BMW CleanEnergy – Fuel Systems.
ZEV Technology Symposium.

Liquid Hydrogen Vehicle Storage.

Tobias Brunner

BMW Group

Liquid Hydrogen Vehicle Storage.

Outline

- Hydrogen Storage - “Why LH_2?”
- Liquid hydrogen storage - Vehicle constraints.
- Liquid hydrogen storage - Road map.
- Liquid hydrogen storage - Safety issues.
- Conclusion.

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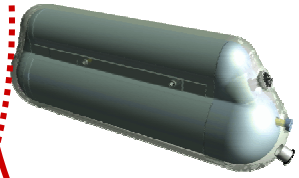
Hydrogen storage - Why LH_2?

Automotive H_2 storage application.

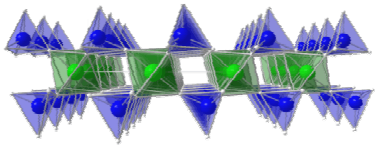
Mobile H_2-storage

- physical storage
  - compress. „CGH2“
  - supercrit. „SCH2“ (cryo-compressed) “cryogenic compressed gaseous hydrogen”
  - cryogenic „LH2“
- solid storage
  - chemical „Hydrides“
  - adsorption „MOF“

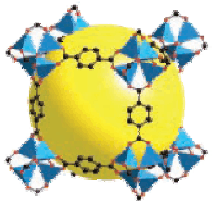
Source: Dynetek



Source: BMW



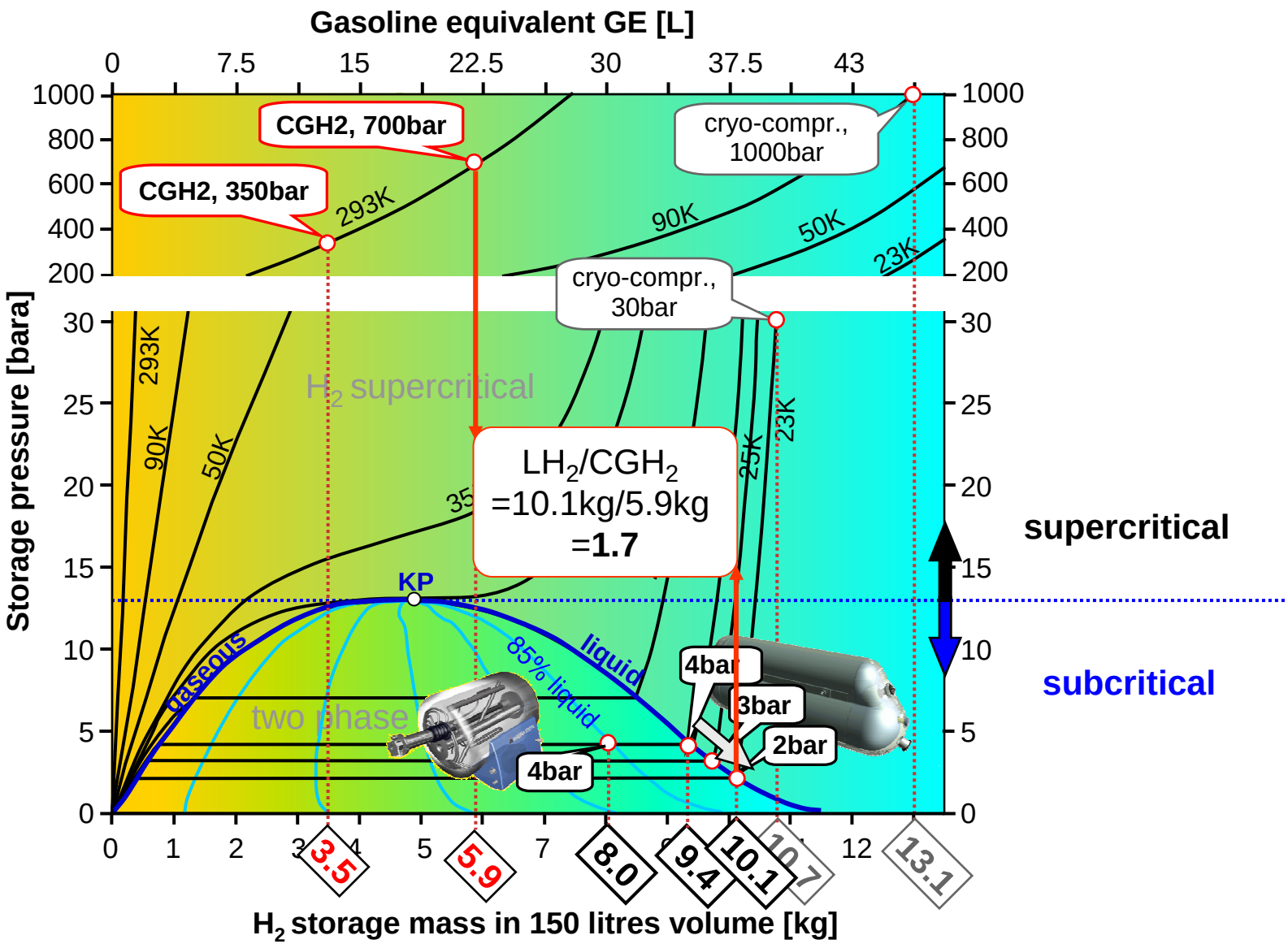
Source: FZ Karlsruhe ($MgAl_2H_8$)



Source: Science (MOF-5)

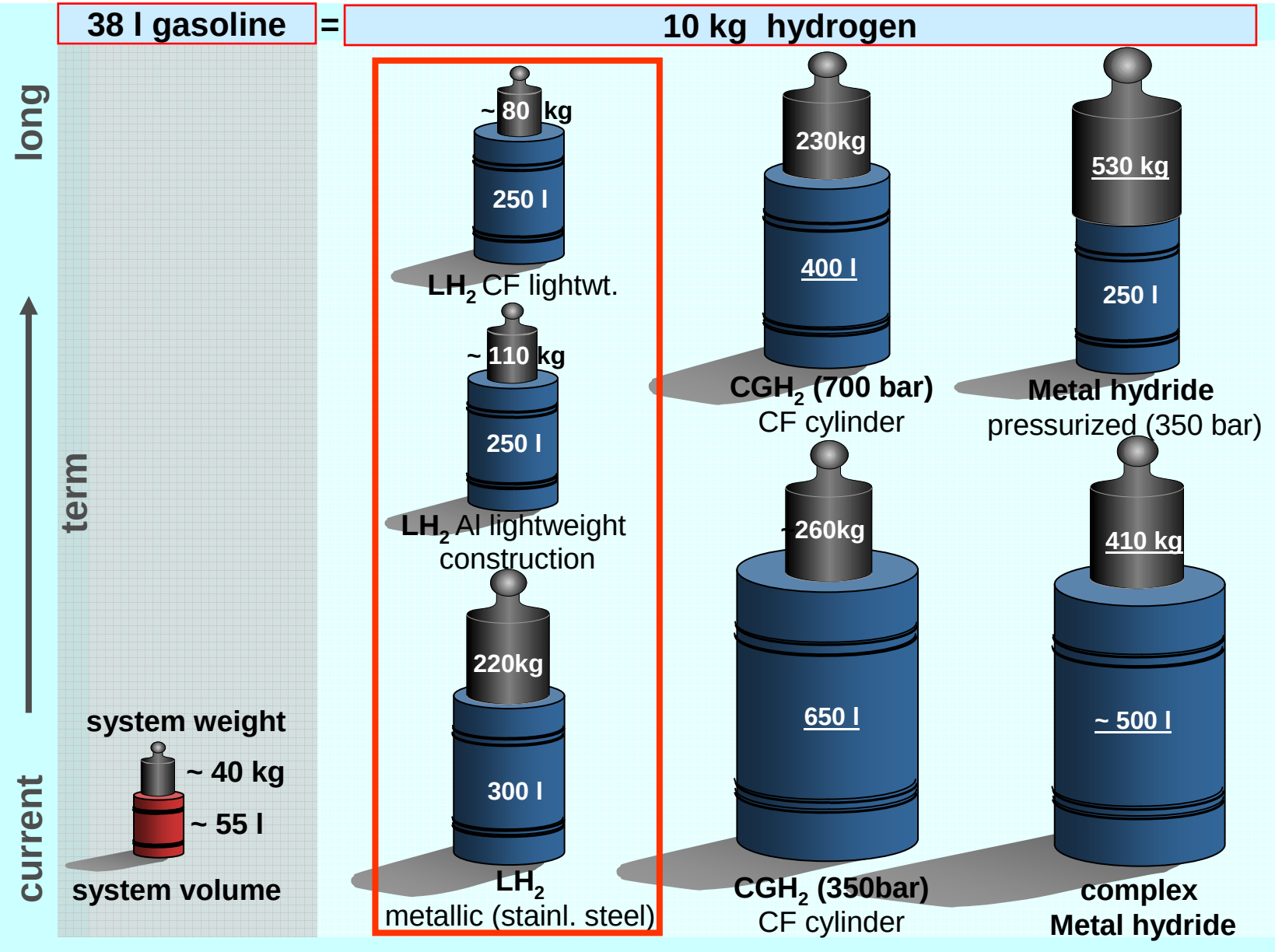
Hydrogen storage - Why LH_2?

Why LH_2 at low storage pressure?



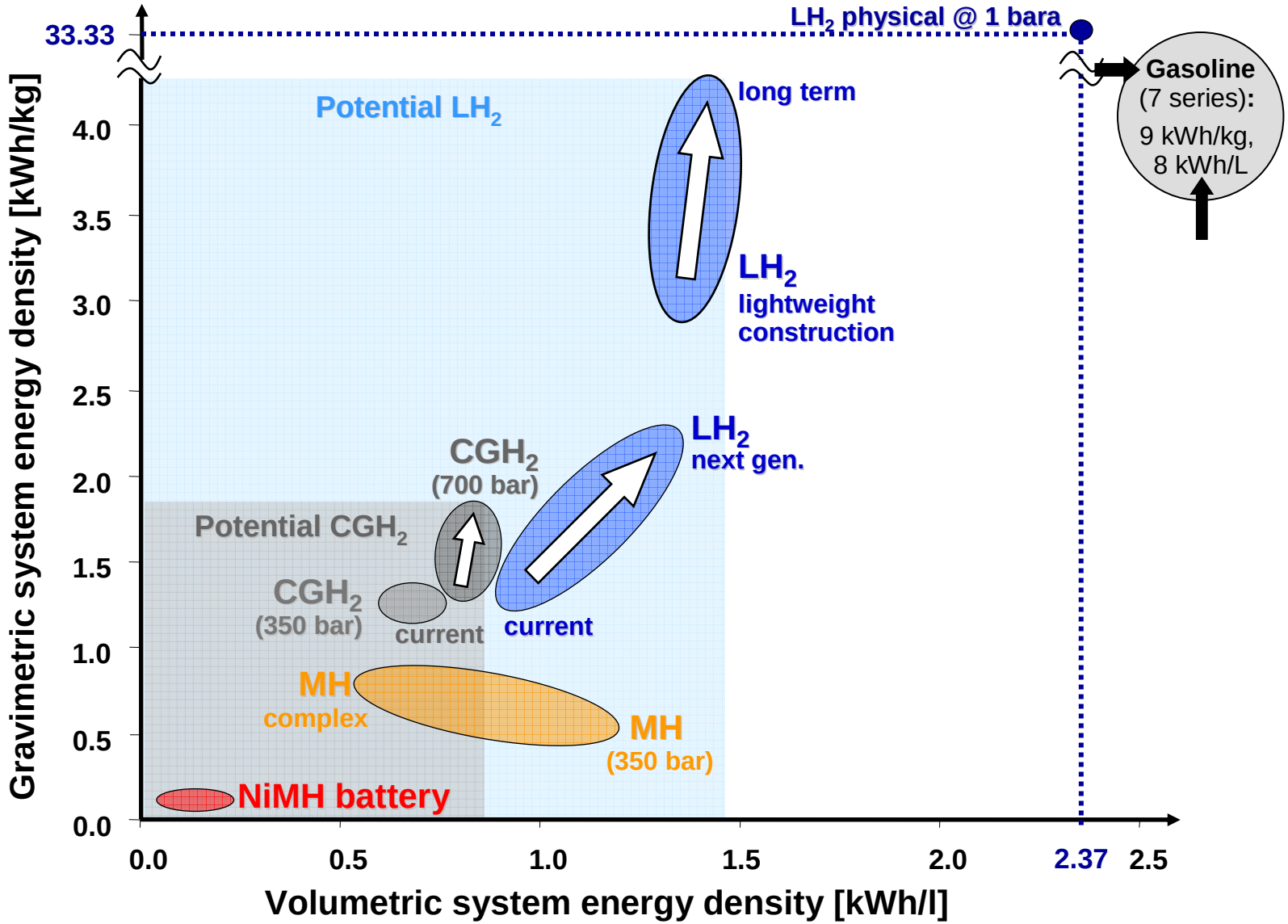
Hydrogen storage - Why LH_2?

Package constraints - system volume & weight.



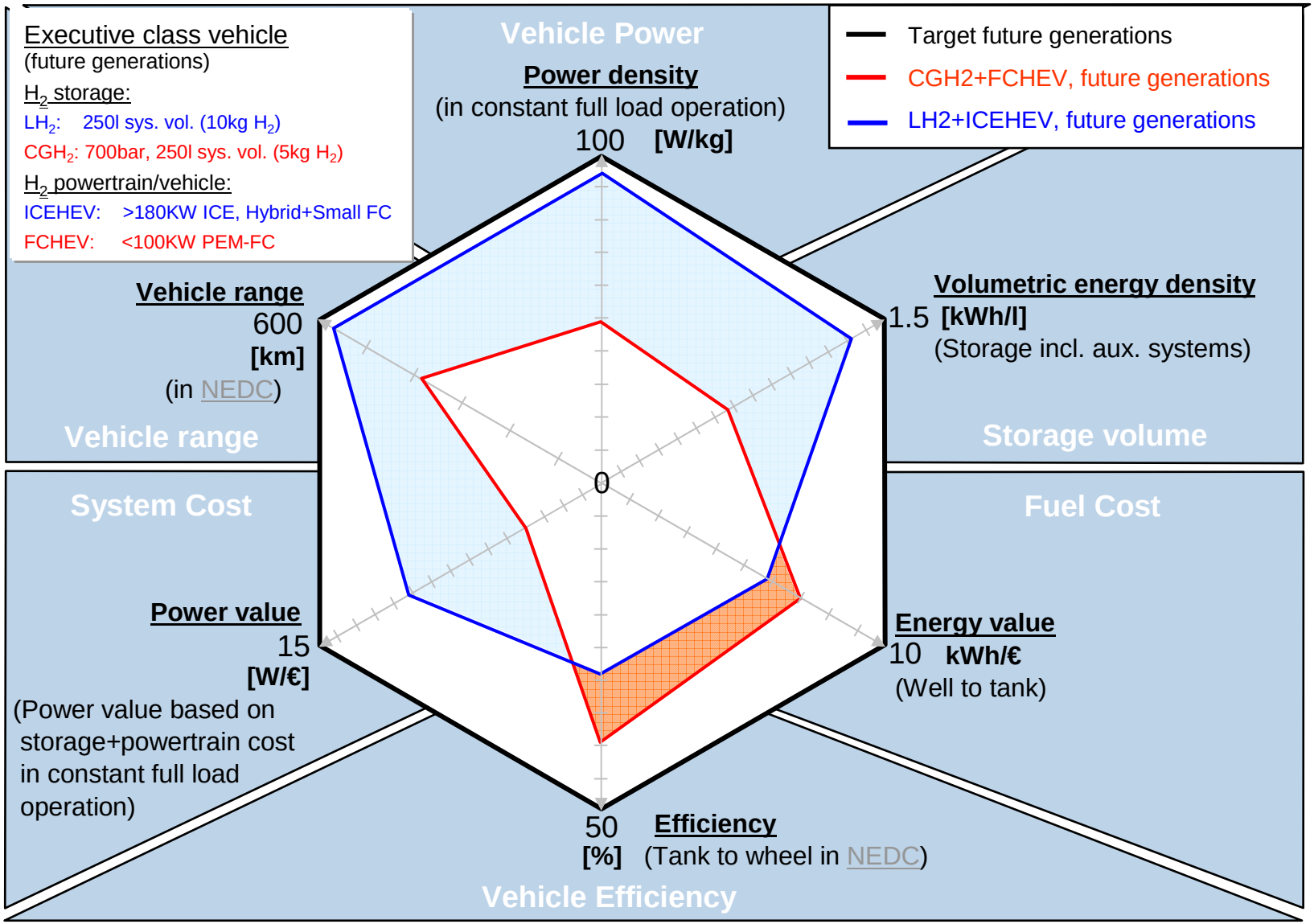
Hydrogen storage - Why LH_2?

Storage system energy density.



Hydrogen storage - Why LH_2?

LH_2+ICEHEV ↔ CGH_2+FCHEV – future prospects.



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Liquid hydrogen storage - Vehicle constraints.

Hydrogen storage constraints.

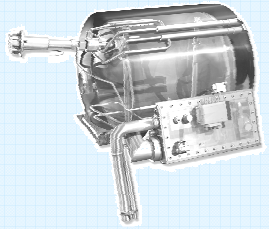
Storage concept

Energy availability
- Stored energy
- Energy losses and autonomy

Fuel supply
- Fuel conditioning
- Refuelling process
- Cold start operability

Mass production aspects
- Design to Cost
- Design to Manufacturing
- Design to Supplier Competition
- Design to Maintenance

Durability
- Safety-validation of system and components



Optimization of package and weight

H_2-Safety

Storage integration

Vehicle integration
- Functional and geometrical integration

Power train coupling
- Pressure supply and hydrogen conditioning

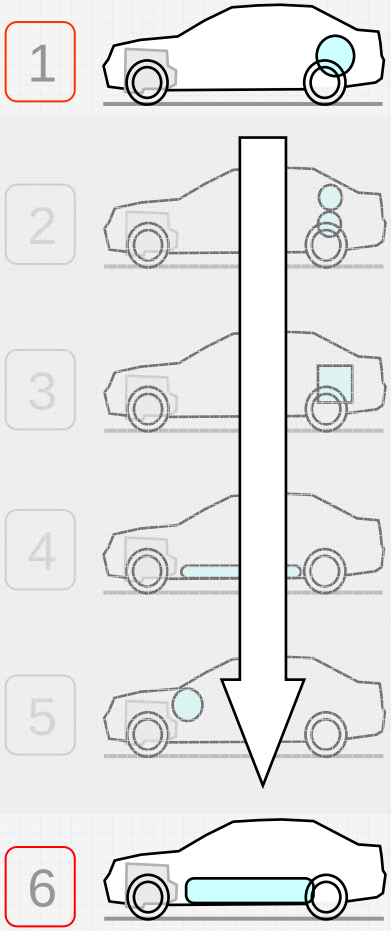
Heat management
- Heat demand and use of “cold energy”

Energy management
- H_2 requirements on vehicle energy management

Liquid hydrogen storage - Vehicle constraints.

Vehicle constraints in a “top-down” approach.

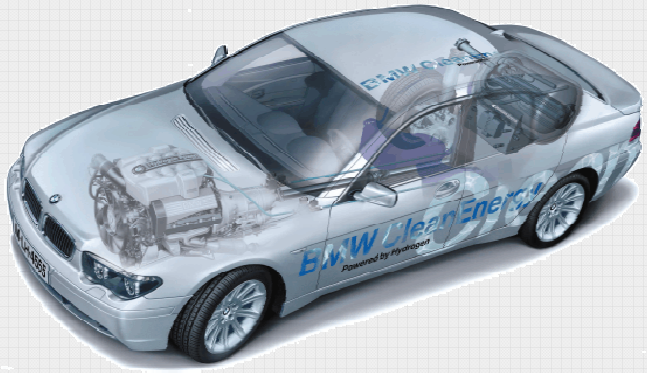
Storage pos. in front engine config.

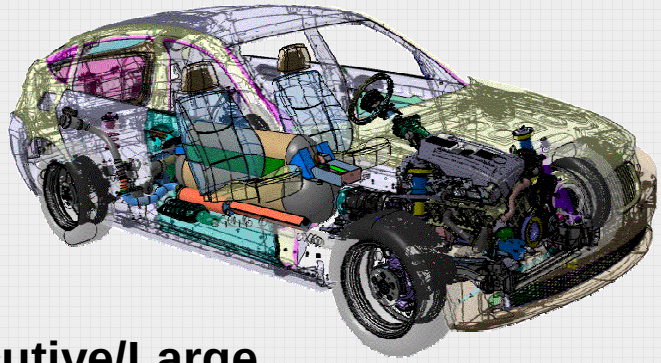


1 Cylindrical storage behind back row

6 Central storage in tunnel

Luxury





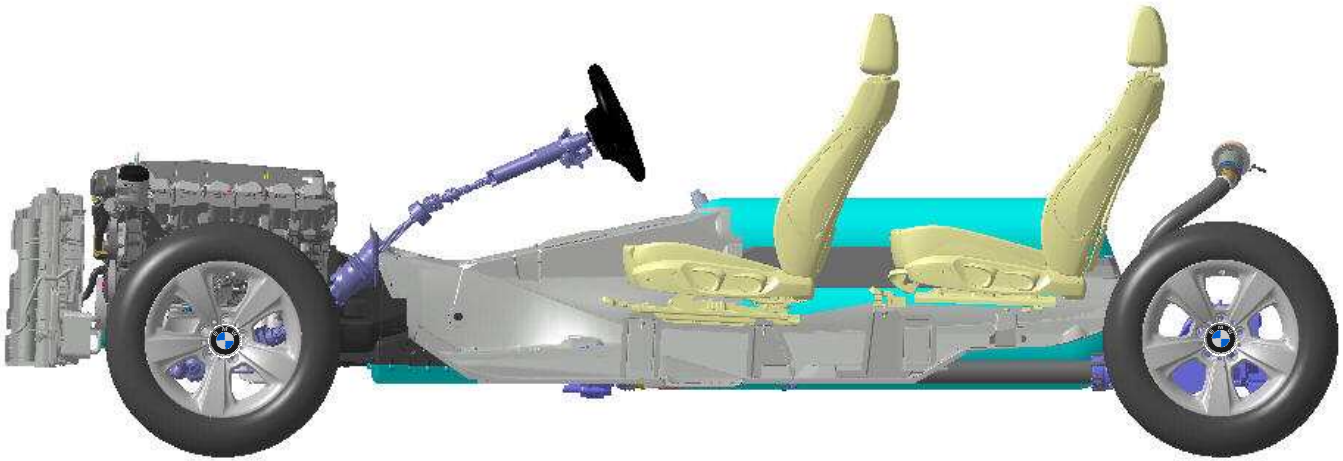
Executive/Large

Liquid hydrogen storage - Vehicle constraints.

Vehicle integrated conformable LH_2 storage.

Central body integration allows for:

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



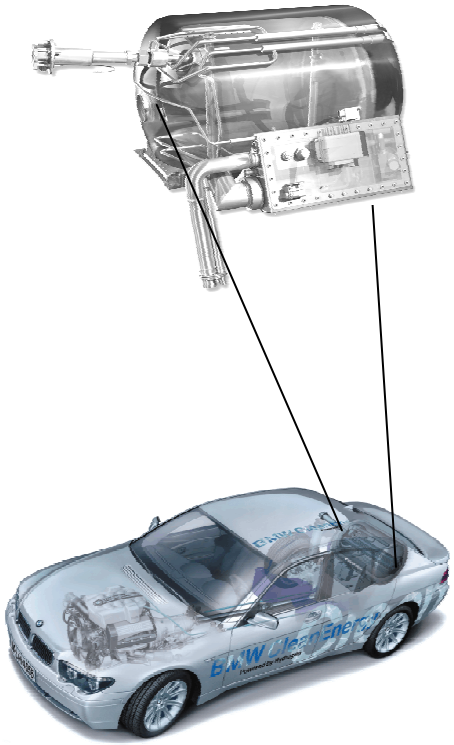
Liquid hydrogen storage - Vehicle constraints.

Geometrical & functional storage constraints.

„Top-Down“

7-series LH_2 storage behind passenger back row

Exec. / large class LH_2 central storage in the tunnel



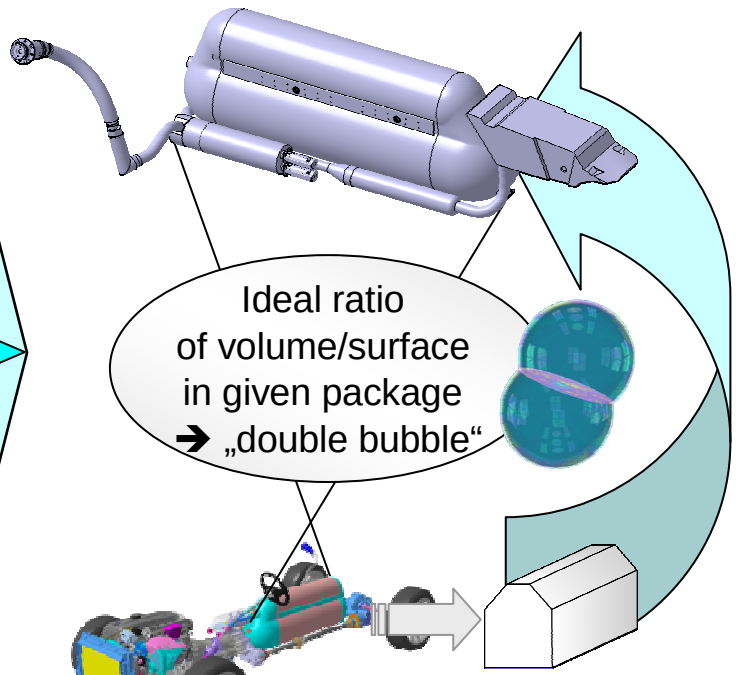
Advanced Concept

- 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



Ideal ratio
of volume/surface
in given package
➔ „double bubble“

Given package
in the tunnel

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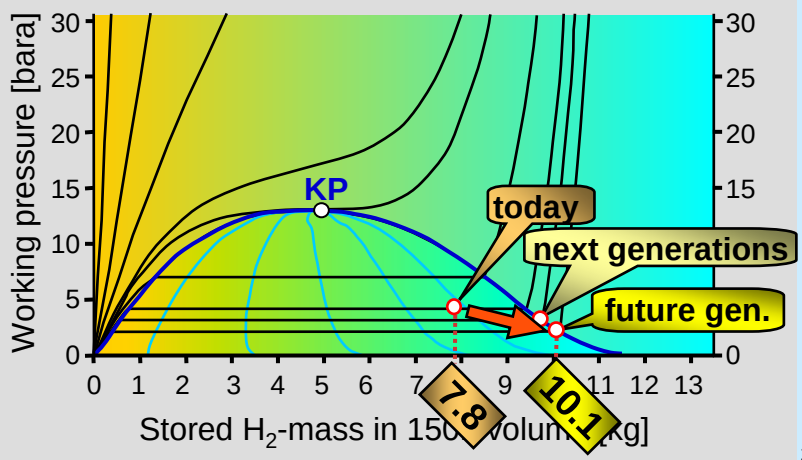
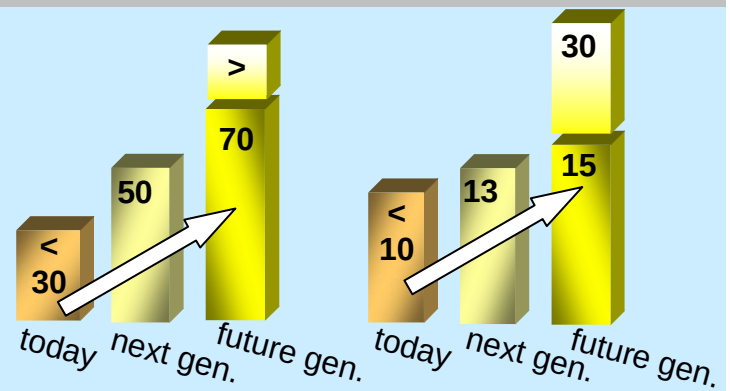
Road Map LH_2 storage.

Performance road map LH_2 storage.

Increase capacity



Increase autonomy

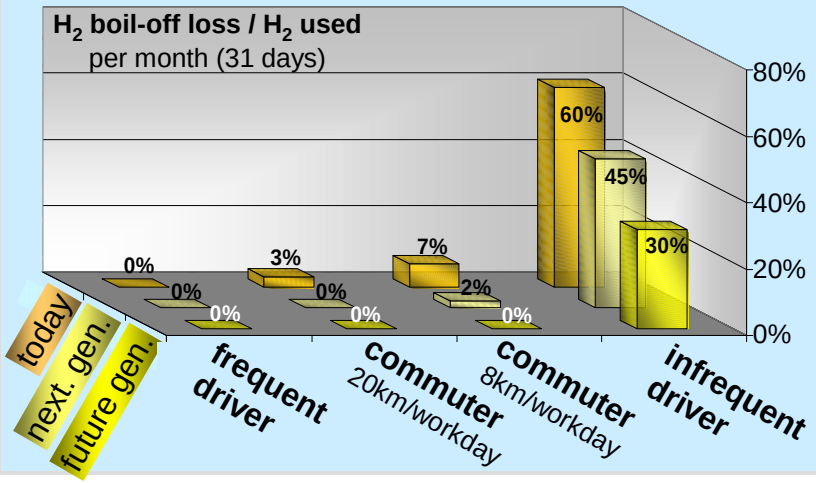


Loss-free dormancy time[1] [h]

Autonomy time[1] [d] (till 20km range)

[1]) starting from a 50% filled storage

Reduce and use boil-off loss



Major performance issues:

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

Road Map LH_2 storage.

Road capability road map.

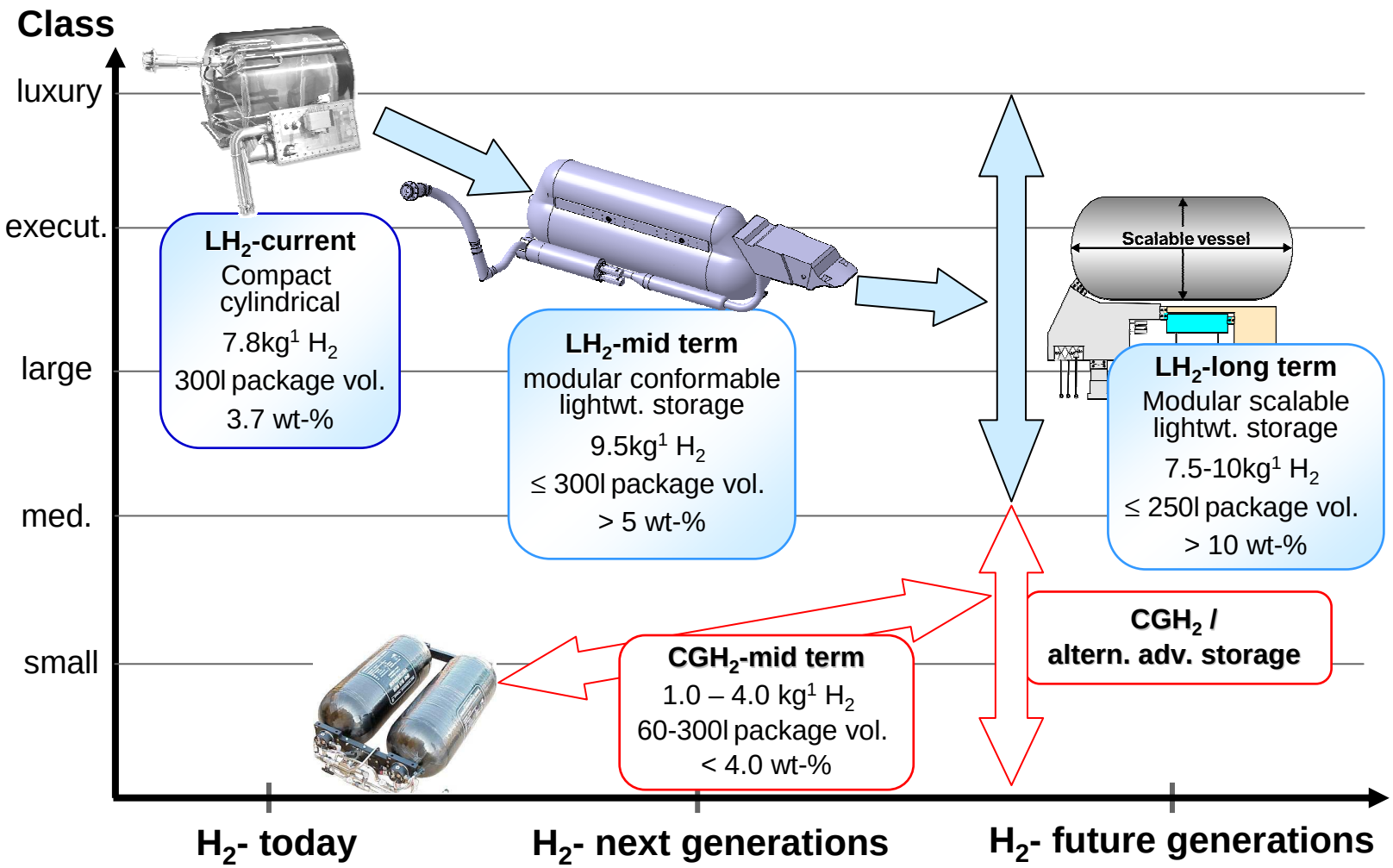
Decrease refueling time	compromise	Minimize refueling recovery
cold [min] < 5 (for 10 kg hydrogen)		cold [%] < 10
warm [min] < 20		warm [%] < 50

"less significant in a large-scale mobile hydrogen economy"

Ensure cold start operability	Major cold start issues:
	➢ optimize heat management ➢ use available buffered warm hydrogen ➢ take advantage of adapted engine requirements
"make low temperature an advantage"	⇒ **profit from lower heat input!**

Road Map LH_2 storage.

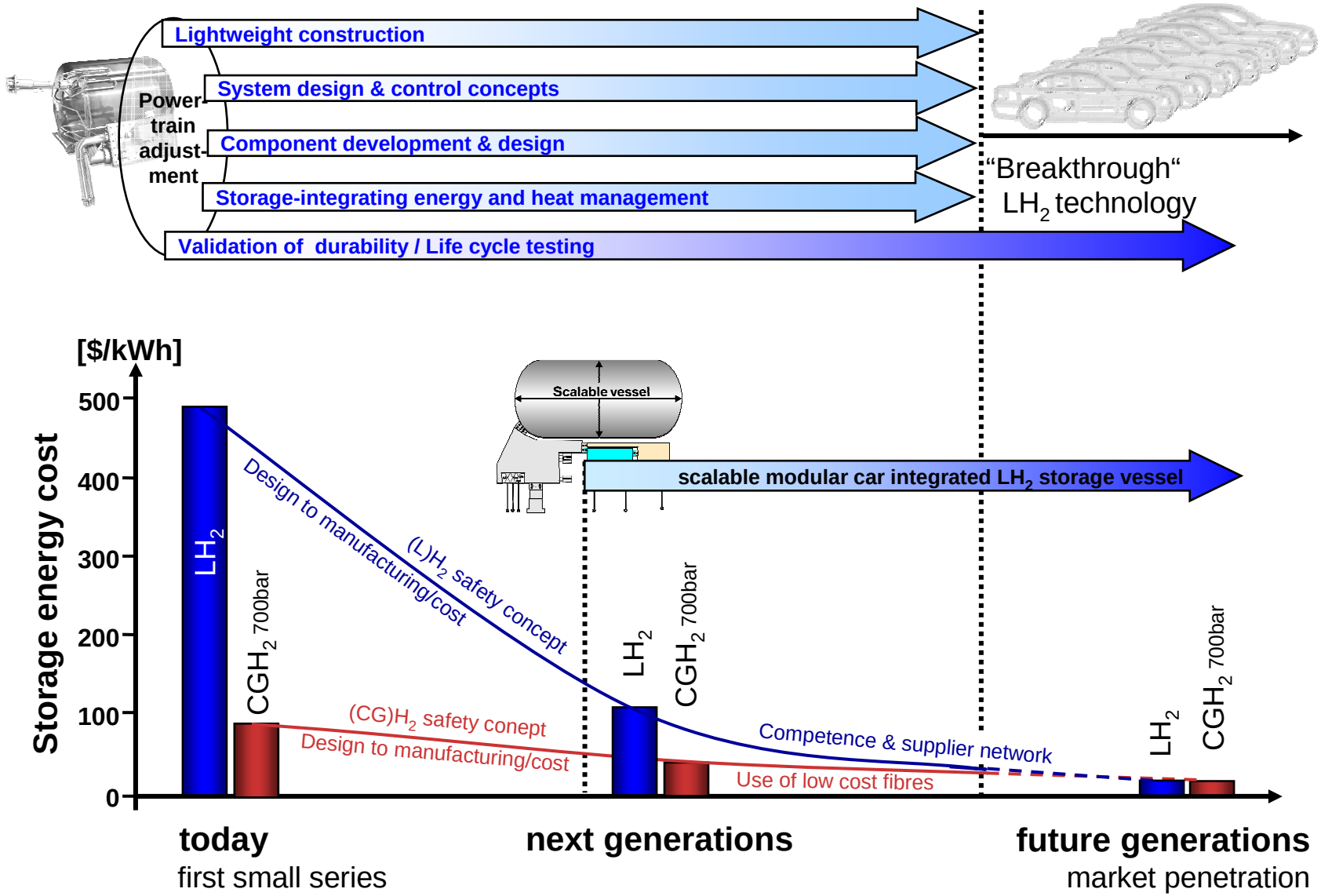
Road map H_2 storage scalability.



[1]) usable (extractable) hydrogen mass

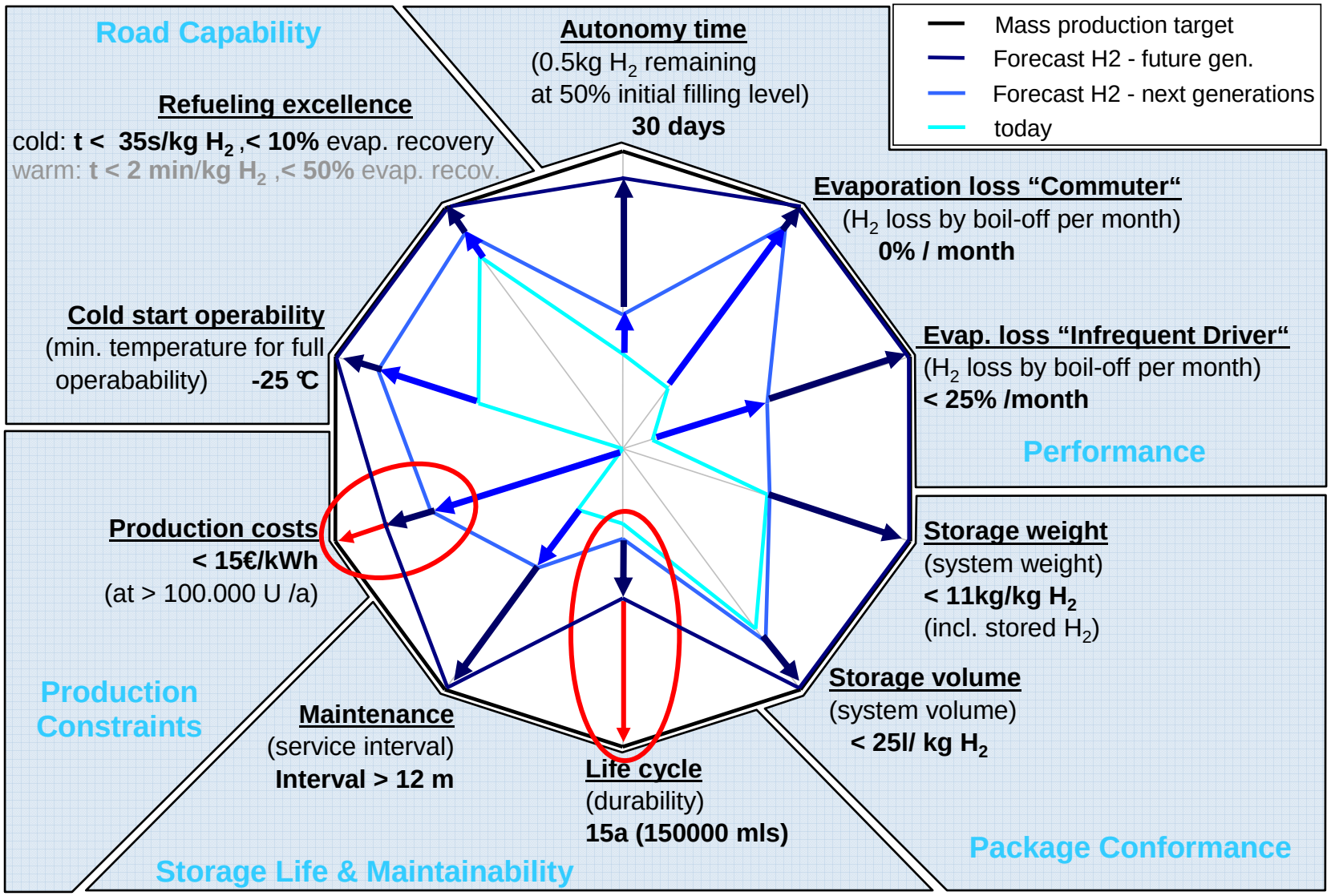
Road Map LH_2 storage.

Energy cost & technology road map H_2 storage.



Road Map LH_2 storage.

LH_2 storage technology breakthrough forecast.



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Liquid Hydrogen Storage – Safety Issues.

LH_2 vehicle safety concept.

Measures:

Gas feed components absolutely tight and impermeable

Crash-proof component layout

External safety measures

Highly reliable tank vacuum

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

Closing of H2 valve

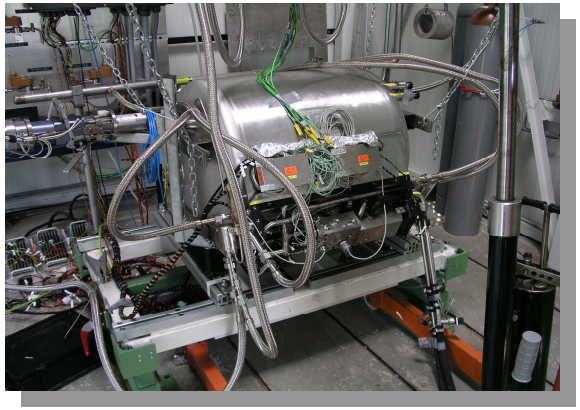
Highly reliable (SIL3) supervision and control system

Safe boil-off utilization

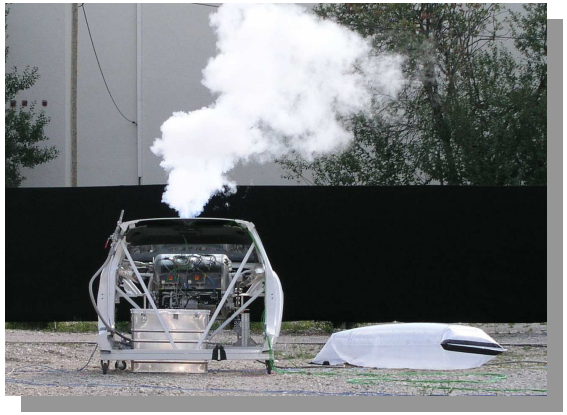
No ignition sources in critical areas

Liquid Hydrogen Storage – Safety Issues.

LH_2 safety proof tests.



LH_2 test rig



Test of sudden vacuum loss

Crash tests

Fire test

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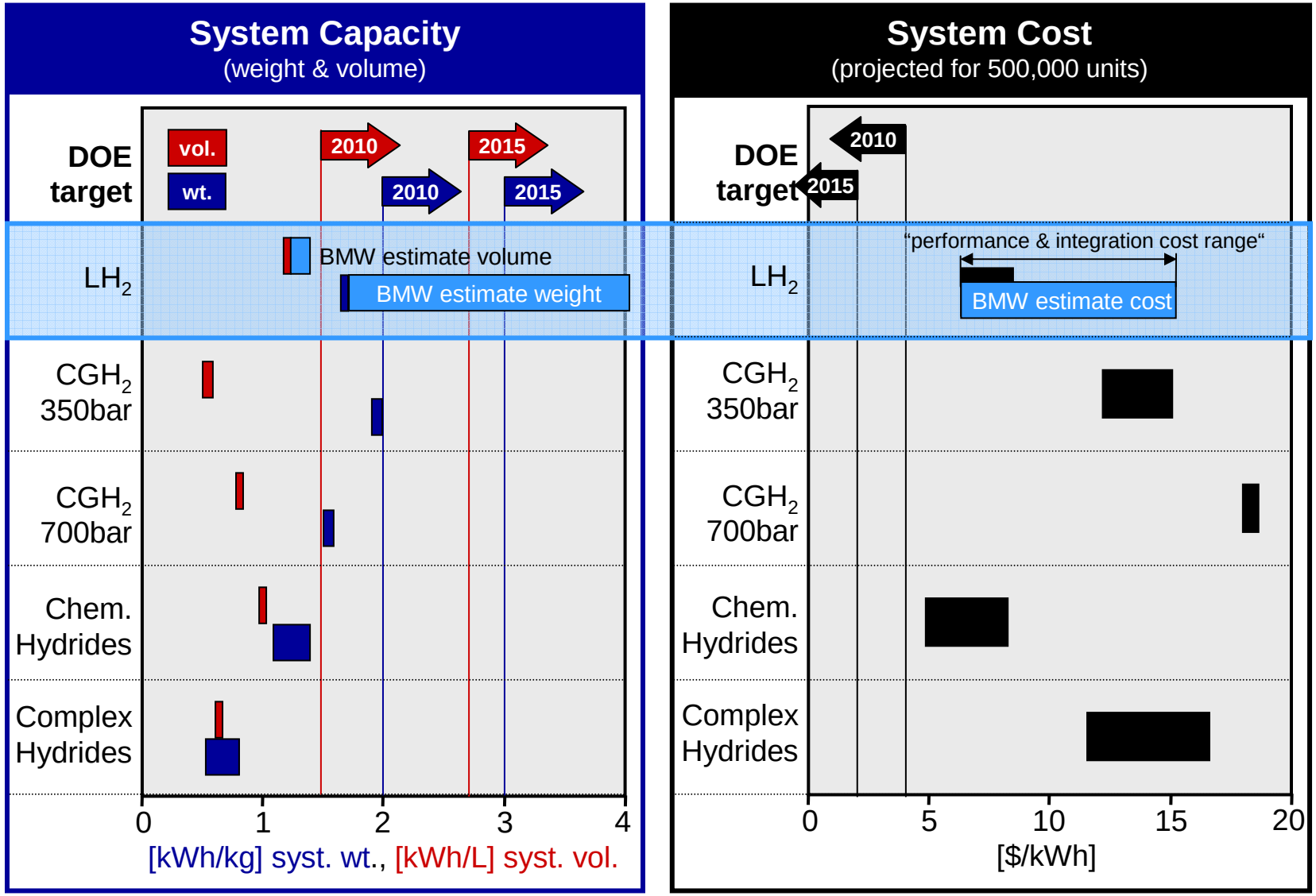
Storage capacity and cost estimate.



"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_2 storage systems will reach a level with satisfactory capacity and minor losses for typical customer profiles in larger vehicle classes. CGH_2 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_2 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!