# Technologies and Trends in $H_2$ Combustion Engines / Implications on the Test Facilities, Systems and Equipment

KAUST Research Conference: Hydrogen-Based Mobility and Power

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# Content

- Introduction to AVL
- Trends & expectations for $H_2$-ICE
- $H_2$-Implications on the Test Facilities, Systems and Equipment
- Summary

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AVL COMPANY PRESENTATION

# Facts and Figures

## Global Footprint

Represented in 26 countries

45 Affiliates divided over 93 locations

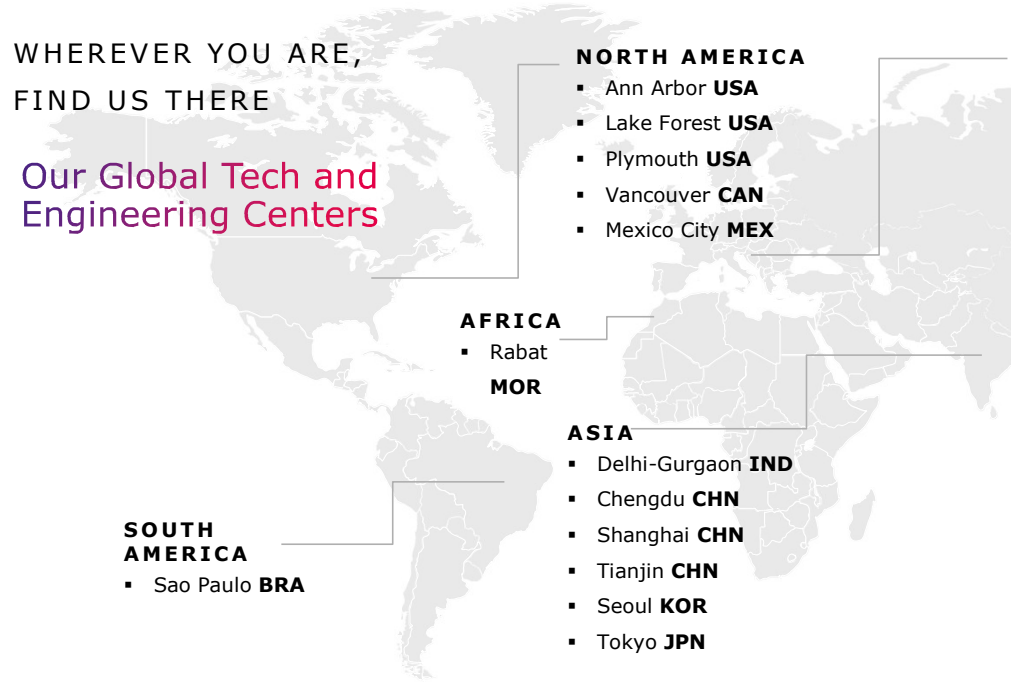
45 Global Tech and Engineering Centers (including Resident Offices)

| Founded | Employees Worldwide | Of Turnover Invested in R&D |
|---|---|---|
| 1948 | 11,000 | 12% |

| Years of Experience | Engineers and Scientists | Granted Patents in Force | Export Quota |
|---|---|---|---|
| 70+ | 65% | 1,500 | 97% |

WHEREVER YOU ARE, FIND US THERE

Our Global Tech and Engineering Centers



**NORTH AMERICA**
- Ann Arbor **USA**
- Lake Forest **USA**
- Plymouth **USA**
- Vancouver **CAN**
- Mexico City **MEX**

**AFRICA**
- Rabat **MOR**

**ASIA**
- Delhi-Gurgaon **IND**
- Chengdu **CHN**
- Shanghai **CHN**
- Tianjin **CHN**
- Seoul **KOR**
- Tokyo **JPN**

**SOUTH AMERICA**
- Sao Paulo **BRA**

**EUROPE**
- HQ Graz **AUT**
- Steyr **AUT**
- Vienna **AUT**
- Berlin **GER**
- Bietigheim-Bissingen **GER**
- Heilbronn **GER**
- Ingolstadt **GER**
- Munich **GER**
- Neuenstadt **GER**
- Regensburg **GER**
- Remscheid **GER**
- Roding **GER**
- Stuttgart **GER**
- Wolfsburg **GER**
- Paris **FRA**
- Valladolid **ESP**
- Reggio Emilia **ITA**
- Torino **ITA**
- Erd **HUN**
- Kecskemét **HUN**
- Zalaegerszeg **HUN**
- Basildon **UK**
- Coventry **UK**
- Gothenburg **SWE**
- Haninge **SWE**
- Södertälje **SWE**
- Trollhättan **SWE**
- Maribor **SLO**
- Istanbul **TUR**
- Moscow **RUS**
- Warsaw **POL**
- Zagreb **CRO**

# Three Disciplines Under One Roof

## ENGINEERING SERVICES

- Design and development services for all elements of ICE, HEV, BEV and FCEV powertrain systems
- System integration into vehicle, stationary or marine applications
- Supporting future technologies in areas such as ADAS and Autonomous Driving
- Technical and engineering centers around the globe

## INSTRUMENTATION AND TEST SYSTEMS

- Advanced and accurate simulation and testing solutions for every aspect of the powertrain development process
- Seamless integration of the latest simulation, automation and testing technologies
- Pushing key tasks to the start of development

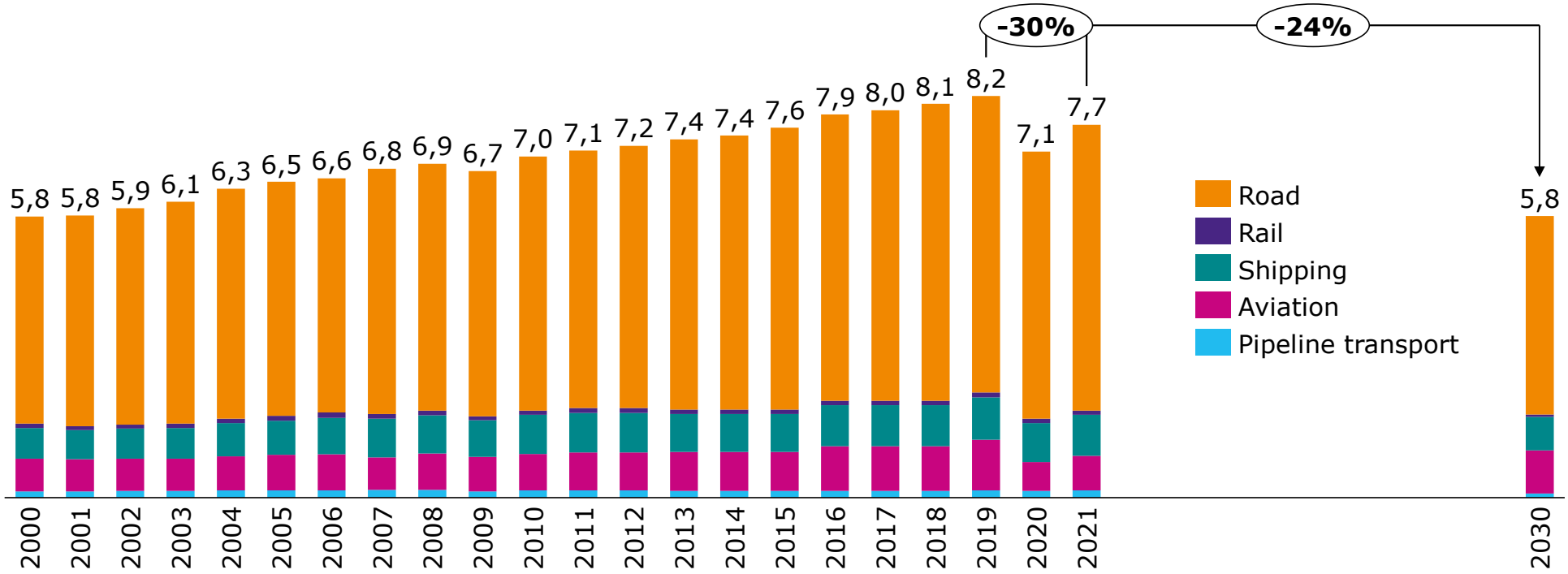
## ADVANCED SIMULATION TECHNOLOGIES

- We are a proven partner in delivering efficiency gains with the help of virtualization
- Simulation solutions for all phases of the powertrain and vehicle development process
- High-definition insights into the behavior and interactions of components, systems and entire vehicles

# Content

# We need to reduce transport-related CO2 emissions by 24 to 30% within this decade to meet net-zero milestone …

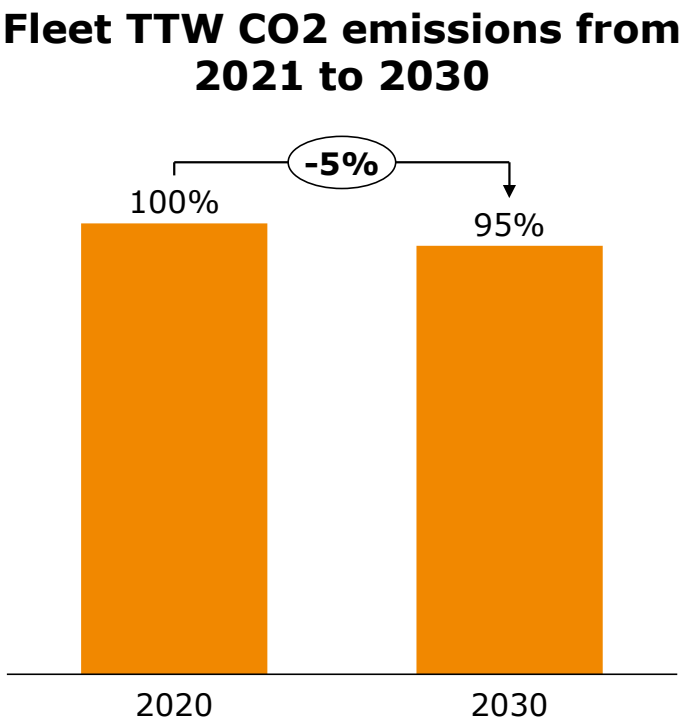
**Transport CO2 emissions globally in giga-tons CO2**




Source: Global CO2 emissions from transport by sub-sector in the Net Zero Scenario, 2000-2030 – Charts – Data & Statistics - IEA

# Where are we now?

**Example for the US light-duty fleet and current forecasts based on IHS**




Source: AVL

Boundaries:

1. Fleet size increase considered
2. Increasing electrification considered
3. Fuel economy improvements considered
4. Shift in vehicle archetypes considered

**What do results tell us?**

1. Even though we are planning w/ strong increasingly sales of BEVs, the impact on fleet CO2 emissions is delayed
2. If we continue like this, we fall short of meeting NZE milestone 2030
3. We need to think about drop-in fuels and increase the introduction of low-carbon technologies w/ a short-time-to-market

# Major choices from a powertrain perspective for decarbonization

**We need to play on all fields …**

| Fuel Cell | BEV | H2 ICE | E-fuels (e.g. FT diesel) |
|---|---|---|---|
| ▪ For on-road applications high TRL<br>▪ High CAPEX & OPEX<br>▪ Uncertain: Robustness, cooling challenge for rather stationary applications, refilling-network<br>▪ Good green image and encouraged by authorities | ▪ Available technology and ready for use w/ highest efficiency<br>▪ Main challenge for topics like payload, milage range and re-charging time<br>▪ Infrastructure for charging stations needs to be developed.<br>▪ Highest or at least same green image as fuel cell | ▪ Today's technology needs to be adopted with only minor effort and manageable investment<br>▪ Still lowest technology readiness level for commercial truck applications<br>▪ Social acceptance uncertain, missing policy support | ▪ Main advantage of using available infrastructure and technology w/ little additional invest<br>▪ Highest effort in view of fuel production costs and energy input (efficiency chain).<br>▪ The social acceptance currently on a low level (In-use emissions) |

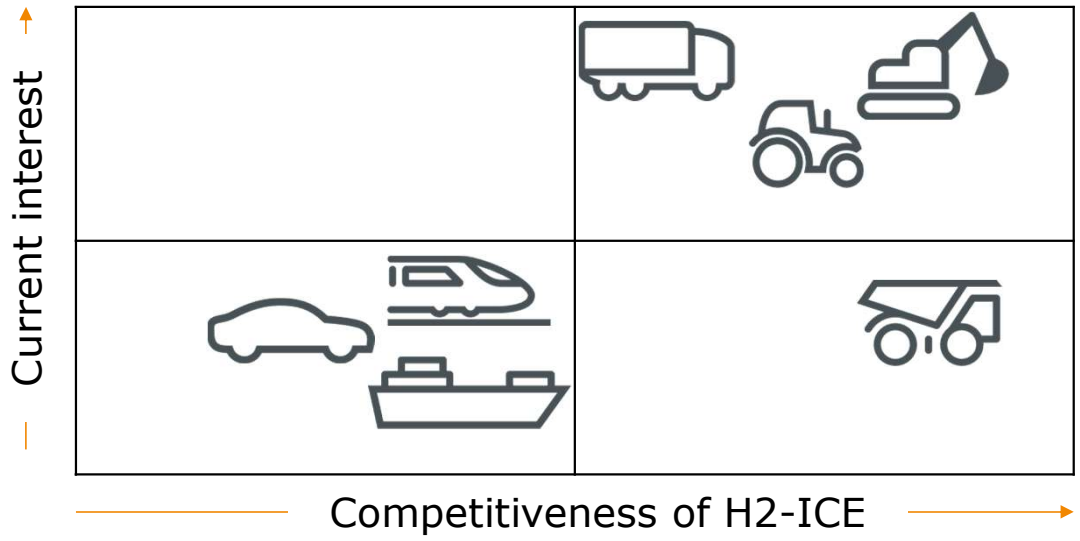
# Where will H2-ICE have best chances for quick commercialization considering competition?

**Starting w/ characteristics, their relevance and expected major applications**

## H2-ICE characteristics

1. ICE is a robust system (Dust, shocks & vibrations, temperatures, experience)
2. Efficient in high power/load areas
3. Quick time-to-market (supply chain, production in place)
4. Competitive CAPEX
5. Engine noise less relevant (High vehicle speed, mining, outside urban areas …)

## AVL's view on H2-ICE's major applications



# What does it take to unleash the full potential of H2-ICE?

**… besides H2-ICE engine technology**

| Technology agnostic boundaries | Storage @ vehicle innovations |
|---|---|
| We need boundaries where H2-ICE as (near) zero-emission solutions also enjoys benefits like toll exemption. We need legislations differentiating between ICE w/ fossil fuels and alternative fuels (e.g. city-bans) | We need innovative H2 storage solutions at the vehicles: Required re-filling frequency compared to diesel is a strong disadvantage |
| **H2 refilling-network** | **Green hydrogen** |
| We need to ramp-up H2 refilling station network on-road AND realize practical small-scale solutions for farms and construction sites. | We need to approach H2-ICE from a "system perspective" – how can the supply-chain for green H2 look like, e.g. Anglo American & First Mode |

# Conclusions

1. The H2-ICE is not the only measure to de-carbonize, but its' characteristics might make it a great solution for specific applications
2. The engine technology is here, we need to think about the additional parts of the systems to make it work
3. It is too early to classify H2-ICE as a "bridging technology", it might well be that we see longer product cycles
4. We need to demonstrate the positive impact and to market success to gain back-up for our work

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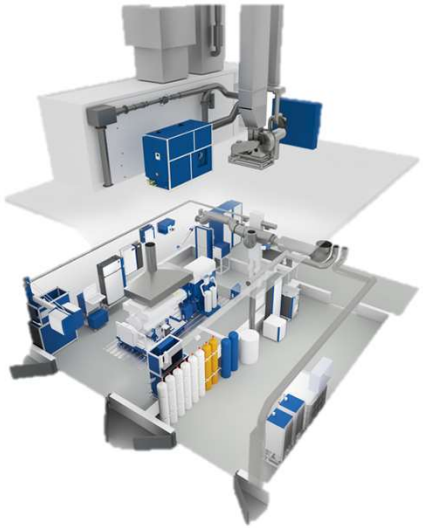
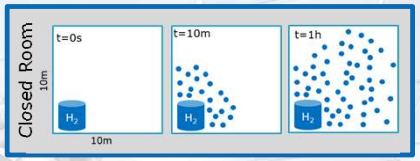
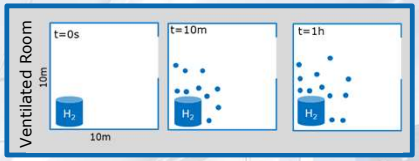
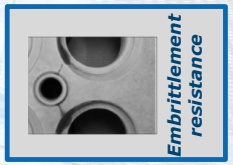
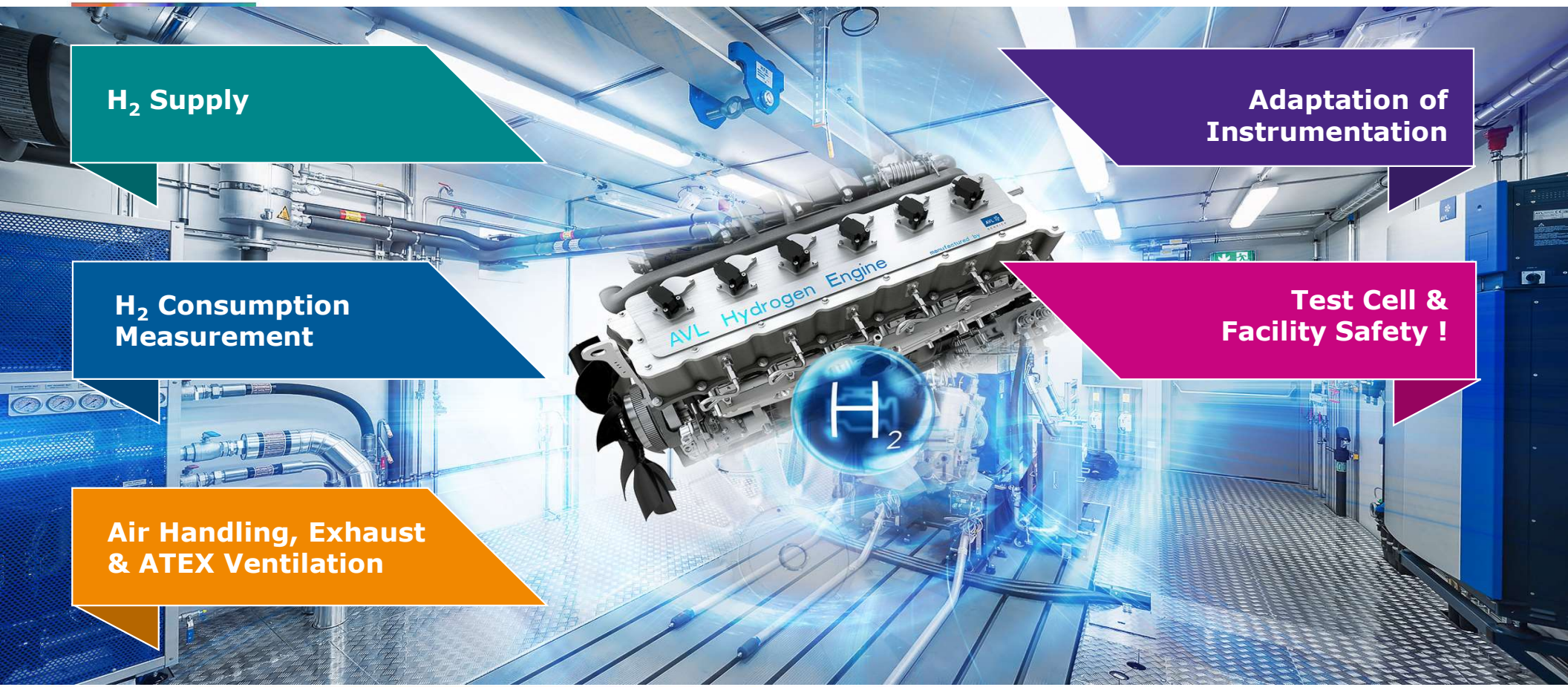


# Hydrogen - Properties and Impacts on the Test Cell

| | Properties | Impacts |
|---|---|---|
| **Diffusion** | • High diffusion<br>• Risk of $H_2$ accumulation in enclosures |   |
| **Buoyancy** | • $H_2$ much lighter than air<br>• $H_2$ rises up quickly |  |
| **Explosion** | • Highly combustible<br>• $H_2$ alone cannot explode<br>• Needs oxidizer (air) and ignition source<br>• Keep $H_2$ concentration under LEL (< 4%) |   |
| **Others** | • $H_2$ is colorless, odorless, tasteless<br>• Embrittlement |    |

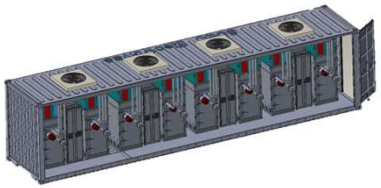
# $H_2$ ICE Testing – Points to consider



# Requirements and Solutions

## $H_2$ Supply

Option:
$H_2$ Generation at site



$H_2$ Storage
& Distribution

✓ Evaluate hydrogen consumption

| engine | |
|---|---|
| [kW] | [kg/h] |
| 50 | 3,29 |
| 100 | 6,57 |
| 150 | 9,86 |
| 200 | 13,14 |
| 250 | 16,43 |
| 300 | 19,71 |
| 350 | 23,00 |
| 400 | 26,29 |
| 450 | 29,57 |
| 500 | 32,86 |

✓ Evaluate the suitable hydrogen storage and supply infrastructure

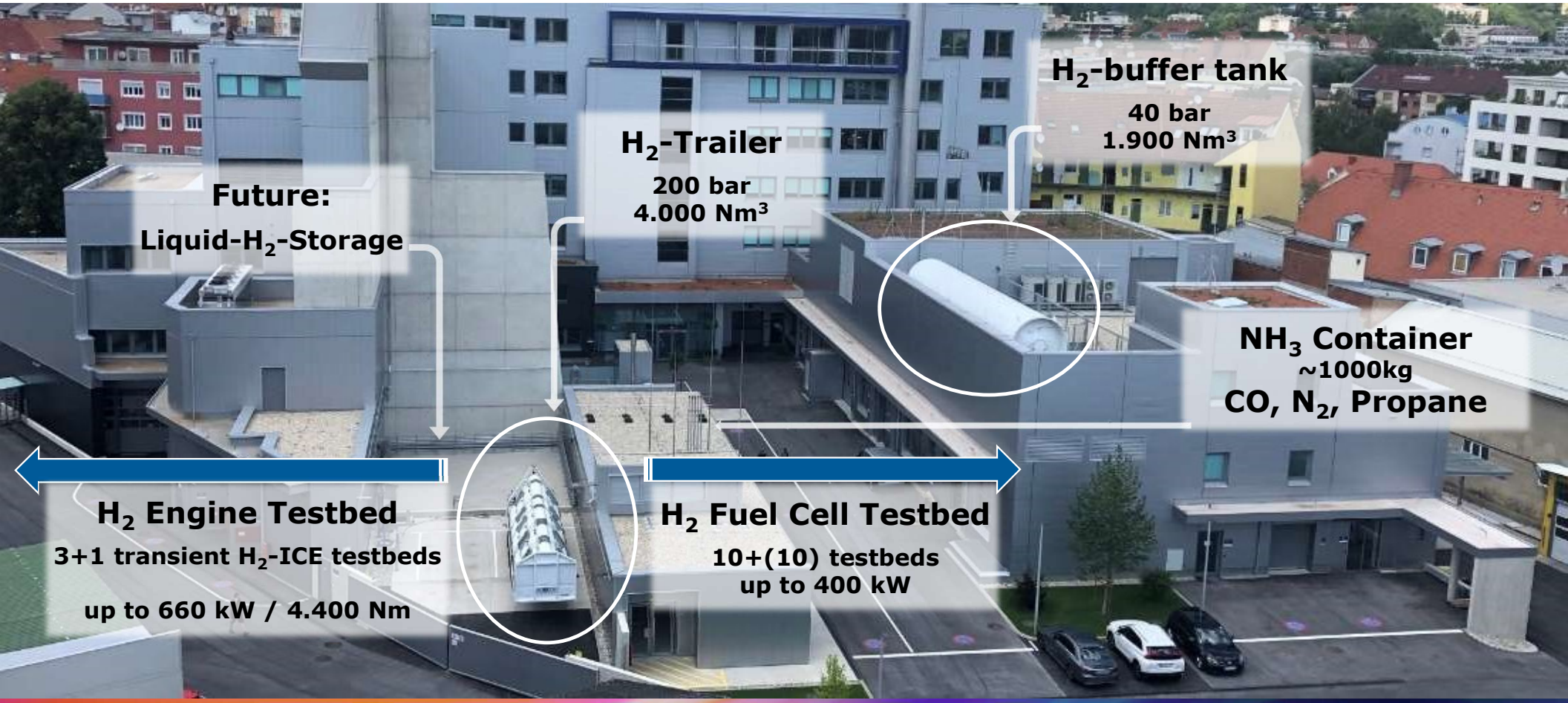
| Unit | Mass [Kg] | Application | Investment |
|---|---|---|---|
| Bottle  | 0.75 | (sub-scale) single cylinder and cell investigations | -H2 Distribution<br>-H2 Storage and control renting<br>-H2 refilling |
| Bundle  | 9 | single cylinder and short-stack investigations | |
| Trailer<br>**Supertrailer**  | 340<br>**1000** | full-size engine and FC systems (small number of stations) | |
| Liquid tank  | 3000 | full-size engines and FC systems (large number of stations) | |
| Electrolyzer<br>+ BufferTank  | 25kg/h<br>~500kg/d | SOEC Technology<br>High efficiency 1MW green power | -H2 Distribution<br>-Electrolyzer<br>-Maintenance |

| Units/week * 150kW load | Units/week * 300kW load |
|---|---|
| - | - |
| 113.5 | 227 |
| 3<br>~1 | 6<br>~2 |
| 0.3 | 0.6 |
| Continuous H2 supply | Continuous H2 supply |

* 80 h/week

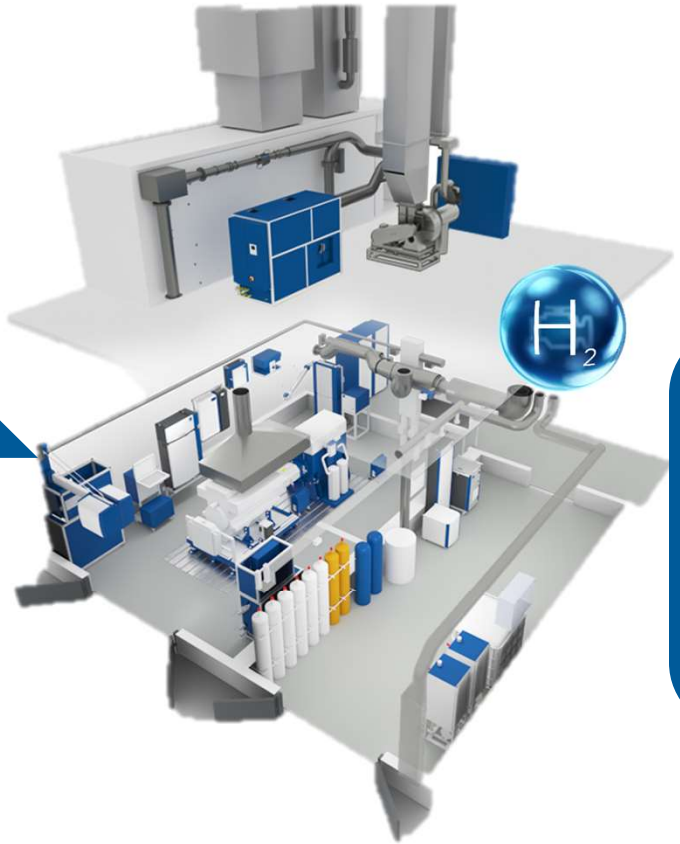
# Fuel Supply Infrastructure @ AVL Graz Test Factory

$H_2$ Supply



# $H_2$ ICE Testing

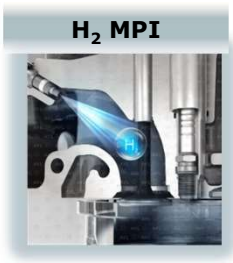
**$H_2$ Consumption Measurement**



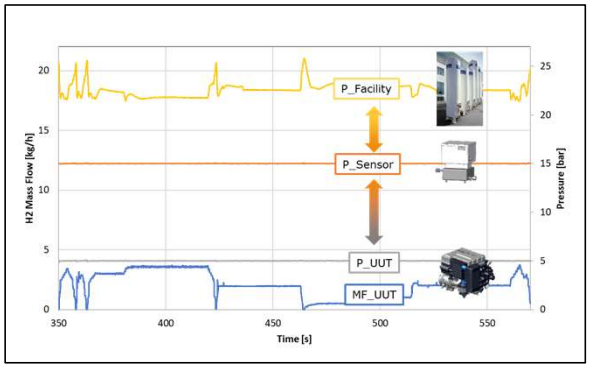

# $H_2$ Consumption Measurement Requirements and Solution

- ✓ Fitting to **Combustion / Injection Concepts** providing **stable $H_2$ supply pressure** to ICE
- ✓ High measurement **Accuracy and Repeatability** (no influence by the injection-related pulsations )
- ✓ Ensuring test cell and operator **Safety** (Leak Check Routines, Purging / Inertization, ..)


| | LP | HP | HP+ |
|---|---|---|---|
| Max. $H_2$ from facility | 25bar | 60bar | 400bar *on request* |
| $H_2$ to ICE | 0..20bar | 5..55bar | x..350bar |





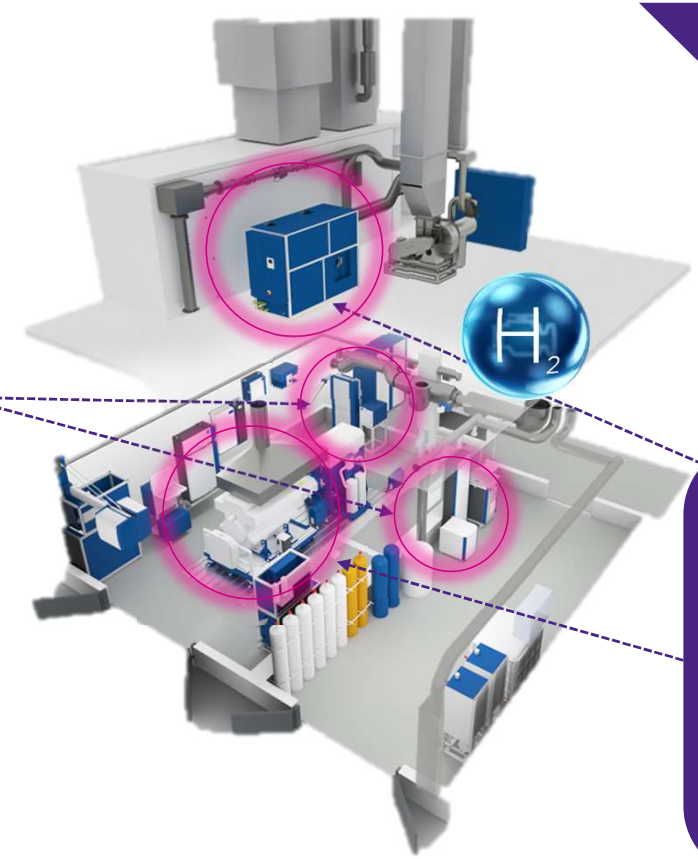
# $H_2$ ICE Testing

**Exhaust Emission Measurement**

**to adapt / add!**

Gaseous Emissions Equipment

Particle Measuring System




**Adaptation of Instrumentation**

**Combustion Air**

**to check!**

Boost Air Conditioning

Air Conditioning

Air Flow Measurement

# Exhaust Emission Measurement – $H_2$ ICE Requirements and Solutions

Emissions Bench
(AVL AMA SL)

FTIR
(AVL SESAM)

MSS (H2 Meas.)
(AVL H2D)

PF-Particulate
Sampling System
(AVL SPC 478)

Particulate Counting
(AVL APC xApp)

Transient Soot
Measurement
(AVL Mircosoot Sensor)

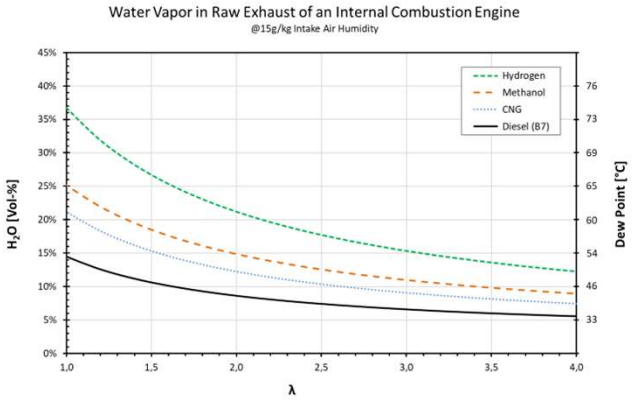
Filter Soot
Measurement
(AVL Smoke Meter)

Opacimeter
(AVL Opacimeter)

AVL Emissions & Particulate Measurement Product Portfolio

**Adaptation of Instrumentation**

✓ **Manage higher water content** in exhaust gas (gas chiller, cross sensitivity, higher dilution, … FTIR evaluation software adaptation )



# Exhaust Emission Measurement – $H_2$ ICE Requirements and Solutions

Emissions Bench
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FTIR
(AVL SESAM)

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Measurement
(AVL Smoke Meter)

Opacimeter
(AVL Opacimeter)

AVL Emissions & Particulate Measurement Product Portfolio

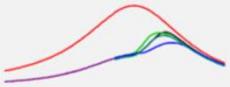
**Adaptation of Instrumentation**

- ✓ **Explosion Risk Assessment**
  ( safety assessment of measuring devices )
- ✓ **Integration** in test cell´s **overall safety concept**
  ( direct / indirect misfire detection, preventing explosive atmosphere in test cell )
- ✓ **$H_2$ Analyzer** for slip measurement

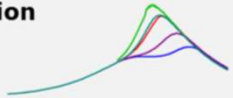
# $H_2$ ICE Testing
# Requirements and Solutions

## Combustion Analysis

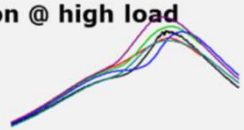
**Early Pre-Ignition / Backfire**



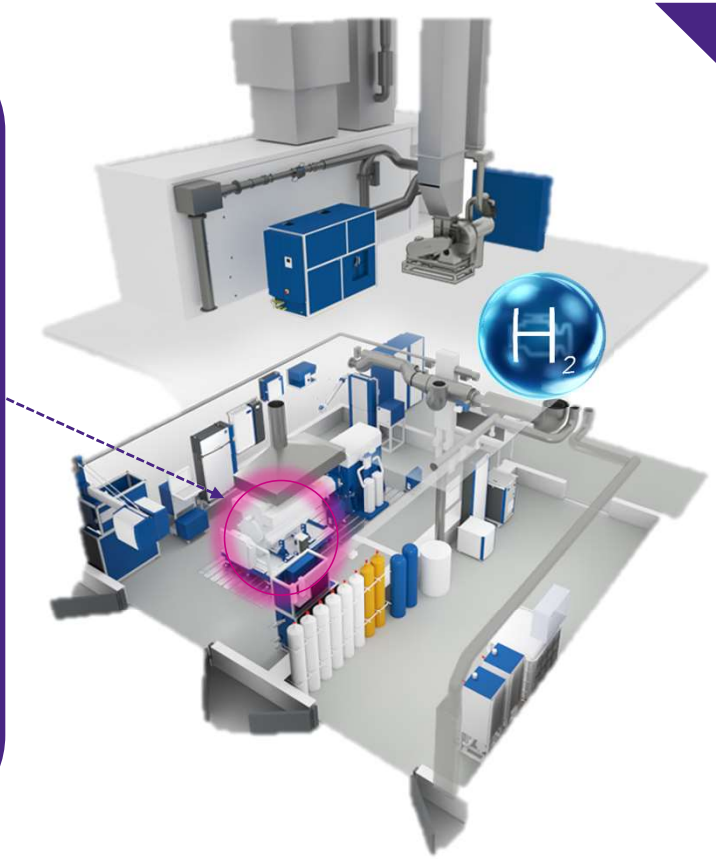
**Late Pre-Ignition**



**Cycle Variation @ high load (DI)**



Commercial $H_2$ ICE




## Adaptation of Instrumentation

Available

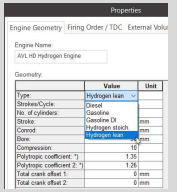
**AVL X-ion™**

**AVL Pressure sensor & charge amplifier**

Available

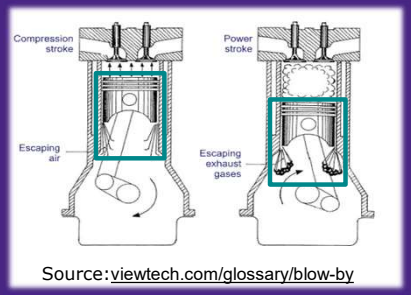
AVL IndiCom™

**$H_2$ combustion - heat release calculations**

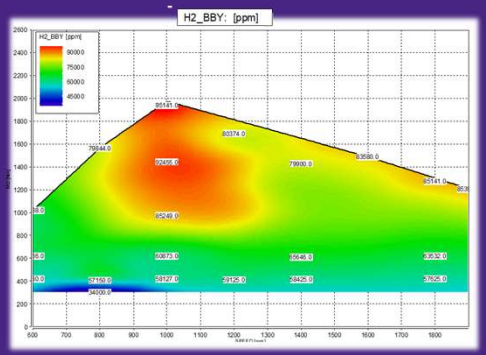


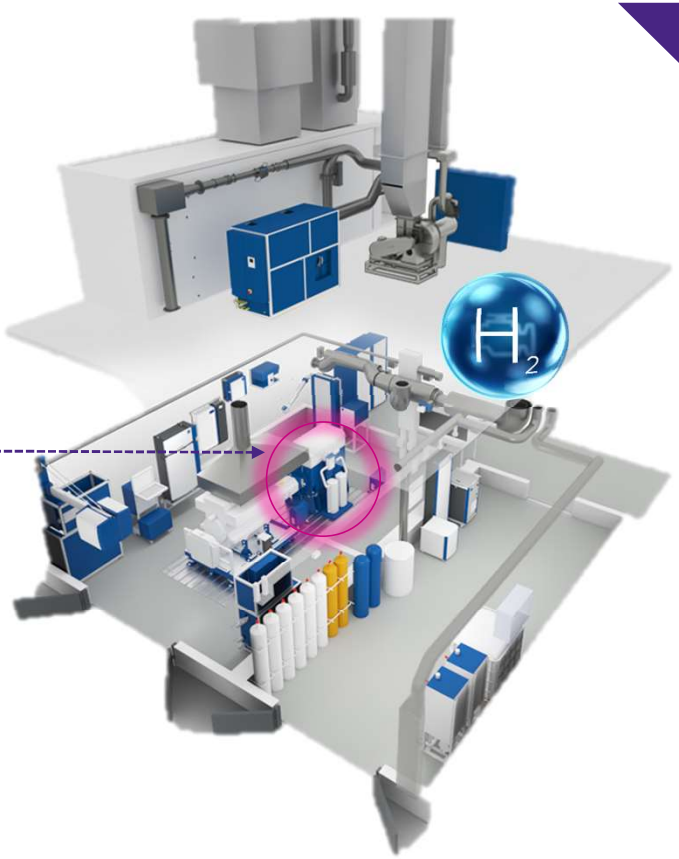
# $H_2$ ICE Testing Requirements and Solutions

## Blow-By (BBY) Measurement




Source: viewtech.com/glossary/blow-by




## Adaptation of Instrumentation

**$H_2$ concentration in BBY /** crankcase gas **above LEL of $H_2$**

**Explosion Protection measures** required:

- ✓ **Active crankcase gas (BBY) dilution or**
- ✓ **Pressure relieve valve**

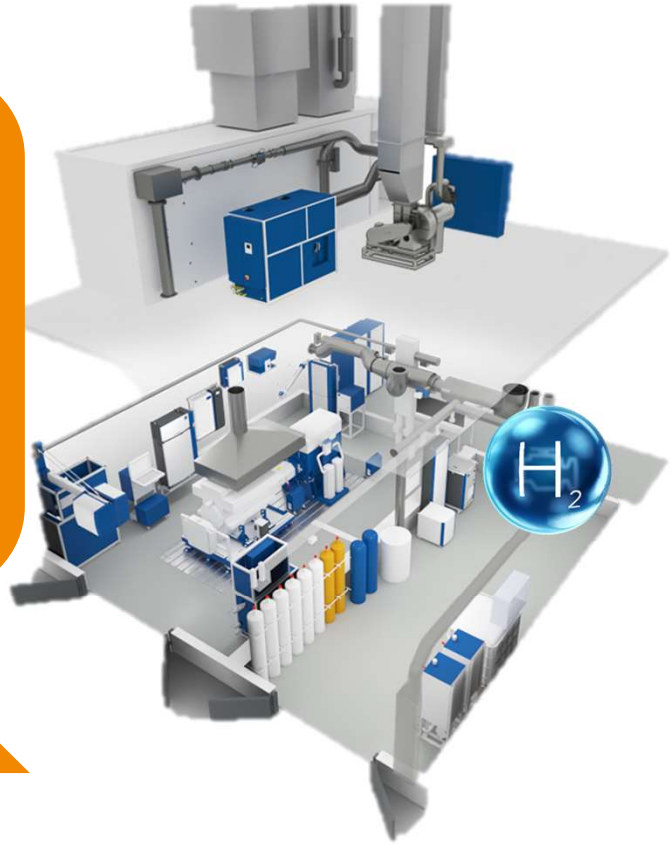
- ✓ **$H_2$ sensor in BBY** measurement line

- ✓ **Ex-proof Blow-By Measurement System**

# $H_2$ ICE Testing


**Explosion Protection**

**Air Handling, Exhaust & ATEX Ventilation**




Test Cell Automation

Test cell PLC

**Test Cell Safety System**

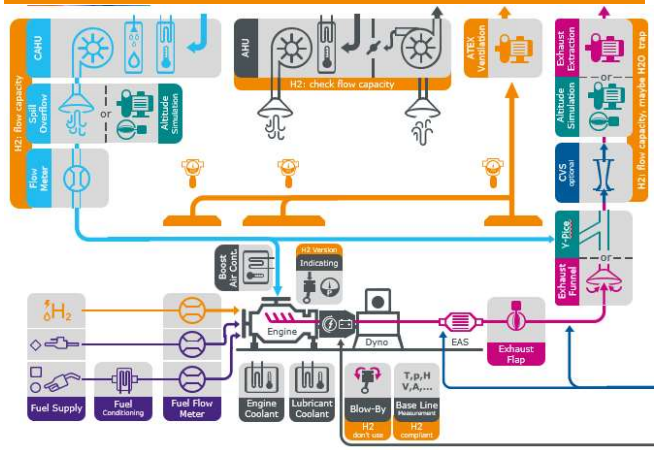
**Test Cell & Facility Safety !**

# Test Cell Air Handling / Ventilation & Safety Requirements and Solutions

## Air Handling, Exhaust / ATEX Ventilation



Adaptations Gas Fueled ICE Test Cells





## Test Cell & Facility Safety

- H2 Sensors
- H2 supply shut-off valves
- others

AVL Test Cell Safety System:

1. AVL PUMA 2
2. Test cell PLC
3. Extended Safety Matrix

Explosion Protection Concept / Document:

1. **Assessment of explosion risks**
2. **Determine safety parameters**
3. **Primary explosion protection**
4. **Secondary explosion protection**
5. **Constructive explosion protection**
6. Information and instruction
7. Inspection
8. Review of protective measures
9. Explosion Protection Document

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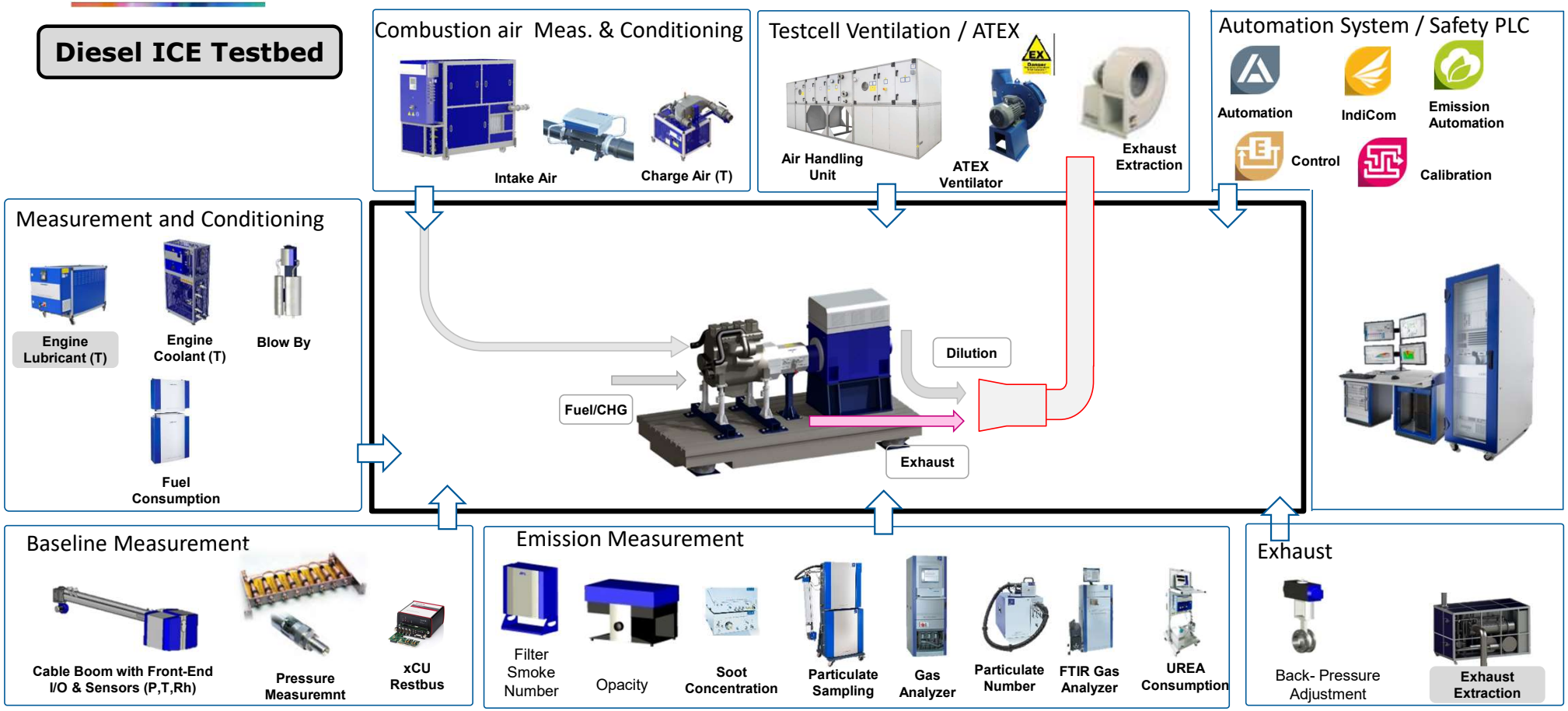
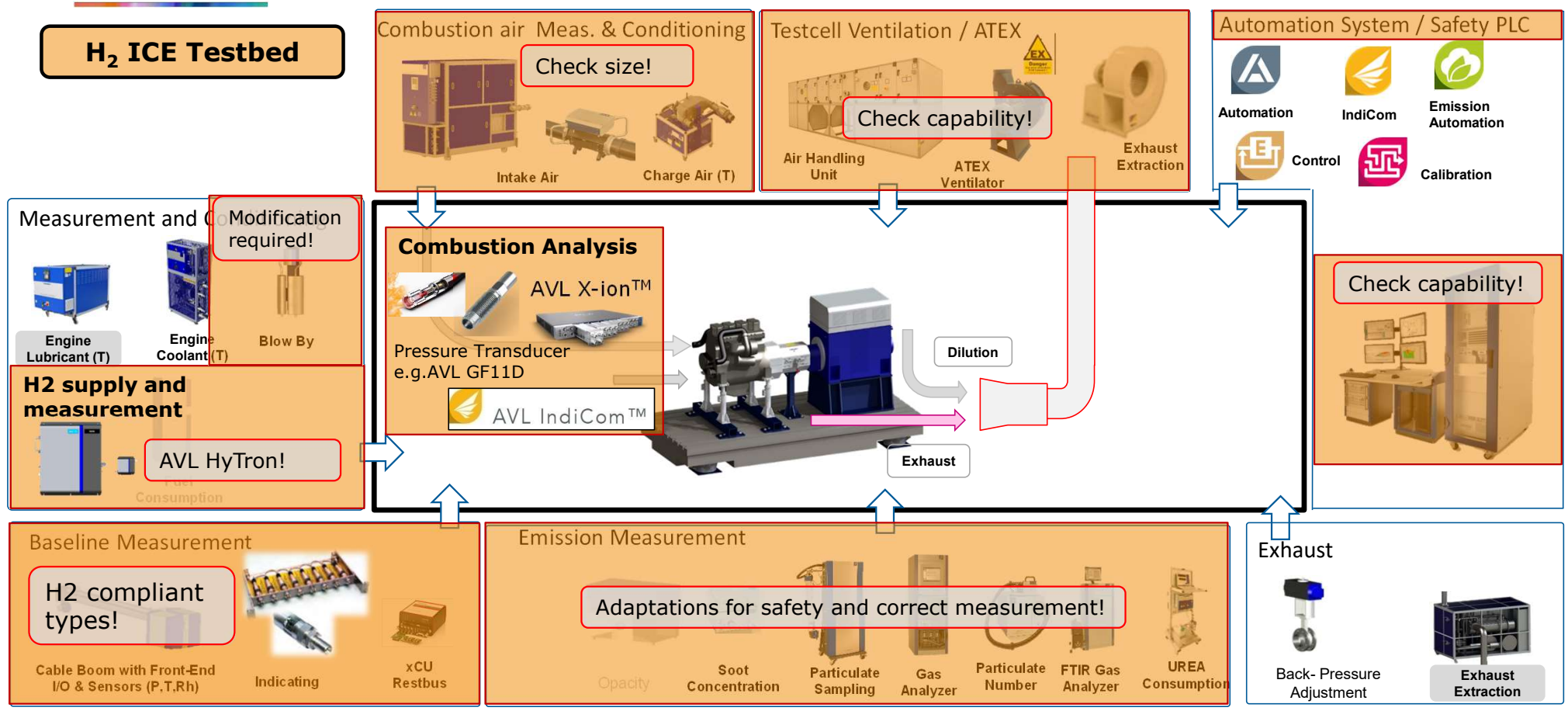
# Summary
# Test Facility View

**Diesel ICE Testbed**



# Summary
# Test Facility View




T H2 ank you
for supporting a sustainable future
AVL HYDROGEN
ICE TEST SYSTEMS
AVL
AVL HYDROGEN
ICE SOLUTIONS
AVL
AVL HYDROGEN
ICE SOLUTIONS