

# **BMW CleanEnergy – Fuel Systems.**

## **ZEV Technology Symposium.**



**Liquid Hydrogen Vehicle Storage.**

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**BMW Group**



# Liquid Hydrogen Vehicle Storage.

## Outline

- Hydrogen Storage - “Why LH<sub>2</sub>?”
- Liquid hydrogen storage - Vehicle constraints.
- Liquid hydrogen storage - Road map.
- Liquid hydrogen storage - Safety issues.
- Conclusion.

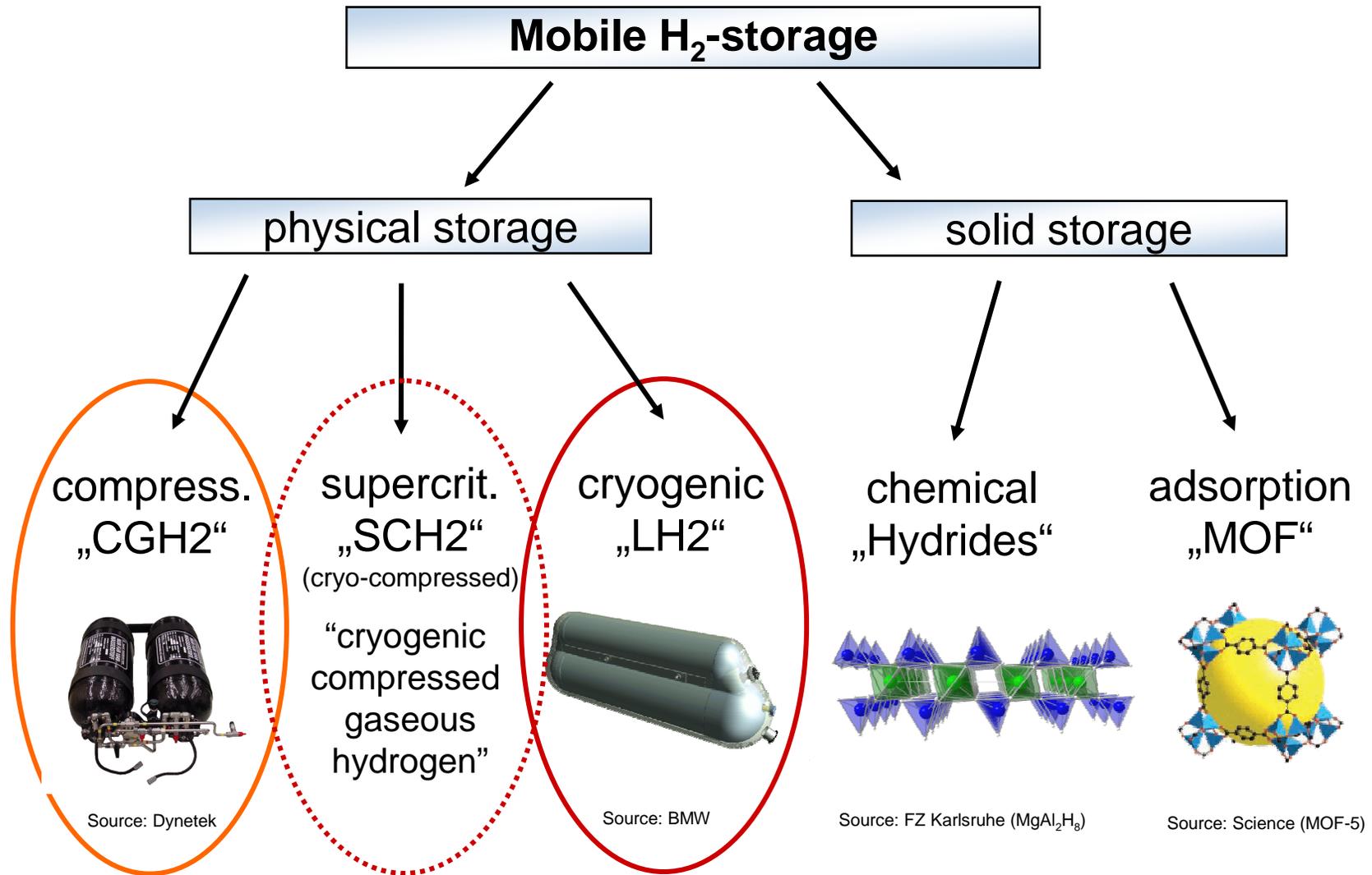
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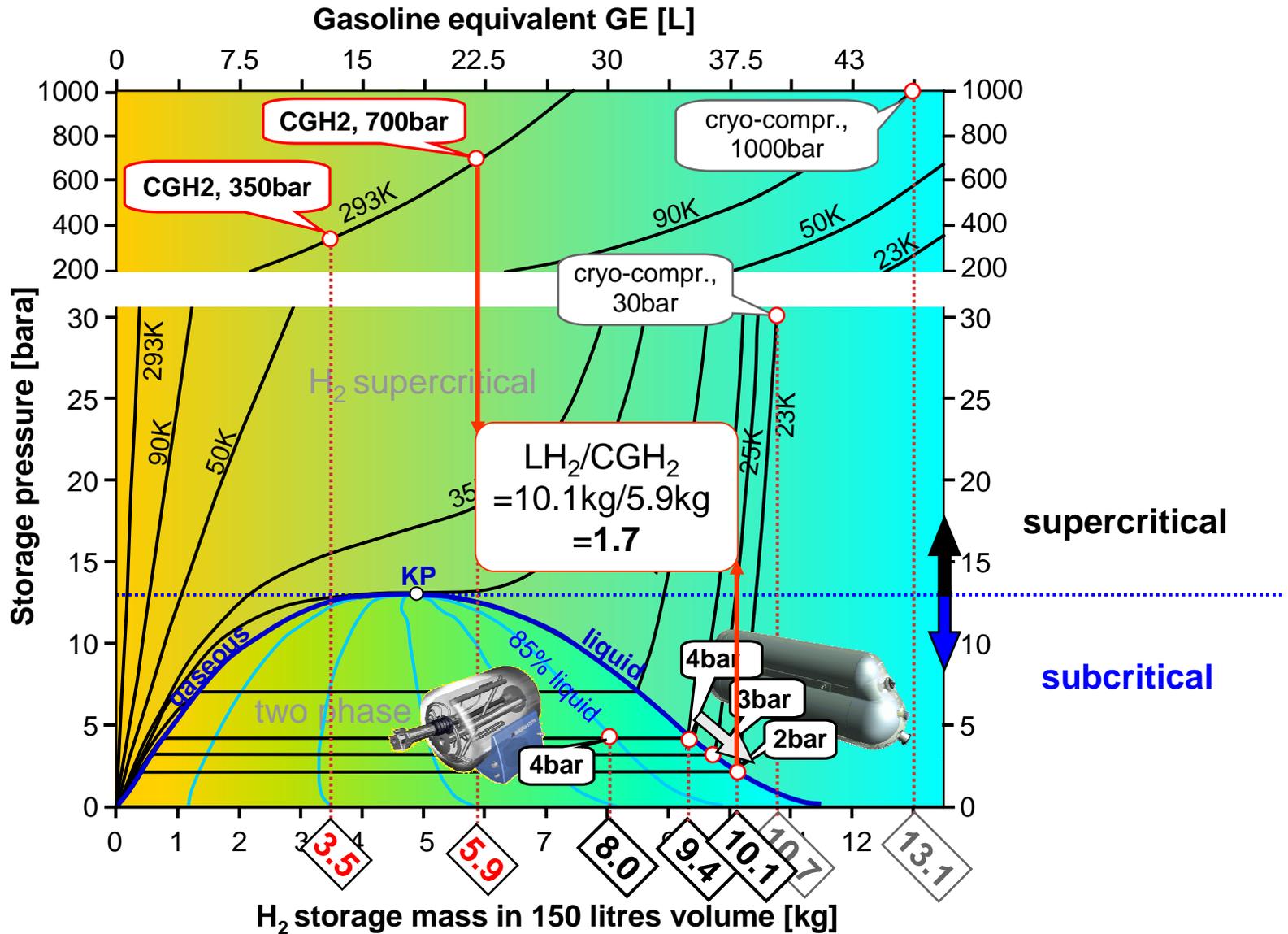
# Hydrogen storage - Why LH<sub>2</sub>?

## Automotive H<sub>2</sub> storage application.



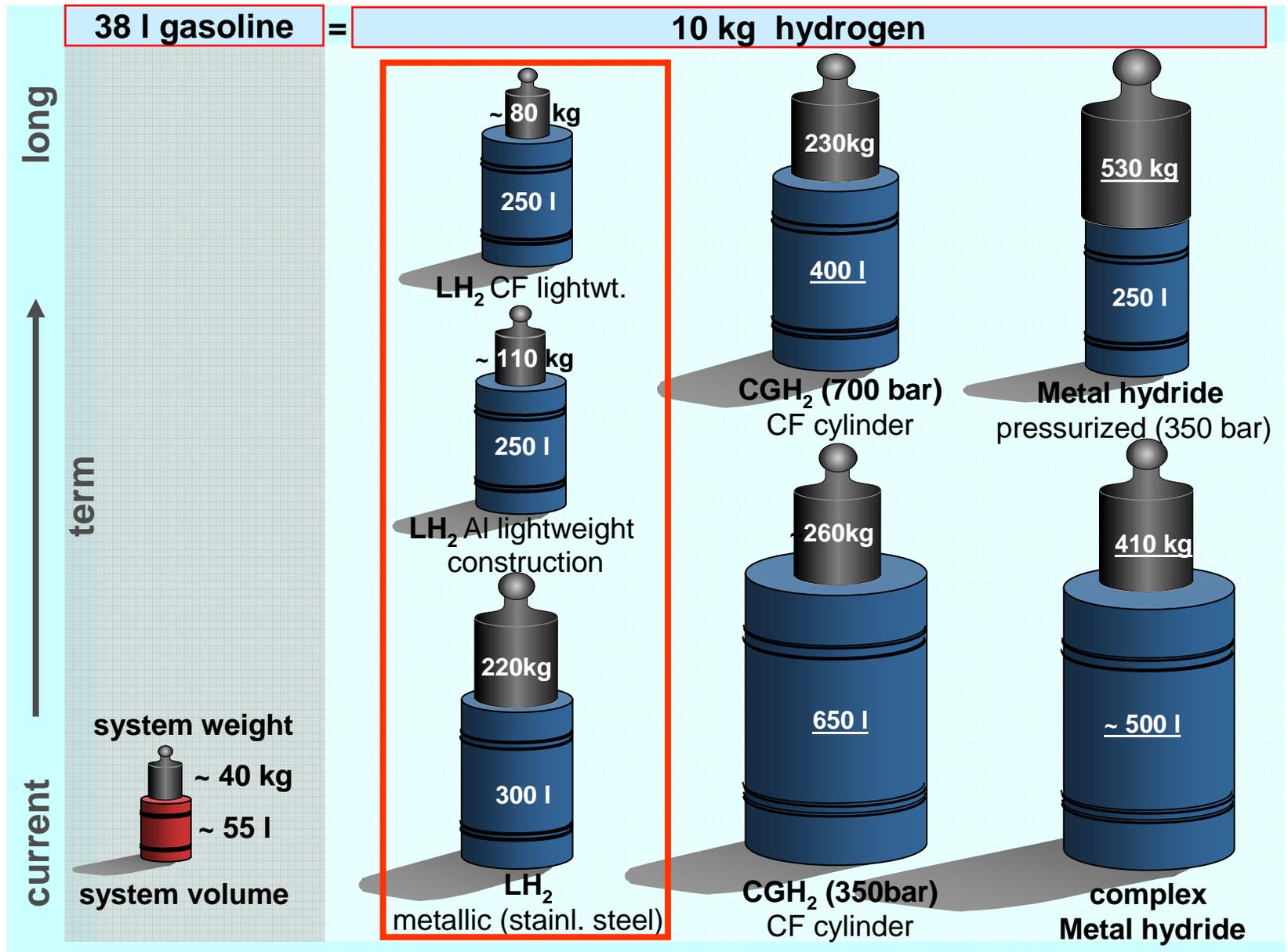
# Hydrogen storage - Why LH<sub>2</sub>?

## Why LH<sub>2</sub> at low storage pressure?



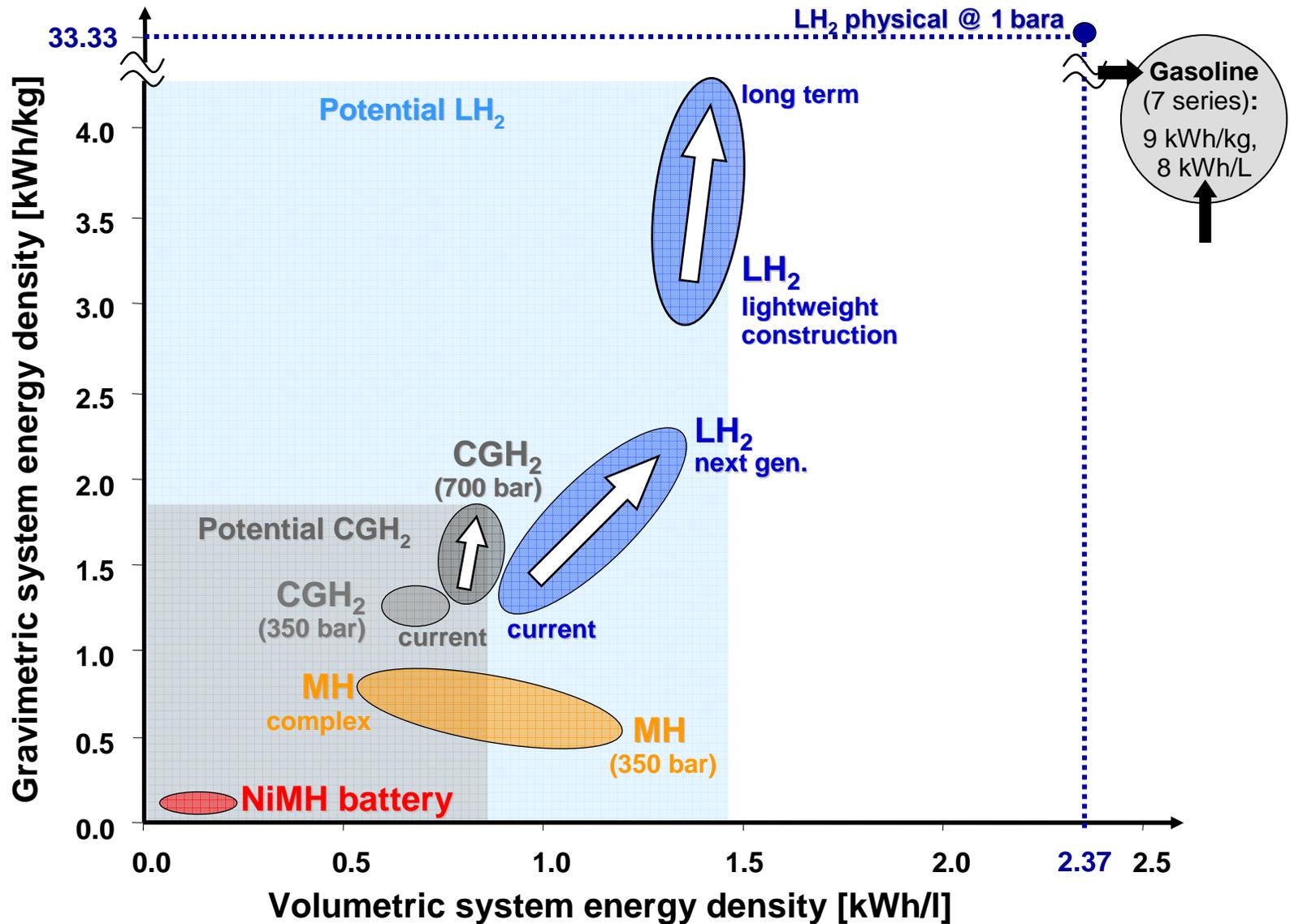
# Hydrogen storage - Why LH<sub>2</sub>?

## Package constraints - system volume & weight.



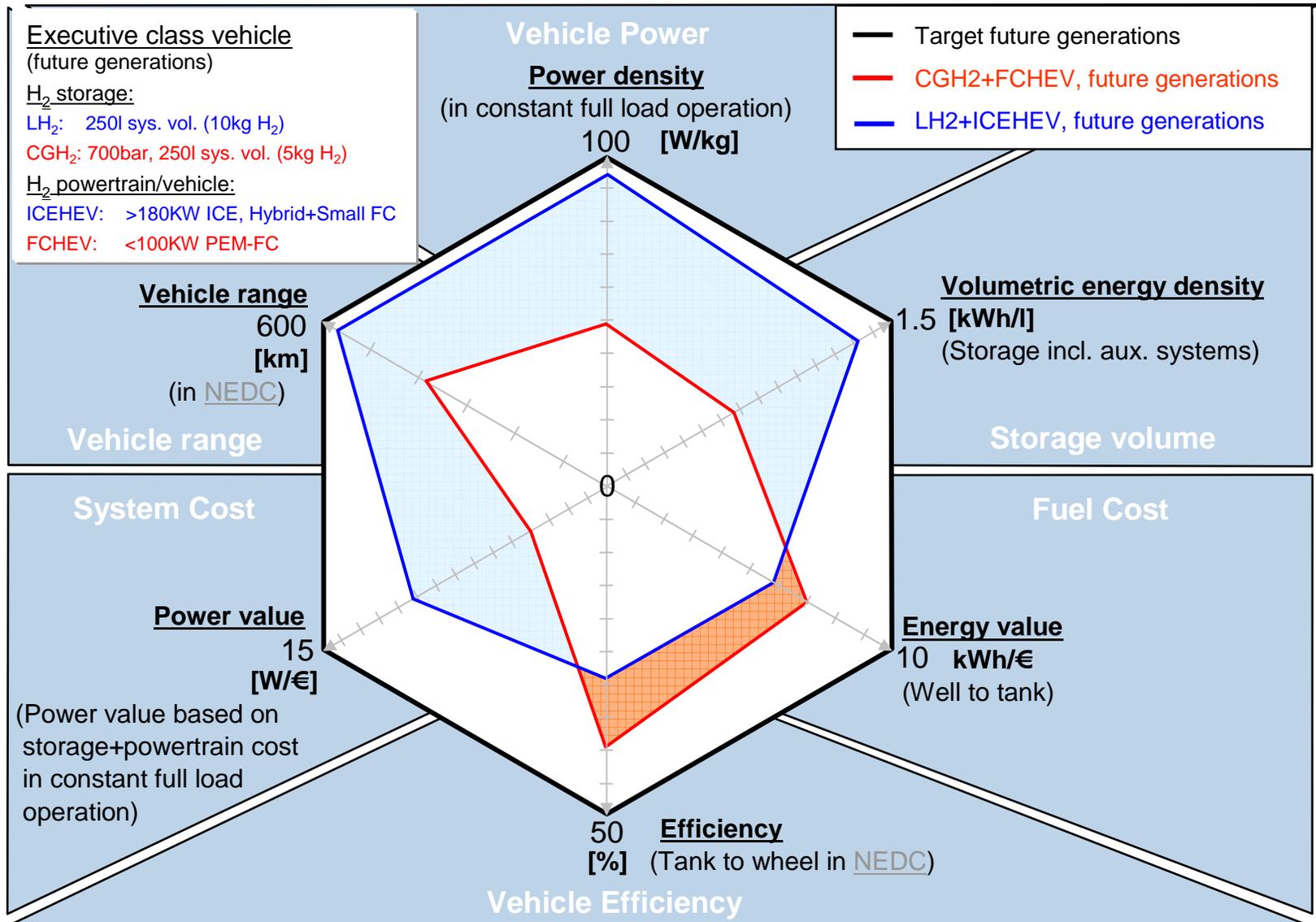
# Hydrogen storage - Why LH<sub>2</sub>?

## Storage system energy density.



# Hydrogen storage - Why LH<sub>2</sub>?

LH<sub>2</sub>+ICEHEV ↔ CGH<sub>2</sub>+FCHEV – future prospects.



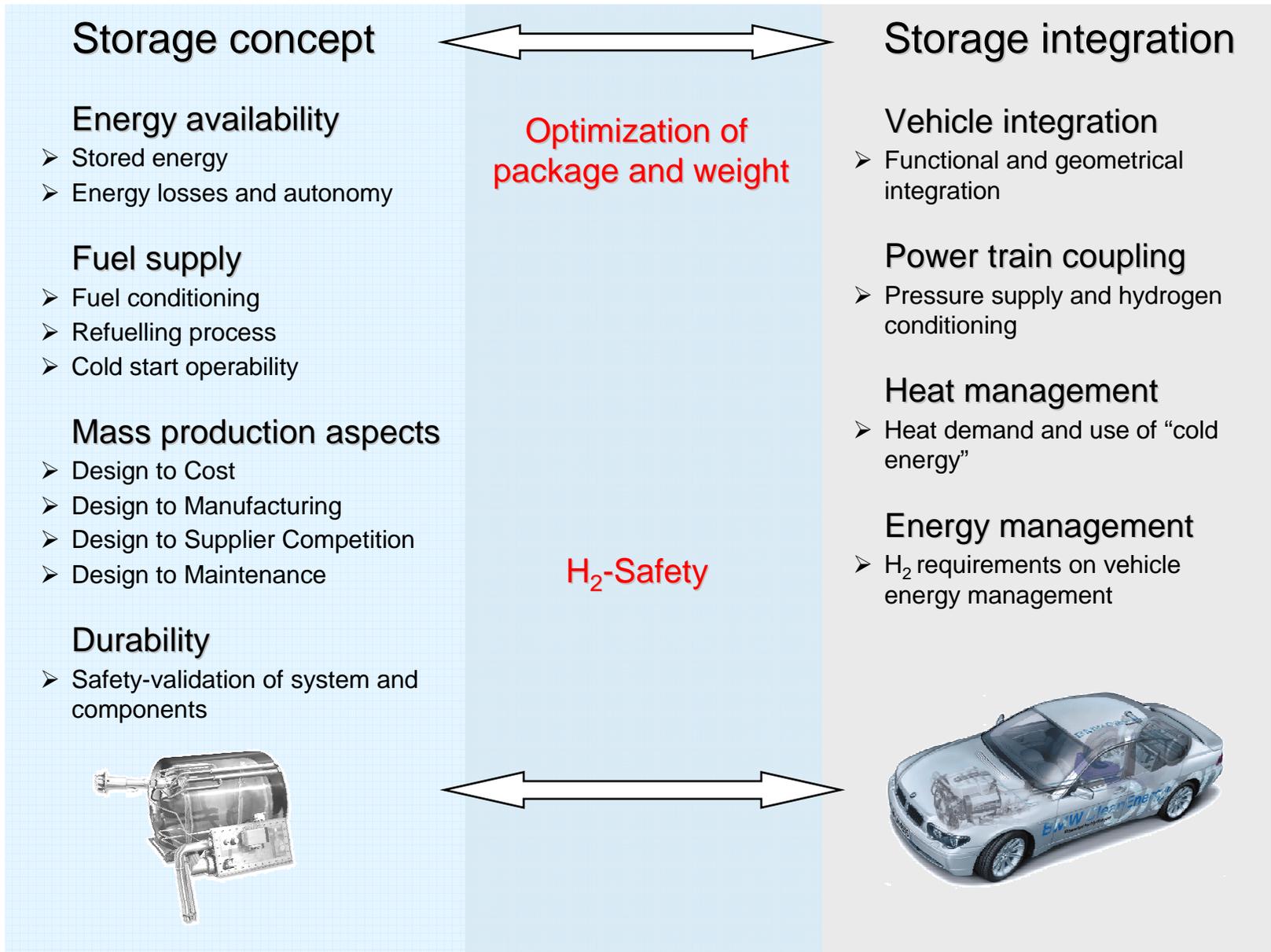
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# Liquid hydrogen storage - Vehicle constraints.

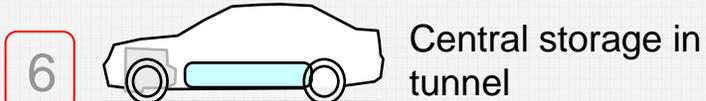
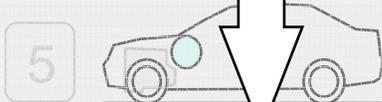
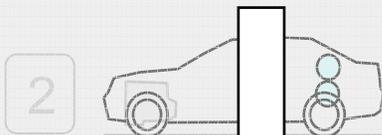
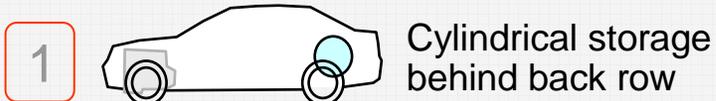
## Hydrogen storage constraints.



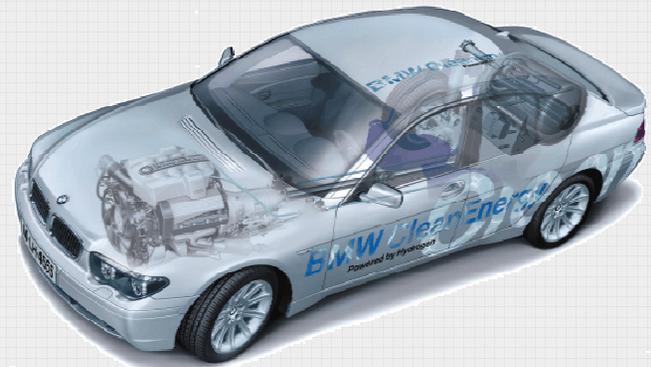
# Liquid hydrogen storage - Vehicle constraints.

## Vehicle constraints in a “top-down” approach.

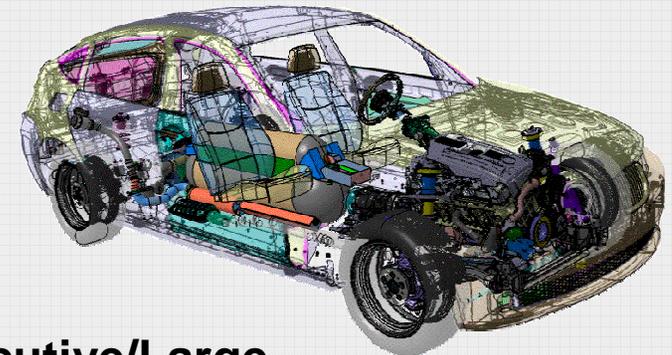
Storage pos. in front engine config.



Luxury



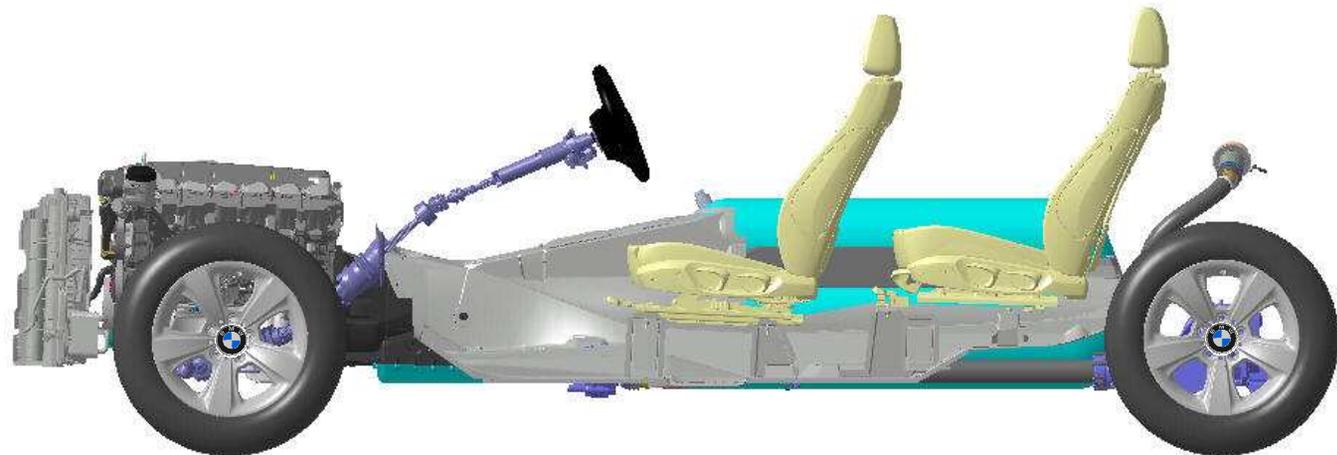
Executive/Large



# Liquid hydrogen storage - Vehicle constraints. Vehicle integrated conformable LH<sub>2</sub> storage.

## Central body integration allows for:

- valuable space concept for passenger compartment
- minimized storage induced vehicle weight increase
- high hydrogen safety level



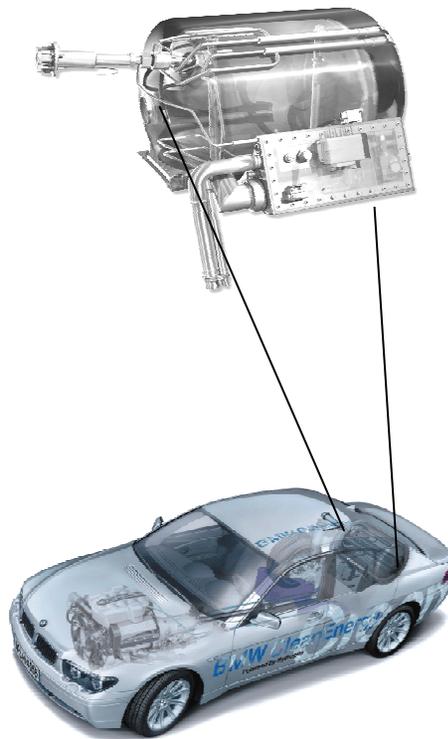
# Liquid hydrogen storage - Vehicle constraints. Geometrical & functional storage constraints.



7-series LH<sub>2</sub> storage behind passenger back row



Exec. / large class LH<sub>2</sub> central storage in the tunnel



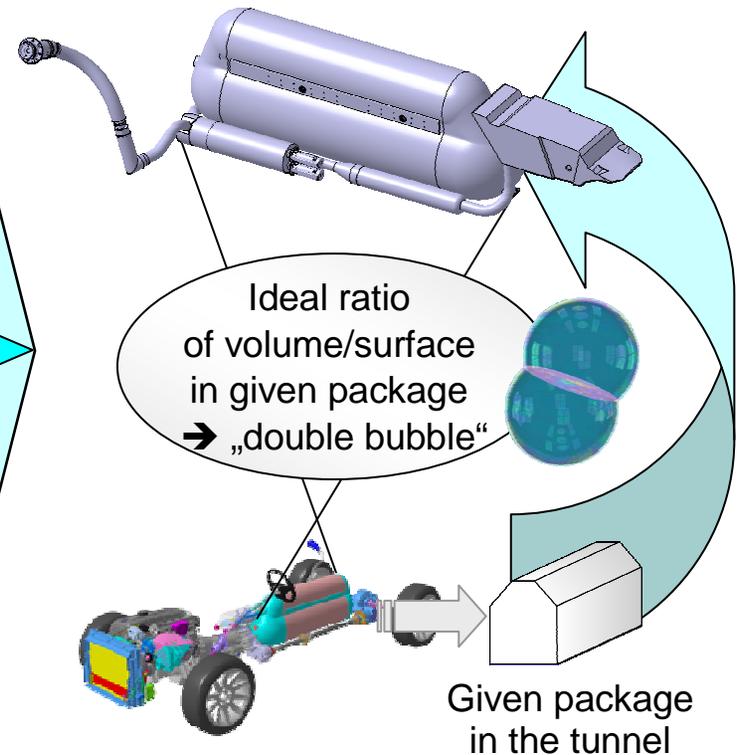
### Advanced Concept

- Shaped storage “Double Bubble”
- Underfloor power train and storage system
- Vehicle body integrated storage

### Modularity

### Design To Cost

- “Reduced” system complexity
- Design to Manufacturing
- Design to supplier competition



# Liquid Hydrogen Vehicle Storage.

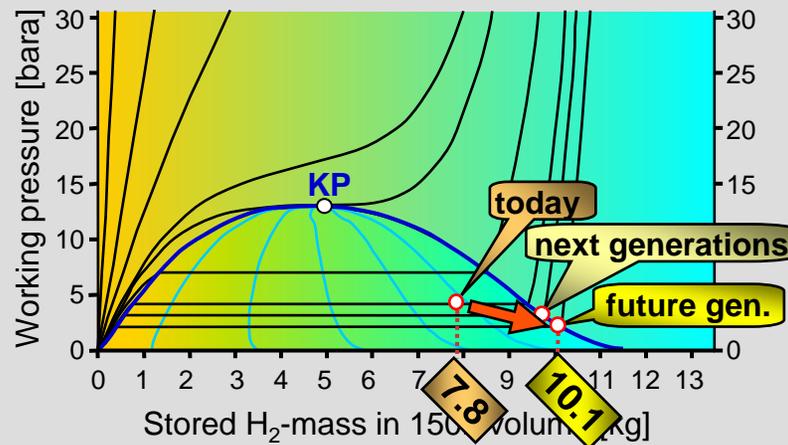
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- **Liquid hydrogen storage - Road map.**
- Liquid hydrogen storage - Safety concept.
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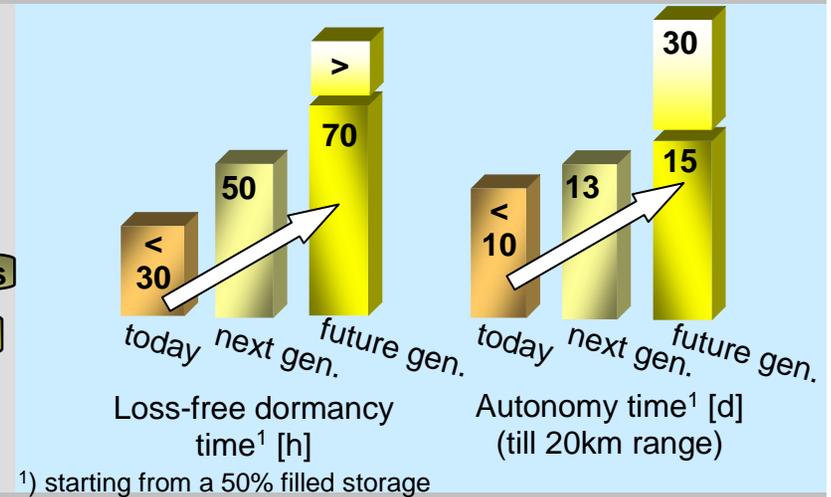
# Road Map LH<sub>2</sub> storage.

## Performance road map LH<sub>2</sub> storage.

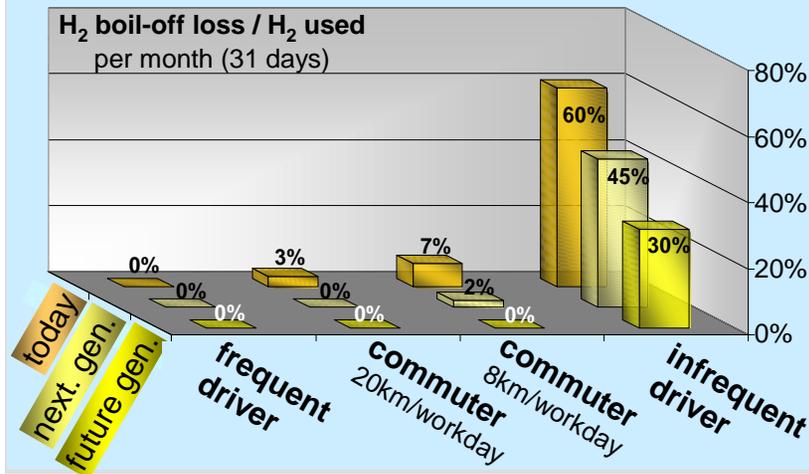
### Increase capacity



### Increase autonomy



### Reduce and use boil-off loss

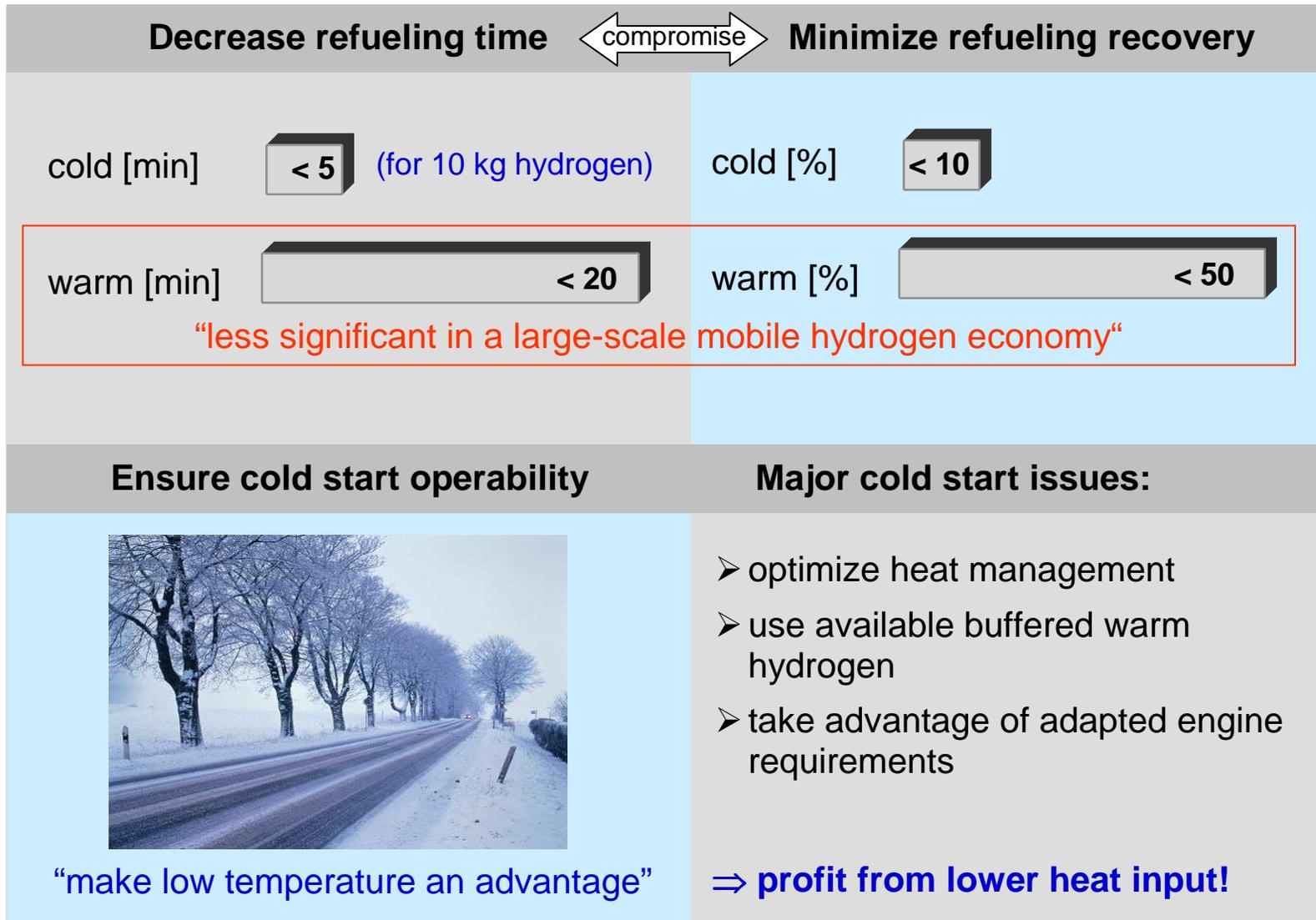


### Major performance issues:

- increase loss-free dormancy time and autonomy time
- use unavoidable boil-off

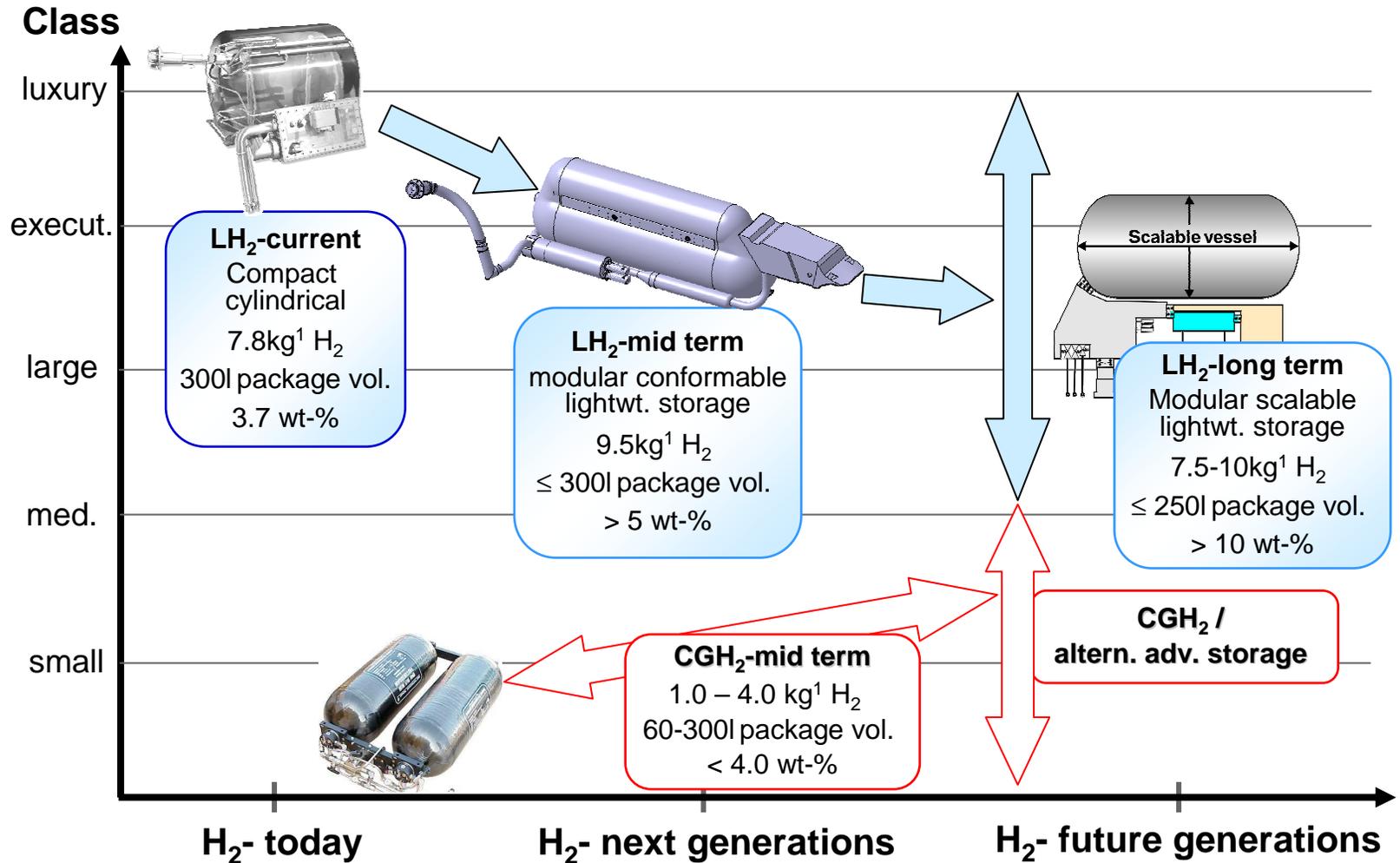
# Road Map LH<sub>2</sub> storage.

## Road capability road map.



# Road Map LH<sub>2</sub> storage.

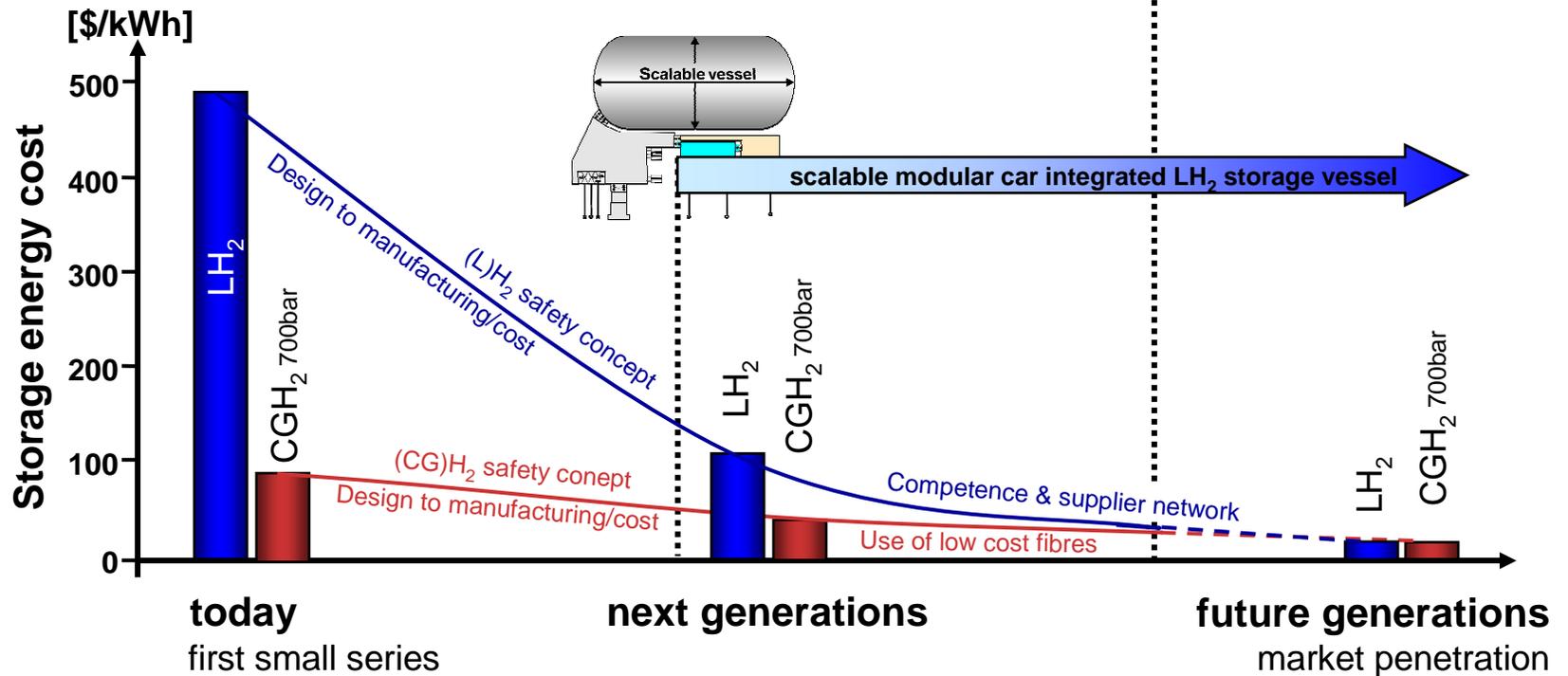
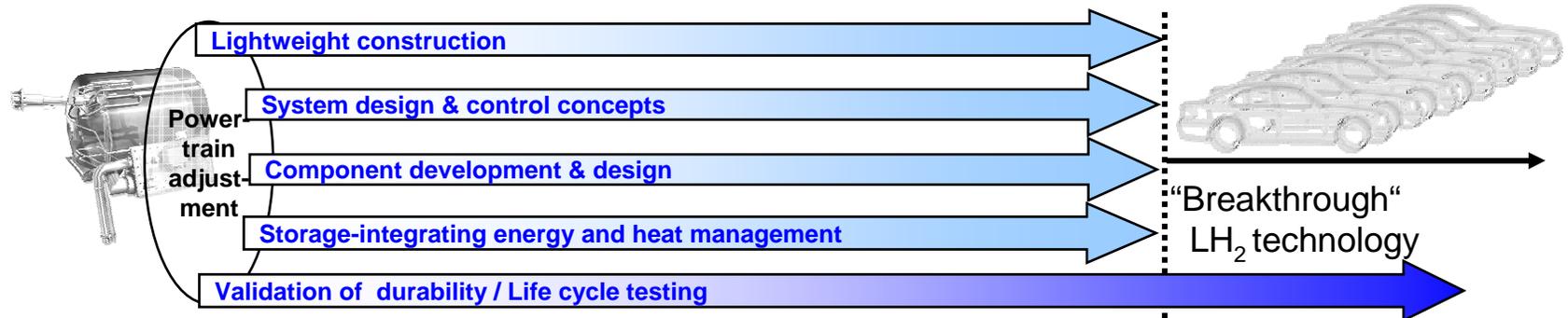
## Road map H<sub>2</sub> storage scalability.



<sup>1</sup>) usable (extractable) hydrogen mass

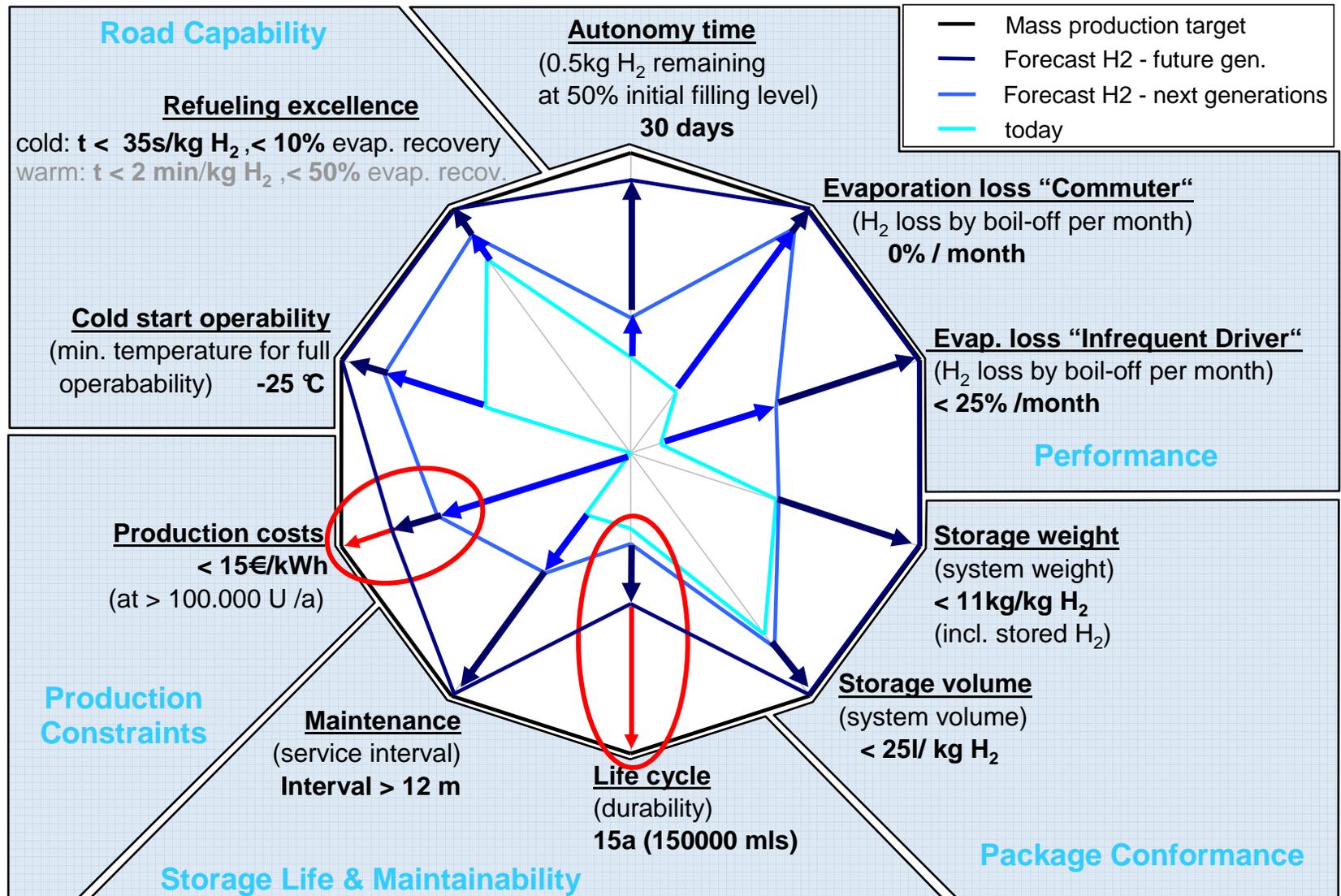
# Road Map LH<sub>2</sub> storage.

## Energy cost & technology road map H<sub>2</sub> storage.



# Road Map LH<sub>2</sub> storage.

## LH<sub>2</sub> storage technology breakthrough forecast.



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# Liquid Hydrogen Storage – Safety Issues.

## LH<sub>2</sub> vehicle safety concept.

### Measures:

Gas feed components absolutely tight and impermeable

Crash-proof component layout

External safety measures

Highly reliable tank vacuum

Closing of H<sub>2</sub> valve

### Protective objectives:

No ignitable mixture (outside of engine)

No cold burns through cryogenic liquids

No bursting of tank, fuel lines or components



Prevention of uncontrolled gas emissions

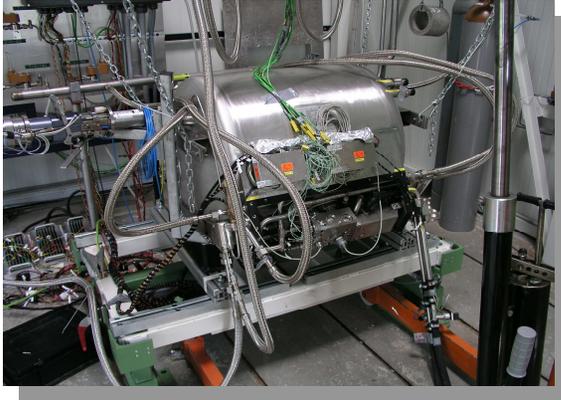
Highly reliable (SIL3) supervision and control system

Safe boil-off utilization

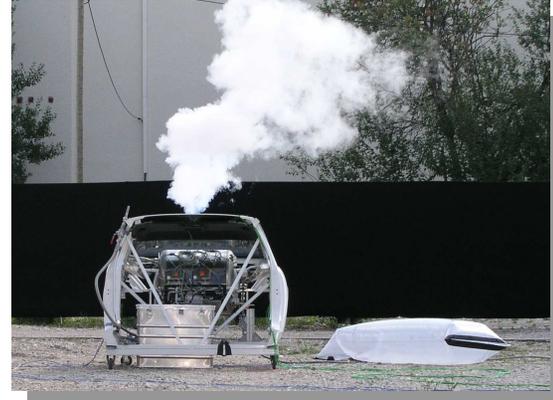
No ignition sources in critical areas

# Liquid Hydrogen Storage – Safety Issues.

## LH<sub>2</sub> safety proof tests.



**LH<sub>2</sub> test rig**



**Test of sudden vacuum loss**



**Crash tests**



**Fire test**

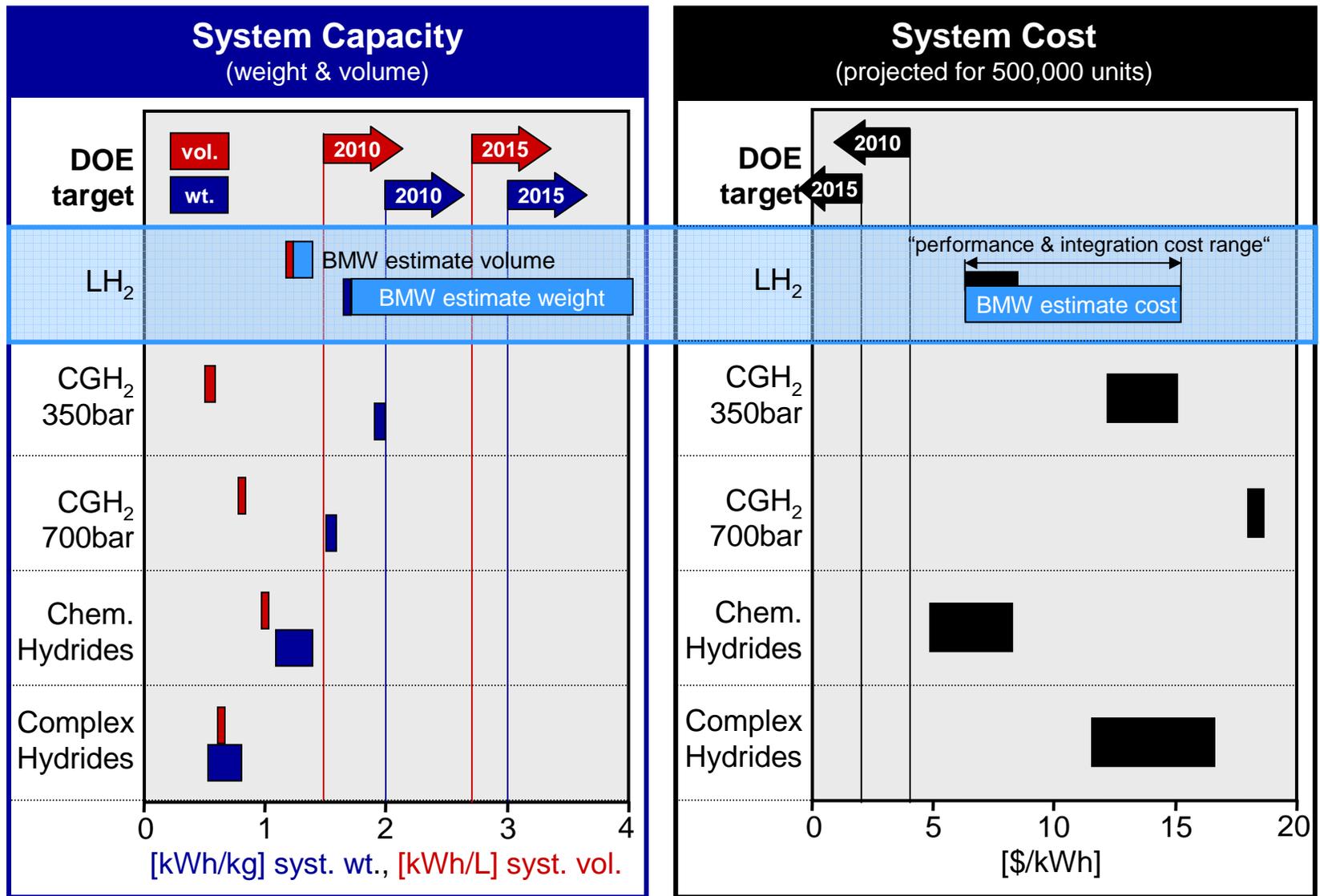
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# Liquid Hydrogen Vehicle Storage.

## Storage capacity and cost estimate.



“DOE estimates from developers - to be continuously updated”

Source: “2006 Annual DOE Hydrogen Program Merit Review – Hydrogen Storage”, S.Satyapal et al.

# Liquid Hydrogen Vehicle Storage. Conclusion.

- Cryogenic liquid hydrogen storage systems enable high gravimetric and volumetric energy densities and therefore guarantee a viable cruising range in future hydrogen-powered cars.
- Storage performance of LH<sub>2</sub> storage systems will reach a level with satisfactory capacity and minor losses for typical customer profiles in larger vehicle classes. CGH<sub>2</sub> or alternative advanced storage systems are favored for application in smaller vehicle classes.
- Intelligent car integration enables for viable future vehicle concepts with integrated LH<sub>2</sub> storage systems.
- The “Design To Mass production” approach promises considerable reduction in complexness and cost and will help to ensure marketability of future hydrogen storage systems.



**Sheer driving pleasure – Powered by hydrogen!**

