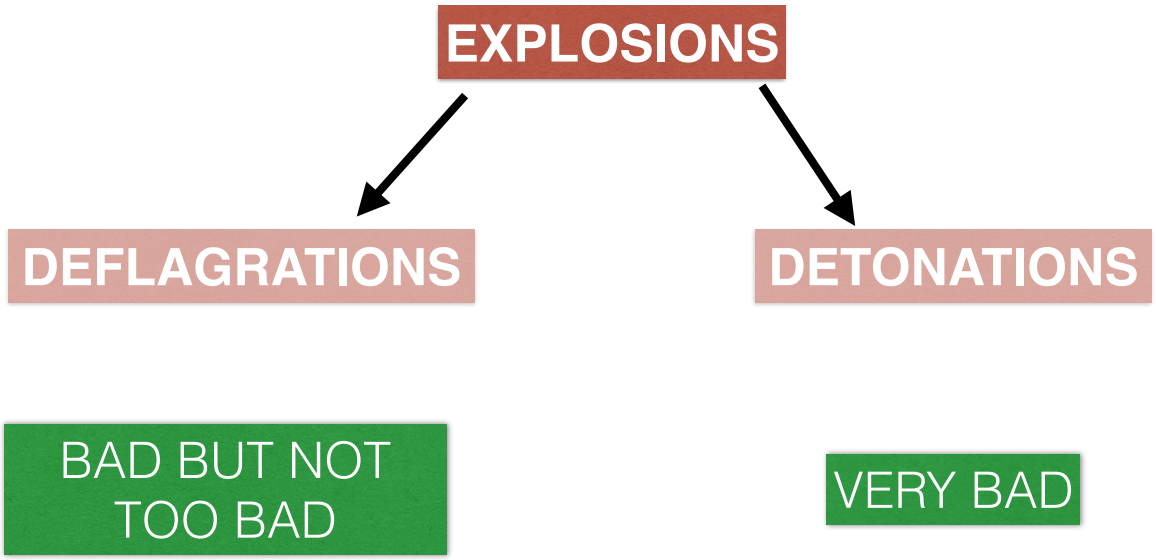
COMBUSTION SAFETY SCENARIOS



COMBUSTION SAFETY SCENARIOS

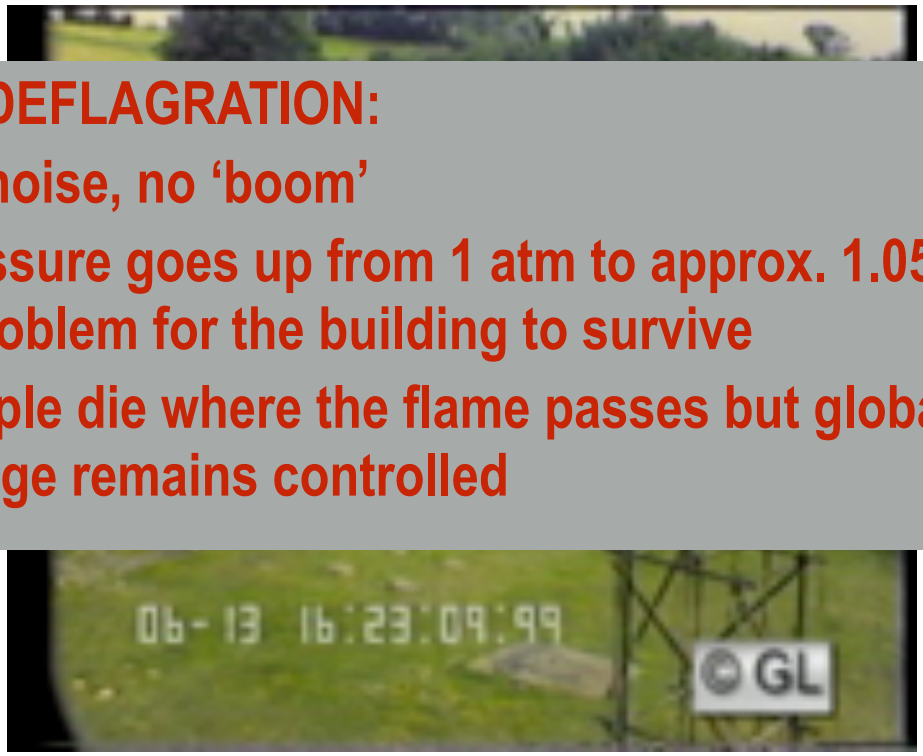


EXPLOSIONS COME INTO TWO FAMILIES:



HYDROGEN LEAKS AND EXPLODES:

DEFLAGRATION:

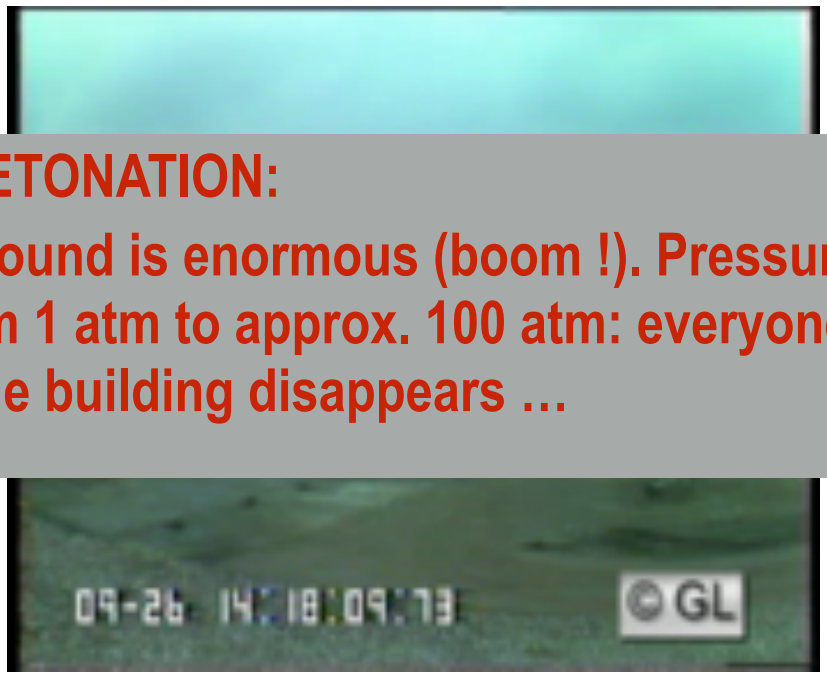


IN A DEFLAGRATION:

- No noise, no 'boom'
- Pressure goes up from 1 atm to approx. 1.05 atm: no problem for the building to survive
- People die where the flame passes but global damage remains controlled

HYDROGEN LEAKS AND EXPLOSIONS

★DETONATION

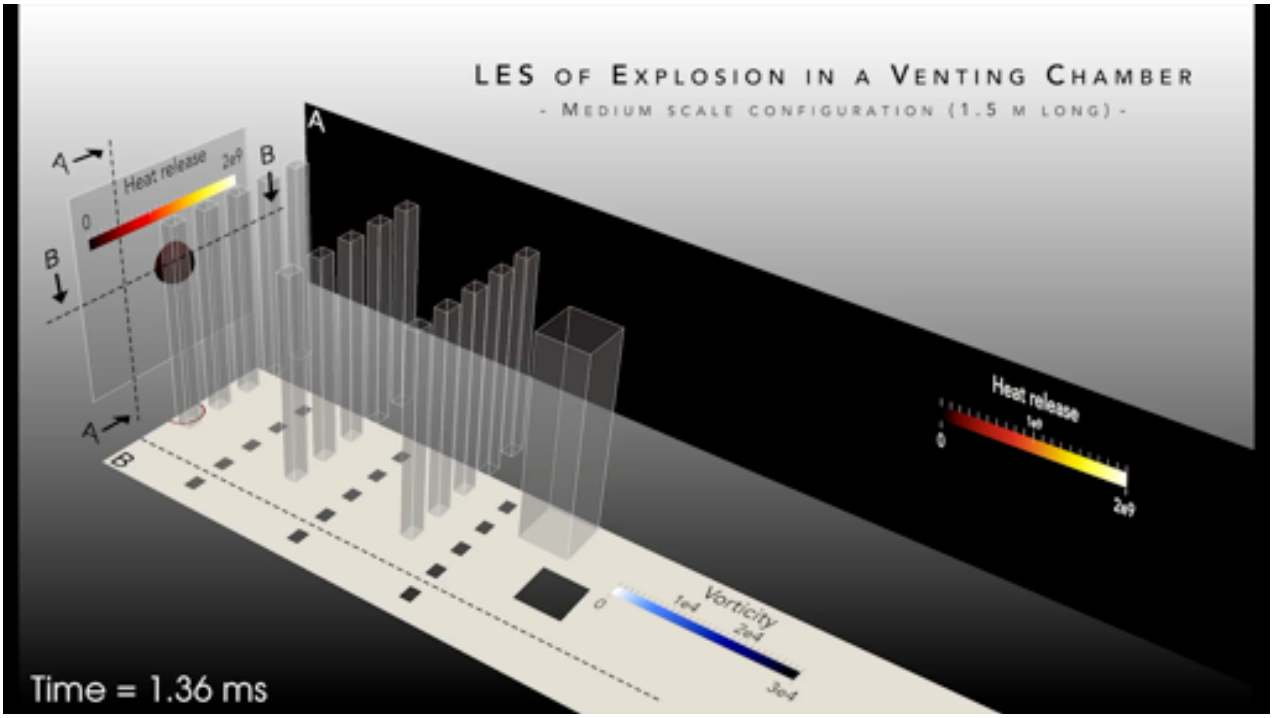


IN A DETONATION:

- The sound is enormous (boom !). Pressure goes up from 1 atm to approx. 100 atm: everyone dies AND the building disappears …

SIMULATIONS

- **WE CAN SIMULATE DEFLAGRATIONS AS WELL AS DETONATIONS. THIS IS EXPENSIVE BUT CHEAPER THAN BLOWING BUILDINGS OR ENGINES TO PIECES**

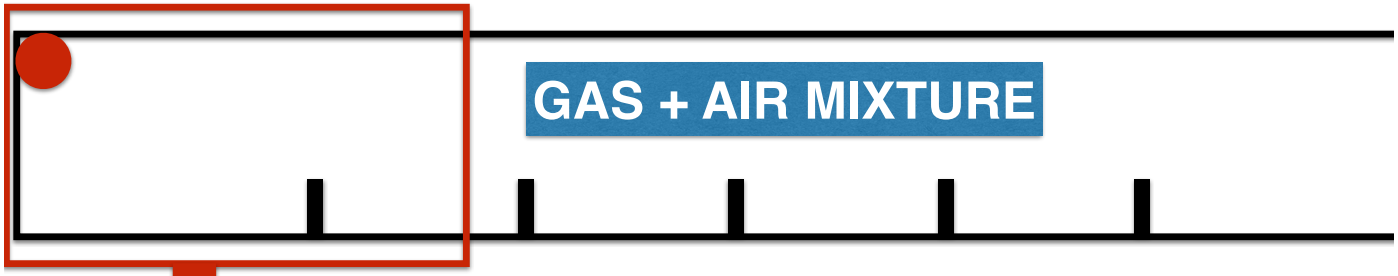


DEFLAGRATIONS CAN BECOME DETONATIONS (DDT): the famous movie of Elaine Oran

SPARK IGNITION

LONG TUBE WITH OBSTACLES

SPARK IGNITION



GAS + AIR MIXTURE

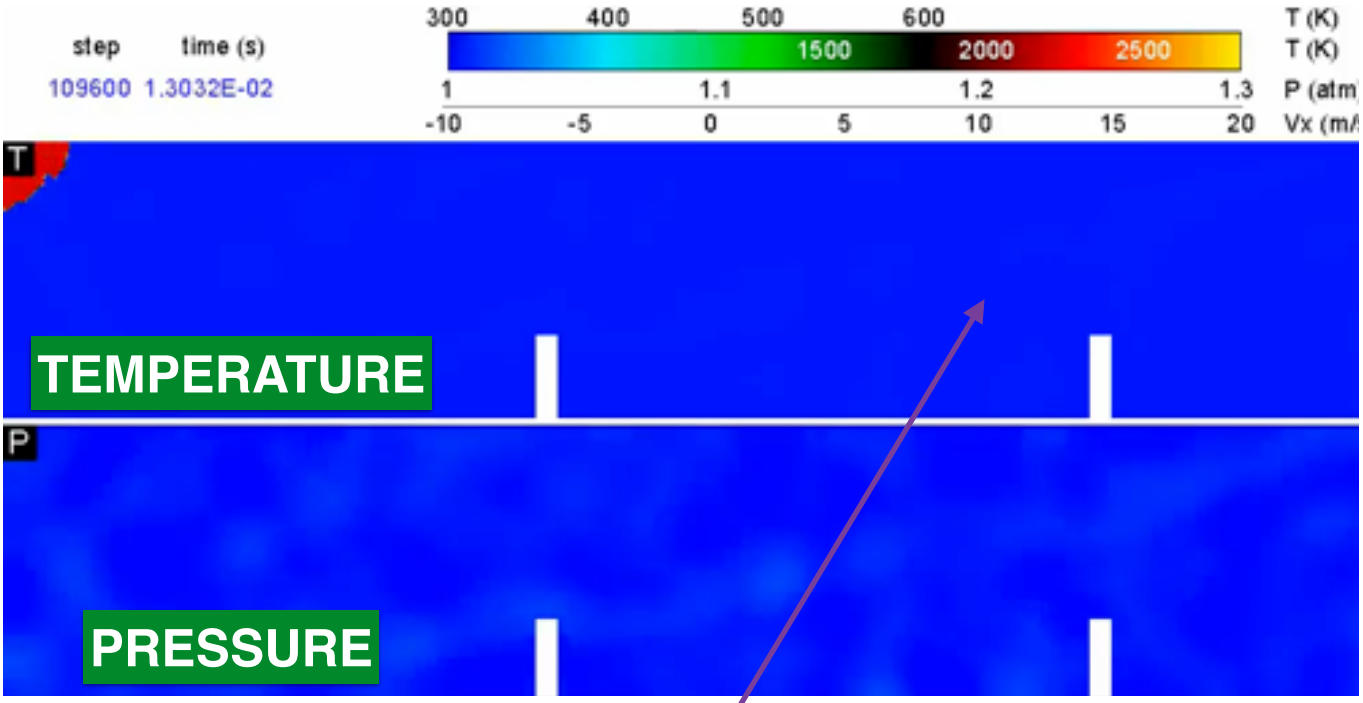
LONG TUBE WITH OBSTACLES

FLAME POSITION

PRESSURE

THE SPEED AT WHICH THE BOX MOVES IS THE FLAME SPEED

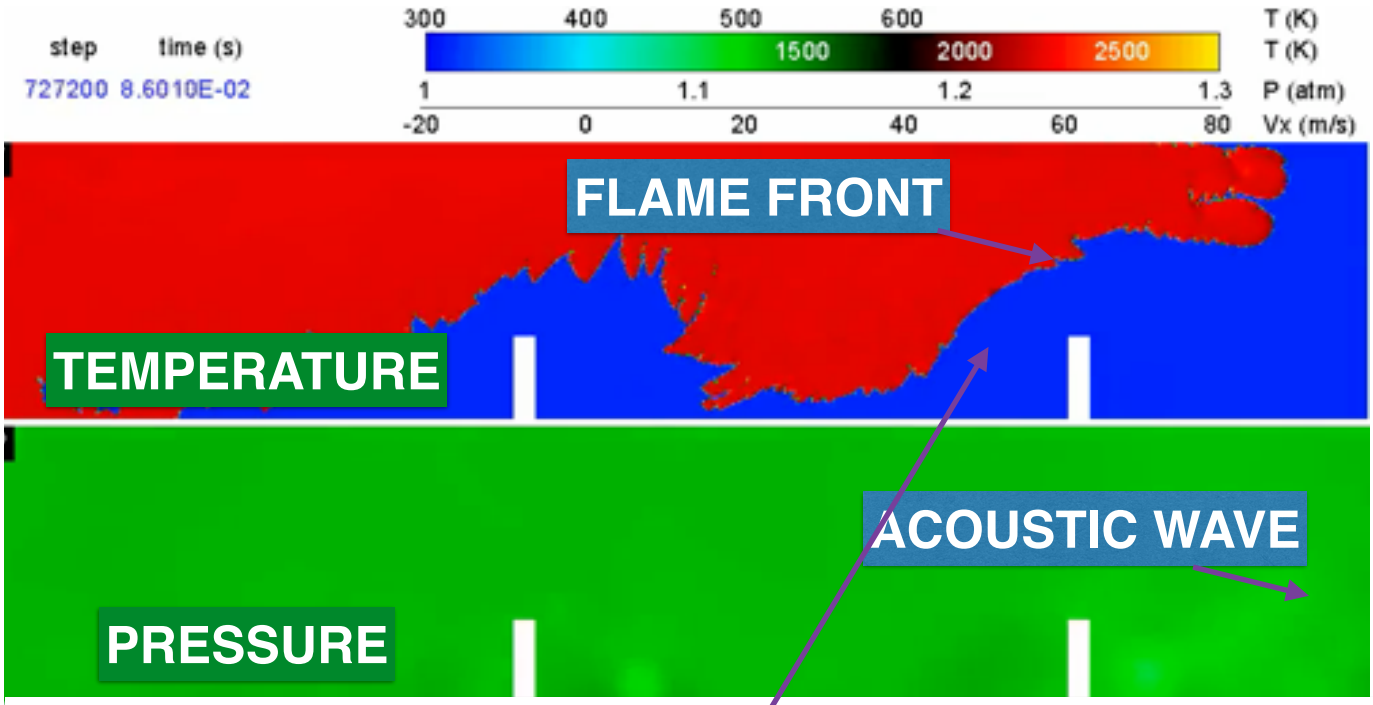
53



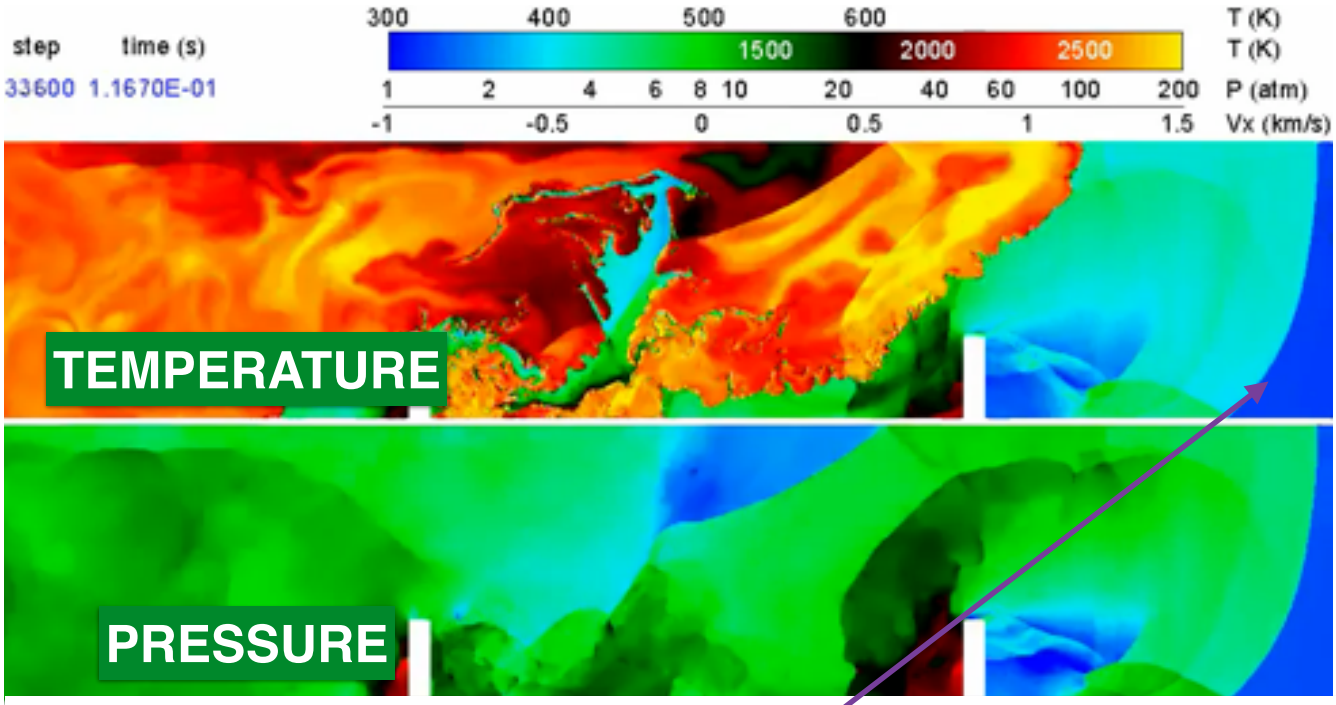
TEMPERATURE

PRESSURE

THIS IS A DEFLAGRATION MOVING AT 1 m/s



FLAME FRONT RUNS BEHIND ACOUSTIC WAVE AT SPEEDS OF THE ORDER OF 1000 m/s



THIS IS A DETONATION MOVING AT 2 km/s EVERYONE IS DEAD…

Typical SAFETY issue for an aircraft

- A FIRE DUE TO H2 LEAK MAY BE ACCEPTABLE IN AN AIRCRAFT IF IT STARTS AND ENDS AS A *DEFLAGRATION*

- IT IS DEFINITELY NOT ACCEPTABLE IF IT BECOMES A *DETONATION*

What do we really know ?

- FOR COMBUSTION SAFETY SCENARIOS INVOLVING H2 WE MISS A LOT OF BASIC FUNDAMENTAL KNOWLEDGE ON IGNITION, DETONATION, FLAME STRUCTURES...

- INDUSTRY WOULD LIKE IMMEDIATE ANSWERS AND THE FIRST QUESTION IS ALWAYS WHEN THEY COME TO US WITH THE IDEA OF GOING TO H2 :

« IS IT SAFE ? »

IS IT SAFE ? see « Marathon Man »!

In this 1976 movie, the bad guy wants to know if it is safe for him to go to the bank to recover his nazi money. He keeps asking:

« Marathon man » with D. Hoffman, R. Scheider 1976

- **WHEN A COMBUSTION EXPERT HEARS 'IS IT SAFE ?' FOR H2, HE FEELS LIKE THIS: WE OFTEN SIMPLY DONT KNOW (YET)…**

CONCLUSIONS

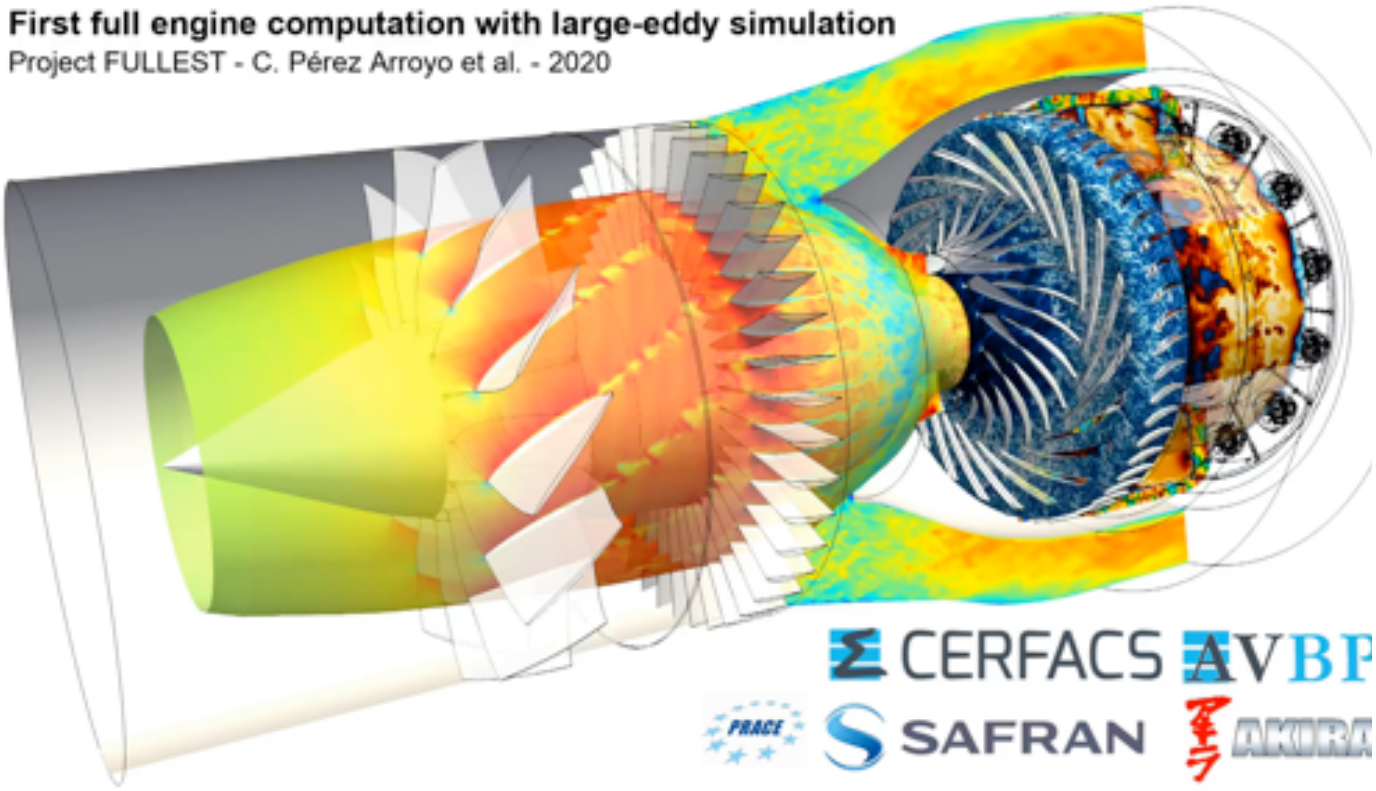
HYDROGEN WILL CERTAINLY BE AVAILABLE BECAUSE DECARBONATION IS ON ITS WAY IN MANY FIELDS

SO, HYDROGEN WILL ALSO BE AVAILABLE FOR AEROSPACE AND TRANSPORTATION APPLICATIONS

FOR AIRCRAFT, CHAMBERS WILL NEED TO BE MODIFIED BUT THE WHOLE AIRCRAFT TOO

SAFETY ISSUES WILL TAKE US INTO UNCHARTED TERRITORIES: FUNDAMENTAL RESEARCH IS NEEDED

THANKS


First full engine computation with large-eddy simulation
Project FULLEST - C. Pérez Arroyo et al. - 2020
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