

BMW CleanEnergy.

CARB ZEV Technology Symposium.



**BMW Hydrogen Near Zero Emission Vehicle
development.**

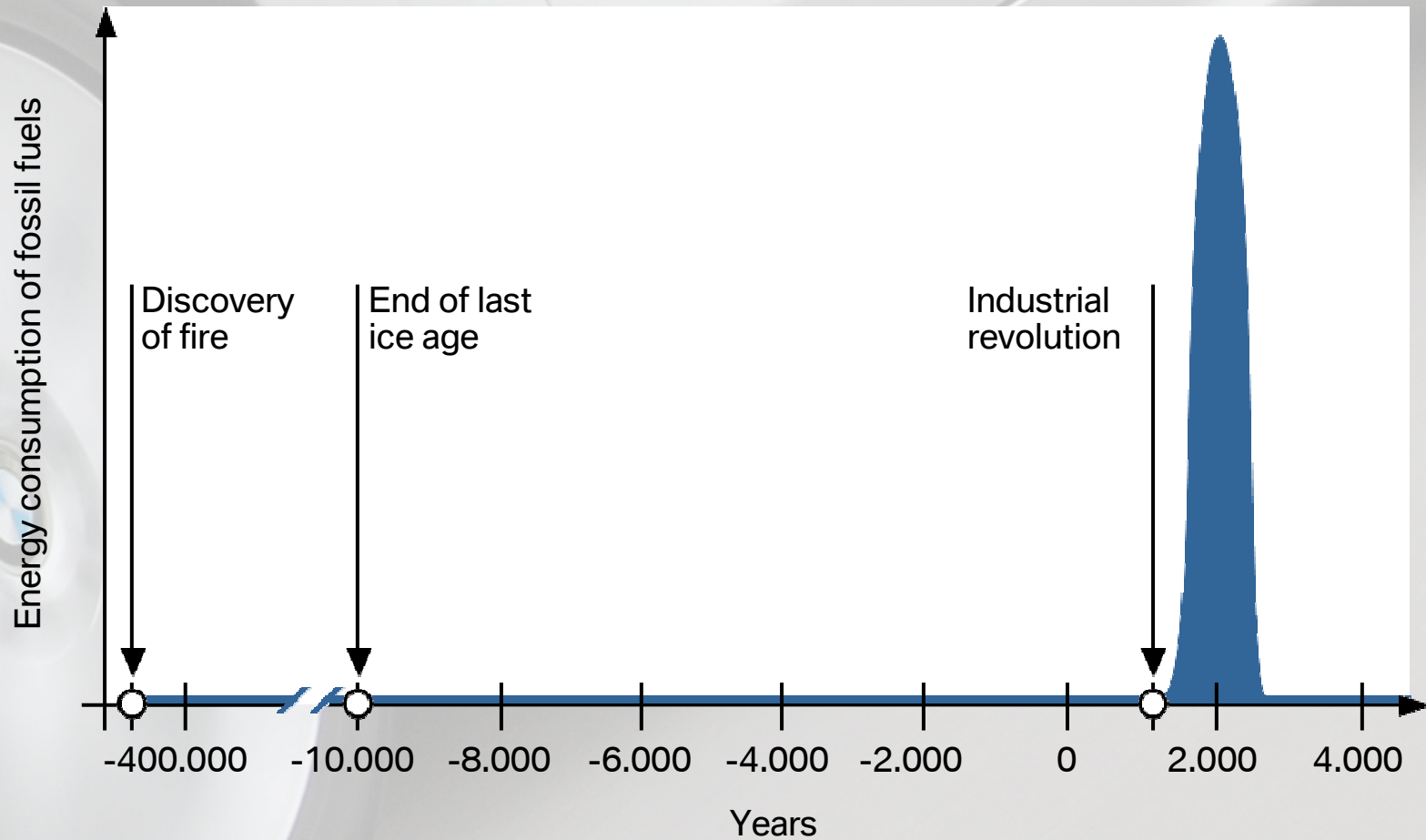
Dr. Edgar Berger.

BMW Group



BMW CleanEnergy.

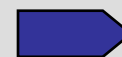
Fossil fuels as momentary event.



Challenges on the Way to Hydrogen. Requirements in transportation sector.



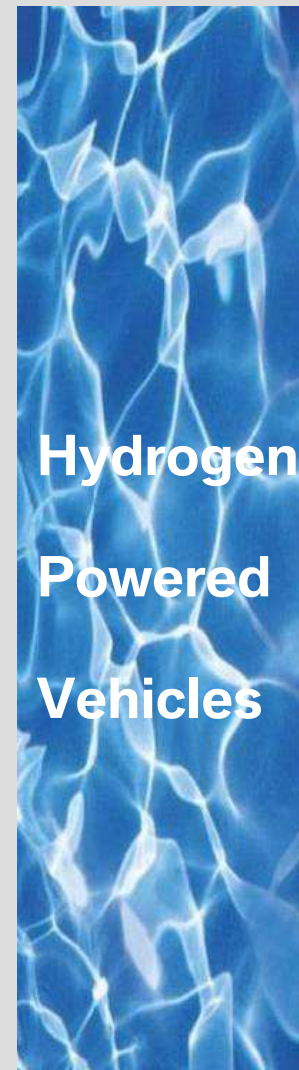
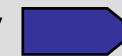
Air Quality
⇒ ZEV Mandate



Global Warming
⇒ Kyoto Protocol



Energy Security



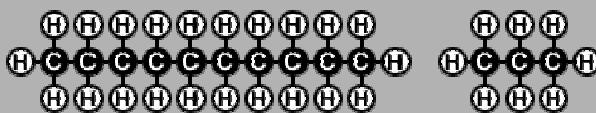


BMW Energy Strategy.

Short-term and long-term solutions.

CO₂

Today

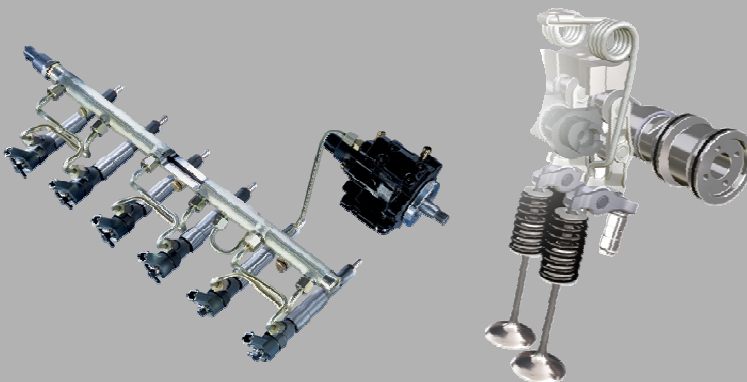


crude oil:
ratio H:C = 2.2-2.6

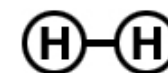
Short- and mid-term targets:

**reduction of
fuel consumption**

Gasoline: e.g. VALVETRONIC, BMW DI
Diesel: e.g. Common-Rail 2. generation



Future (renewable)



hydrogen:
ratio H:C = ∞

Long-term goal:

**Development of competitive and
Sustainable products:**

BMW CleanEnergy → H₂-vehicles





BMW CleanEnergy: H₂ ICE.

Targets H₂ powertrain development.

Efficient dynamics:

- efficiency
- power output
- weight/volume



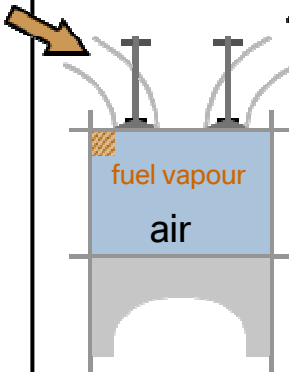
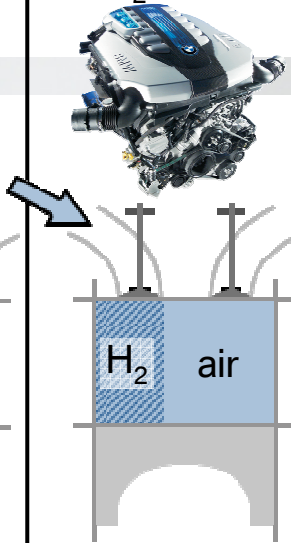
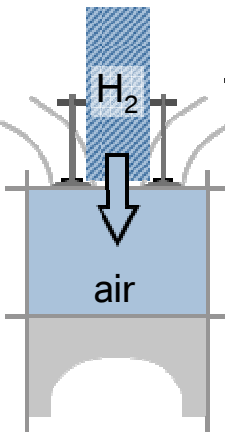
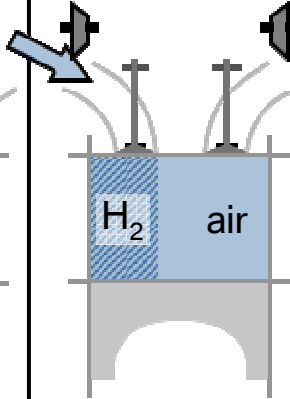
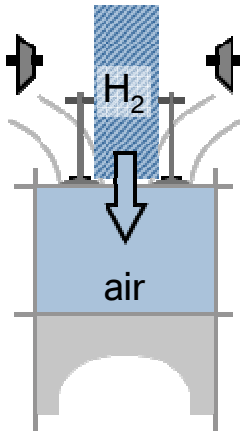
- Near Zero Emissions
- cost efficient engine production
- open issue: H₂ storage





Hydrogen internal combustion engine.

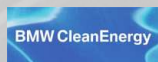
Engine concepts and power output potentials.

	Gasoline PFI	H ₂ -PFI	H ₂ -DI	charged H ₂ -PFI	charged H ₂ -DI
					
Fuel volume	17 ml	296 ml	420 ml	296 ml	420 ml
Air Volume	983 ml	704 ml	1000 ml	704 ml	1000 ml
Calorific value of mixture	100 %	84 %	120 %	$\rho_{\text{mix.}} / \rho_{\text{mix.0}} \times 84 \%$	$\rho_{\text{mix.}} / \rho_{\text{mix.0}} \times 120 \%$

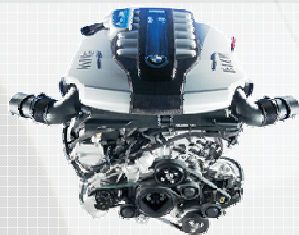
$$\eta_{\text{Vol}} = 1, \lambda = 1, V_{\text{H}} = 1000 \text{ ml}$$

BMW CleanEnergy: H₂ ICE.

Technical data H₂ 7 series.



Engine and performance



Power [kW]

Torque [Nm]

Emission level

6l-V12 bi-fuel

190 kW

390 Nm

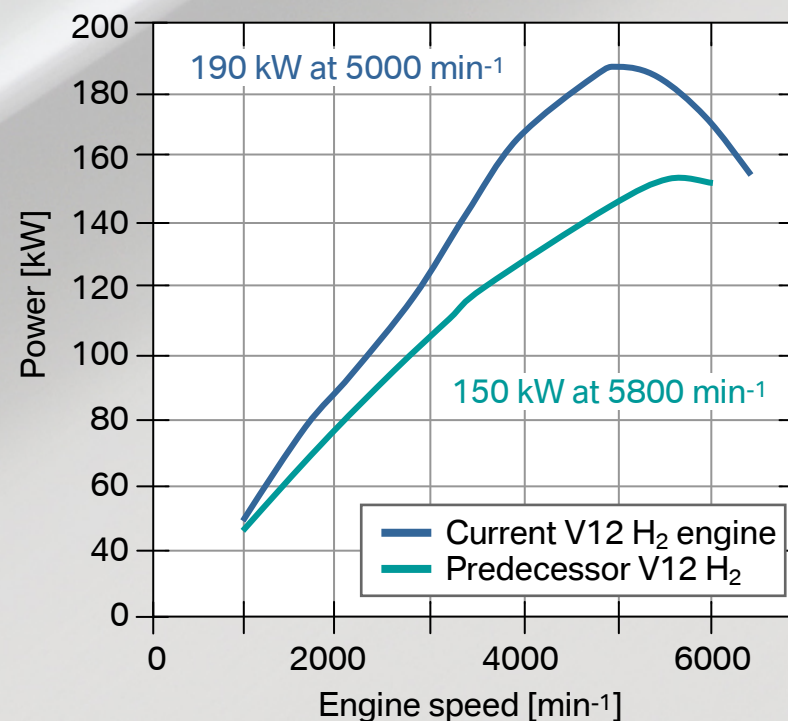
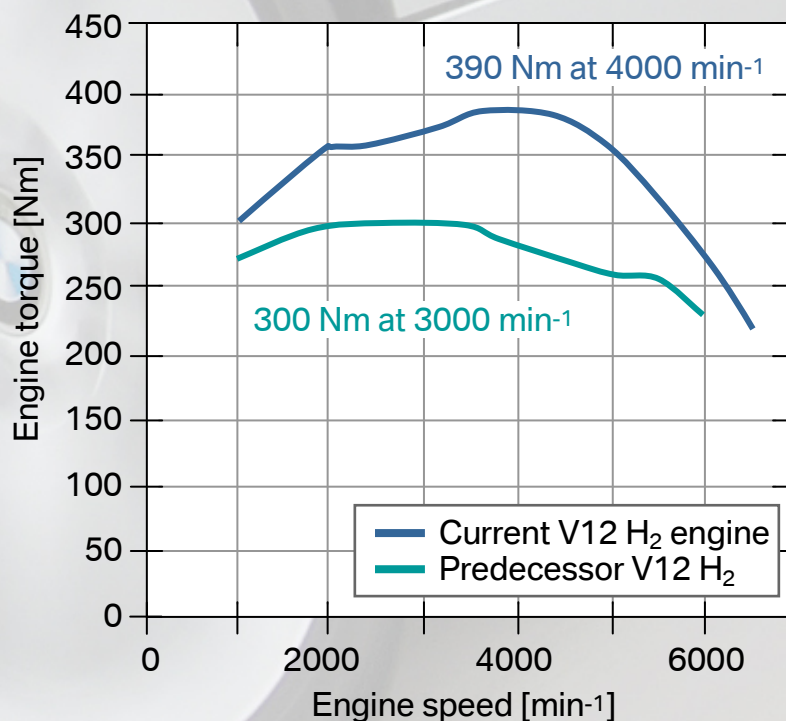
EU 4

6l-V12 mono-fuel

> 190 kW

> 390 Nm

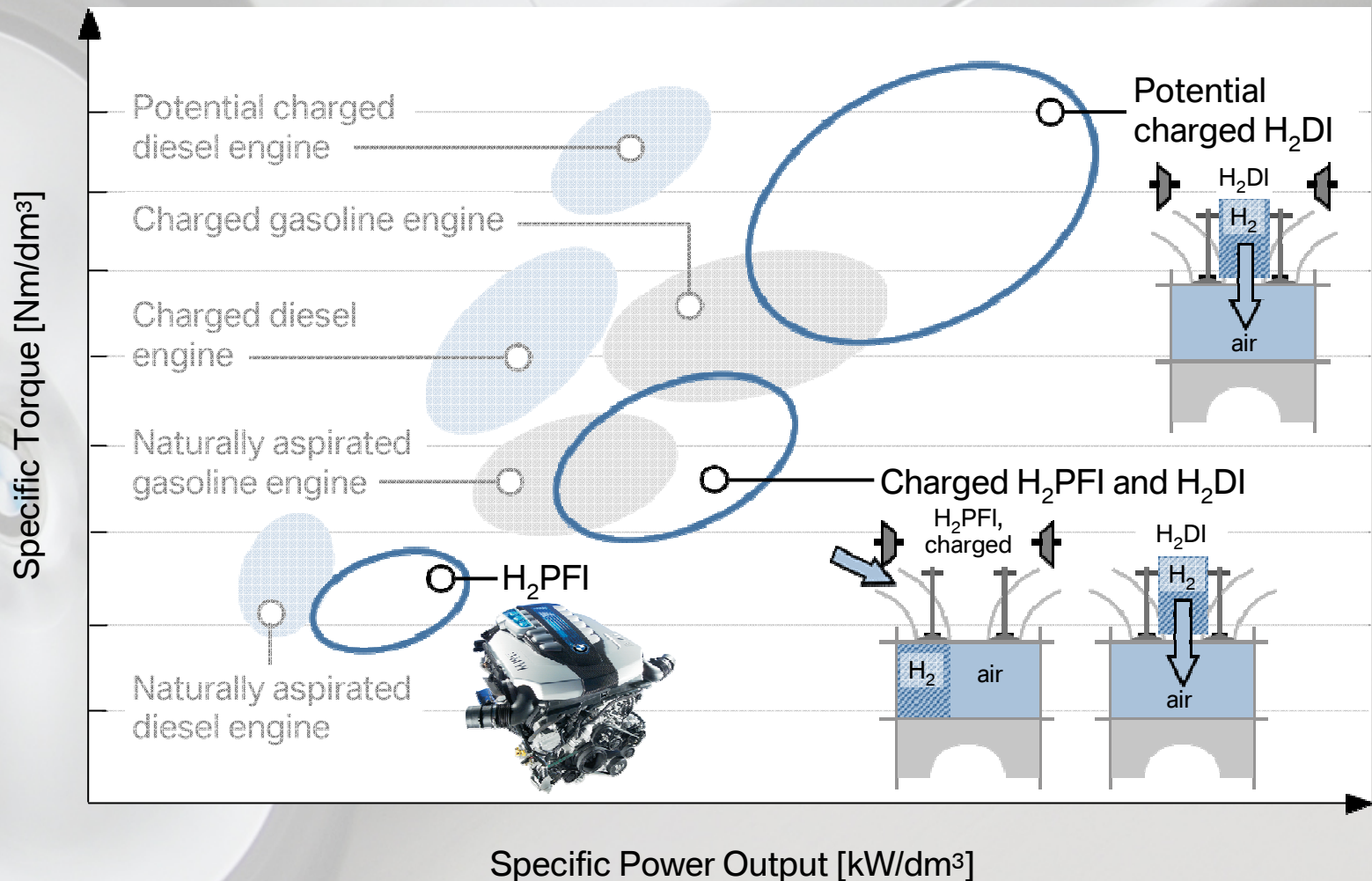
„NZEV“



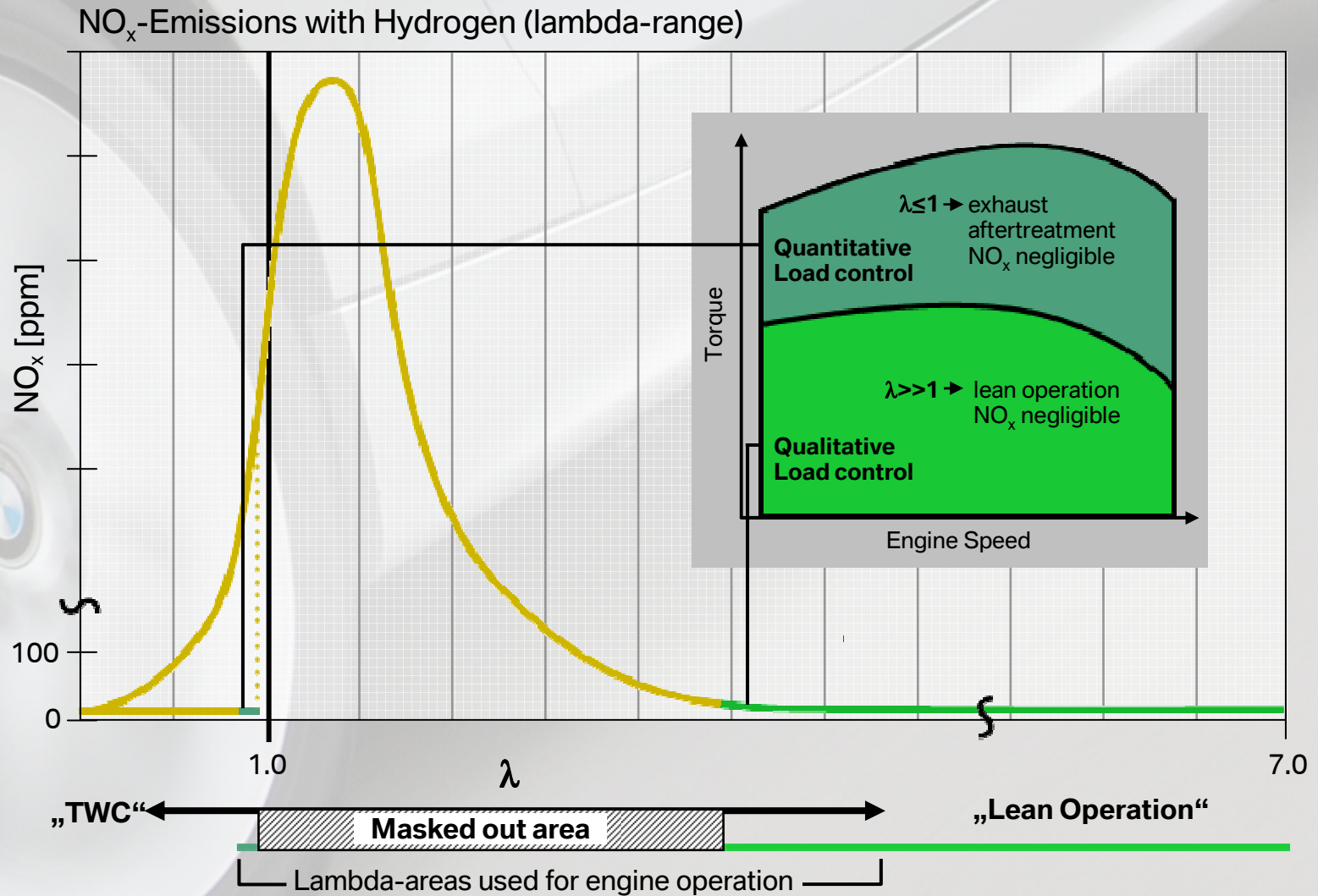


BMW CleanEnergy: H₂ ICE.

Potentials specific power output / torque.



BMW CleanEnergy: H₂ ICE. Operating strategy V12 H₂-mode.





BMW CleanEnergy: H₂ ICE. Emissions 7 series H₂ V12.

Operating points

full load $\lambda = 1$

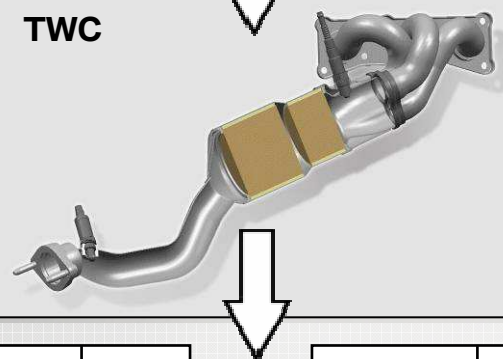
part load $\lambda \gg 1$

Exhaust gas
emissions
before catalytic
converter

	HC [ppm]	CO [ppm]	NO _x [ppm]
H ₂ ($\lambda=1$)	5	0	2000

	HC [ppm]	CO [ppm]	NO _x [ppm]
H ₂ ($\lambda \gg 1$)	< 1	0	< 1

TWC



Tailpipe
emissions

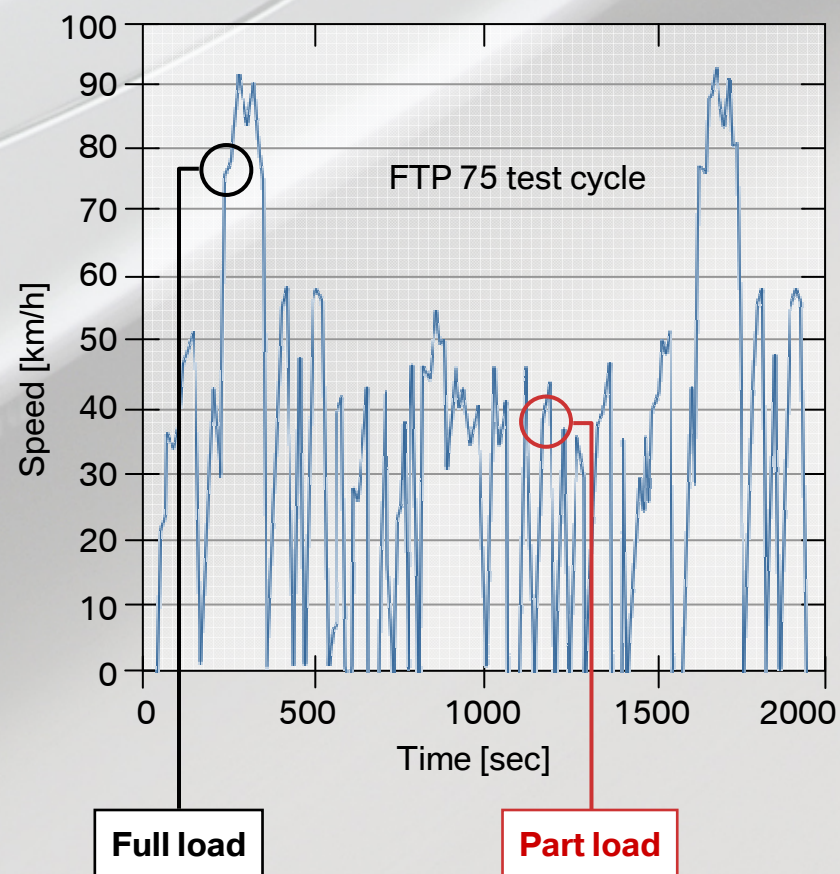
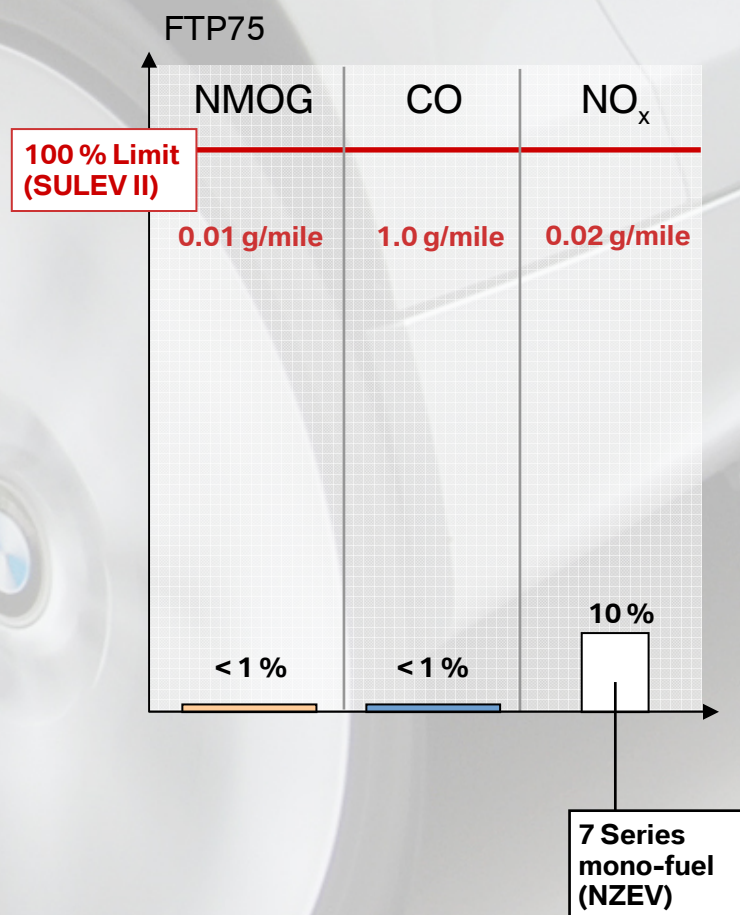
	HC [ppm]	CO [ppm]	NO _x [ppm]
H ₂ ($\lambda=1$)	< 1	0	< 1

	HC [ppm]	CO [ppm]	NO _x [ppm]
H ₂ ($\lambda \gg 1$)	< 1	0	< 1



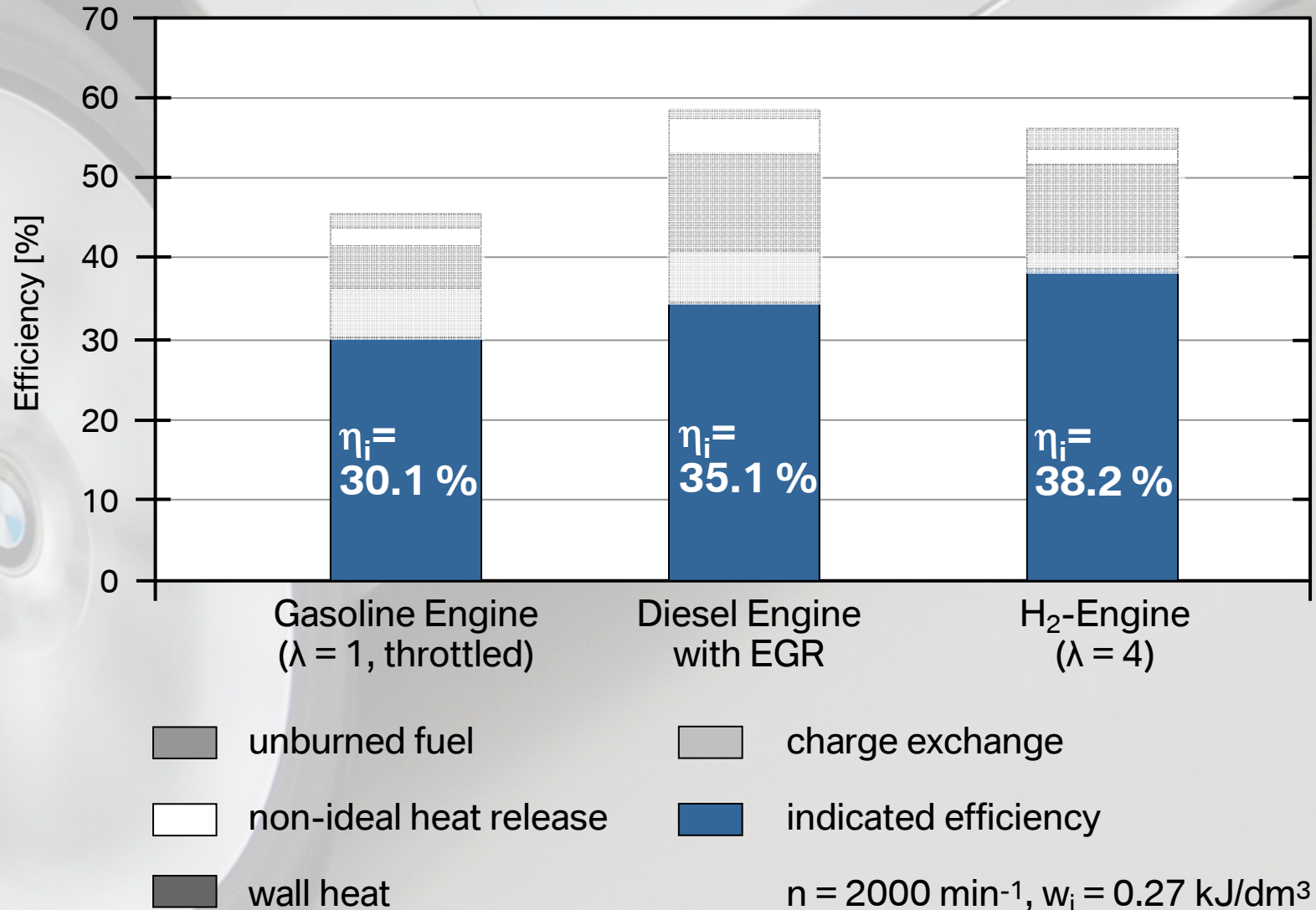
BMW CleanEnergy: H₂ ICE.

Tailpipe emissions 7 Series H₂ in FTP 75 drive cycle.

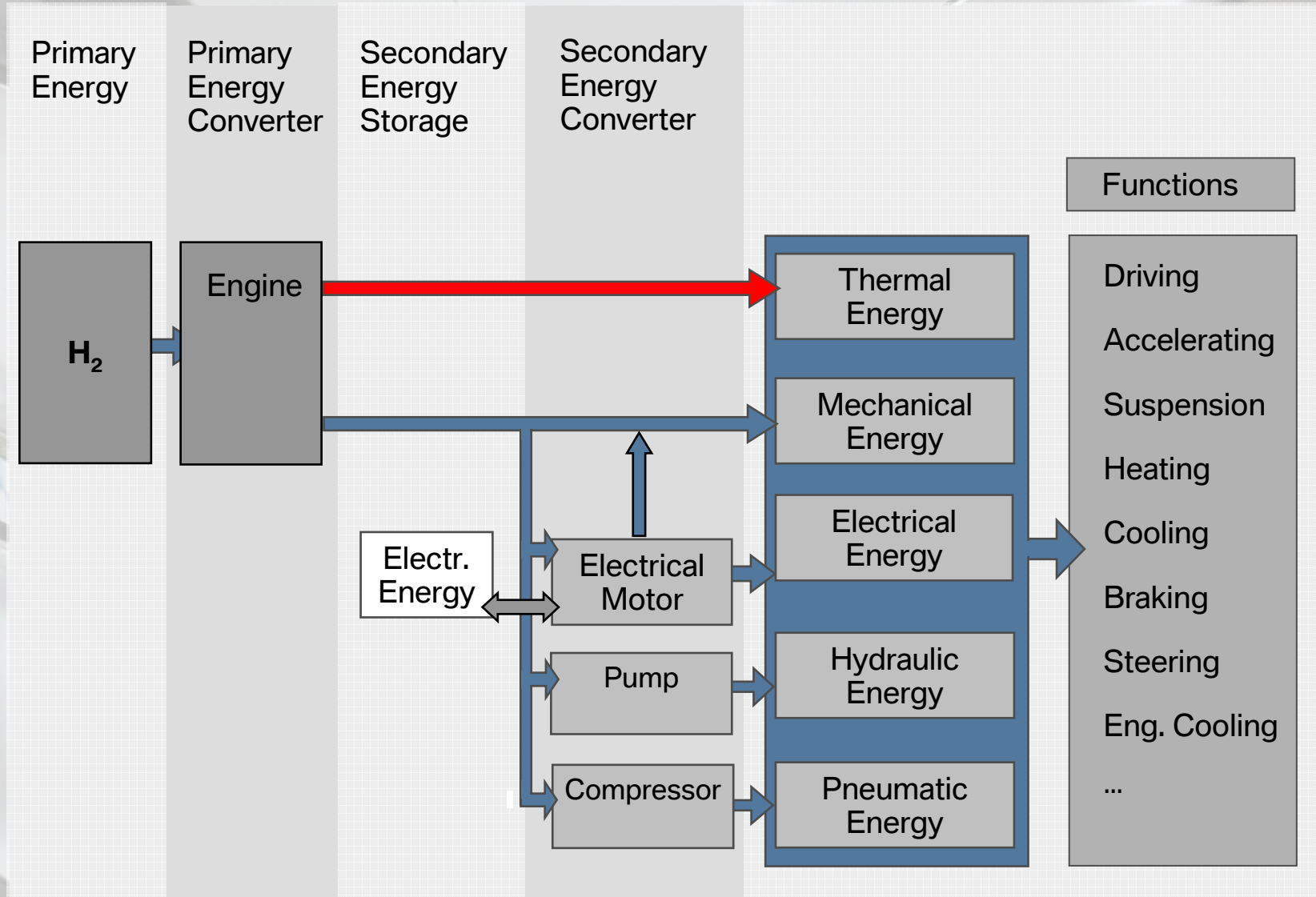


BMW CleanEnergy: H₂ ICE.

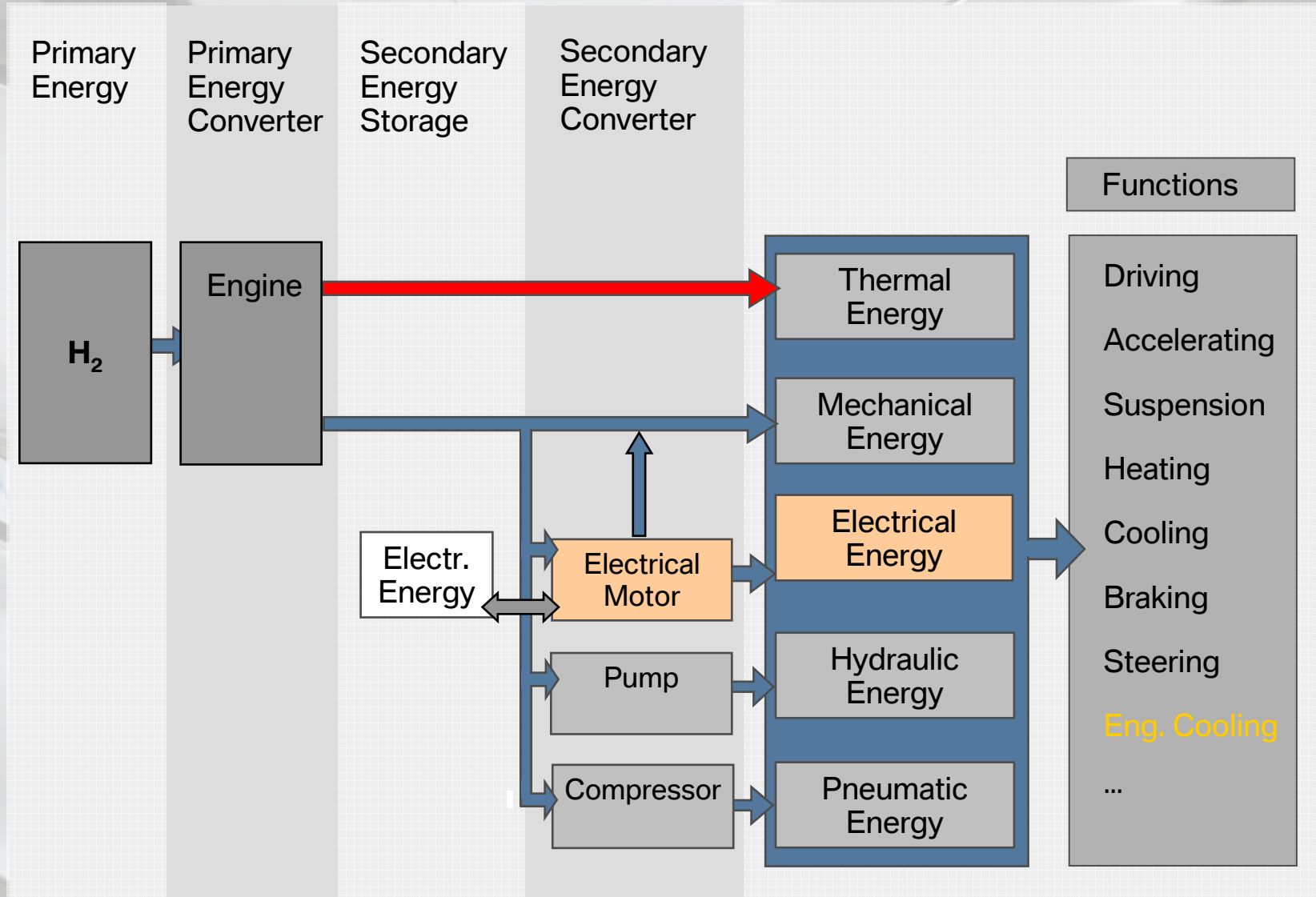
Efficiency at partial load.



Electrification of H₂ drivetrains. Energy management.



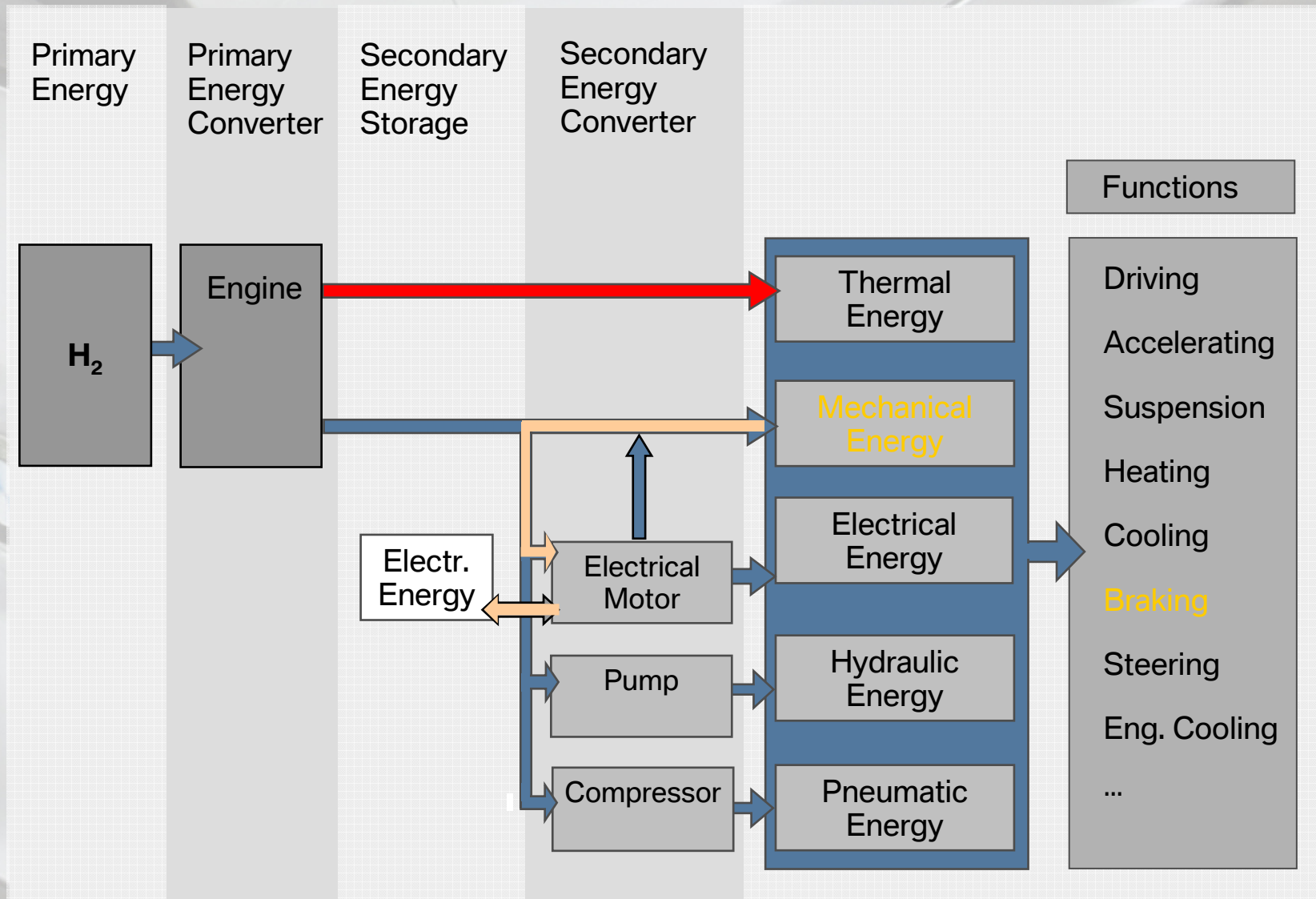
Electrification of H₂ drivetrains. Energy management.





Electrification of H₂ drivetrains.

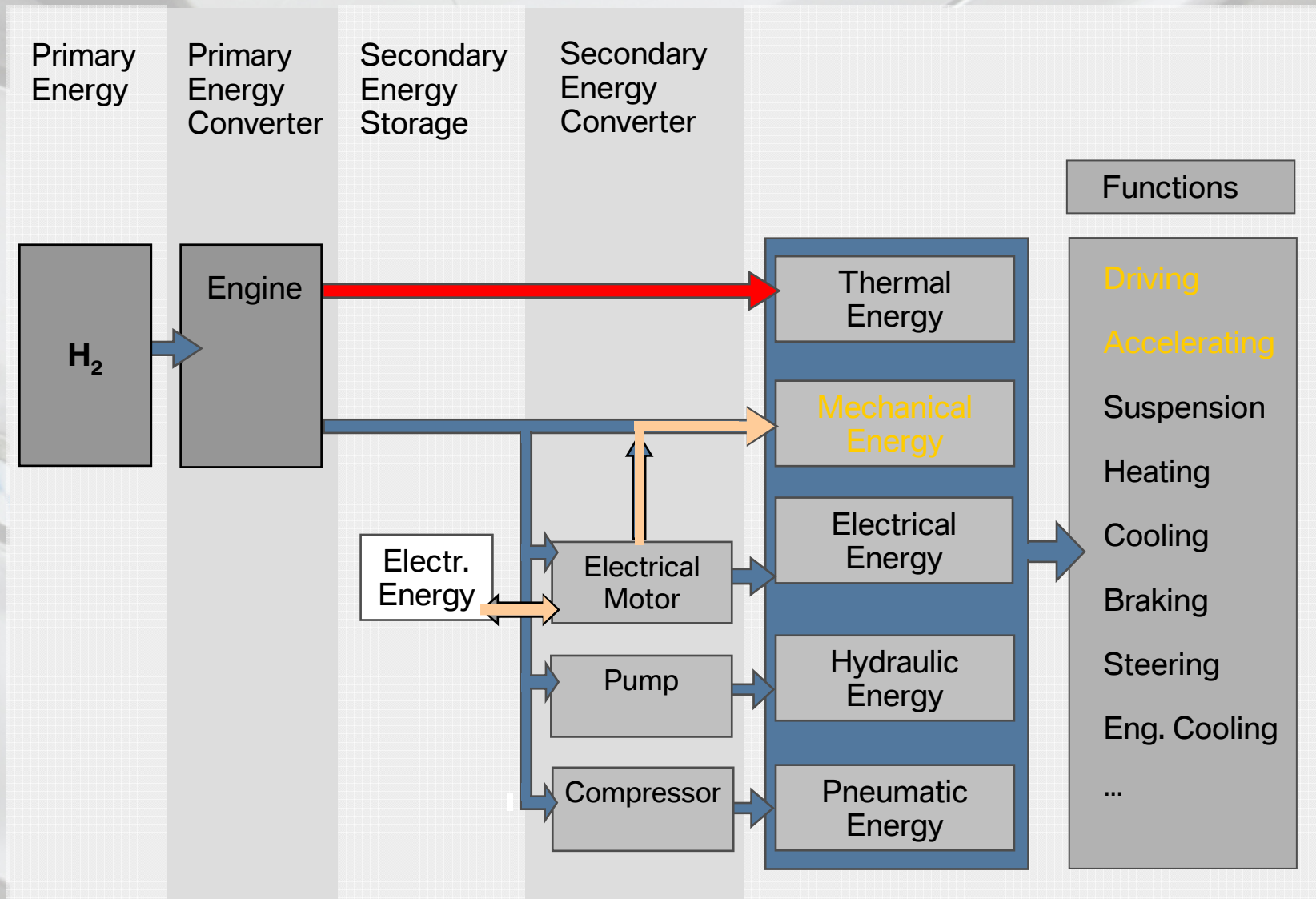
Hybrid powertrain systems: Recuperation.





Electrification of H₂ drivetrains.

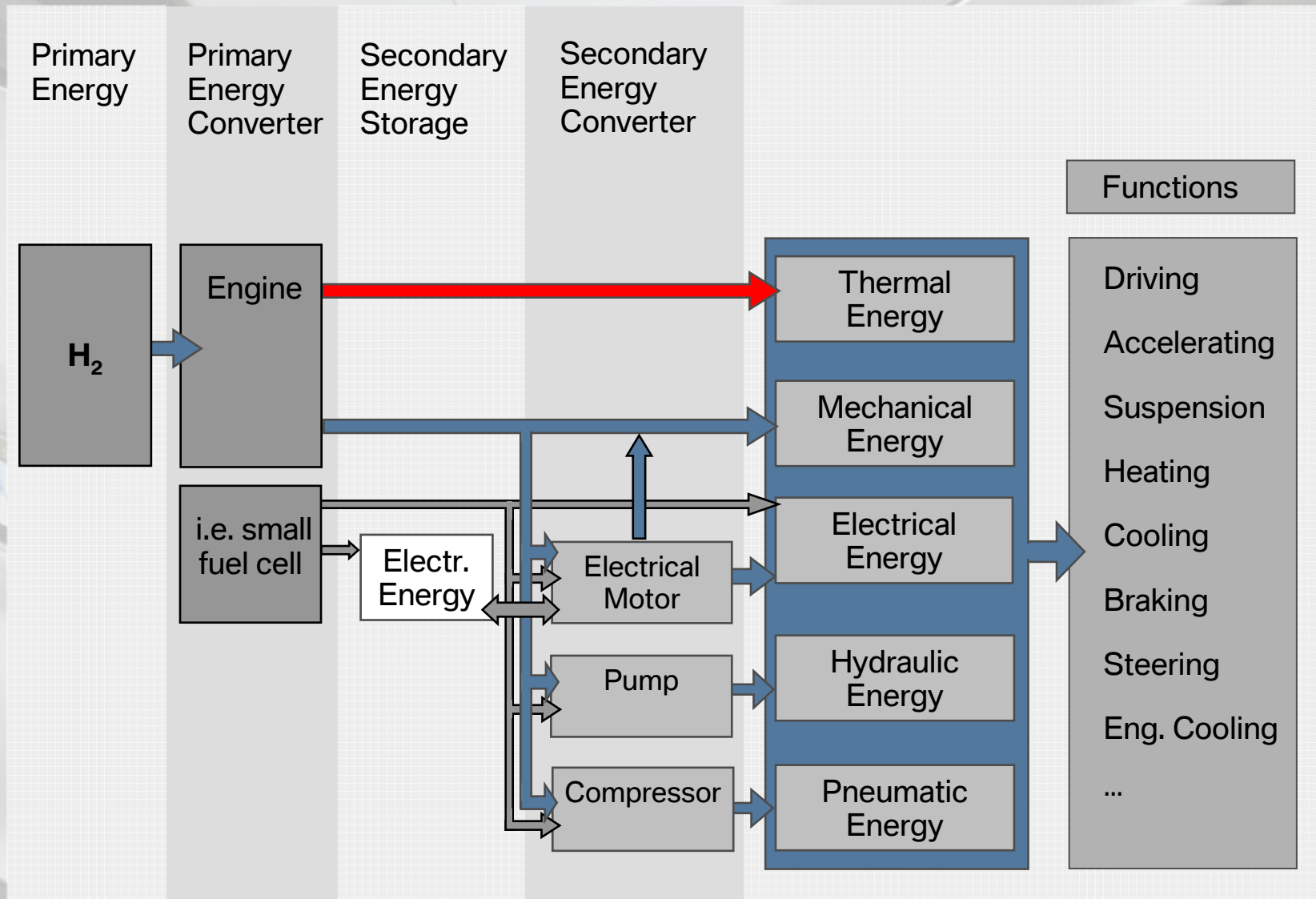
Hybrid powertrain systems: Assisting/Electric driving.





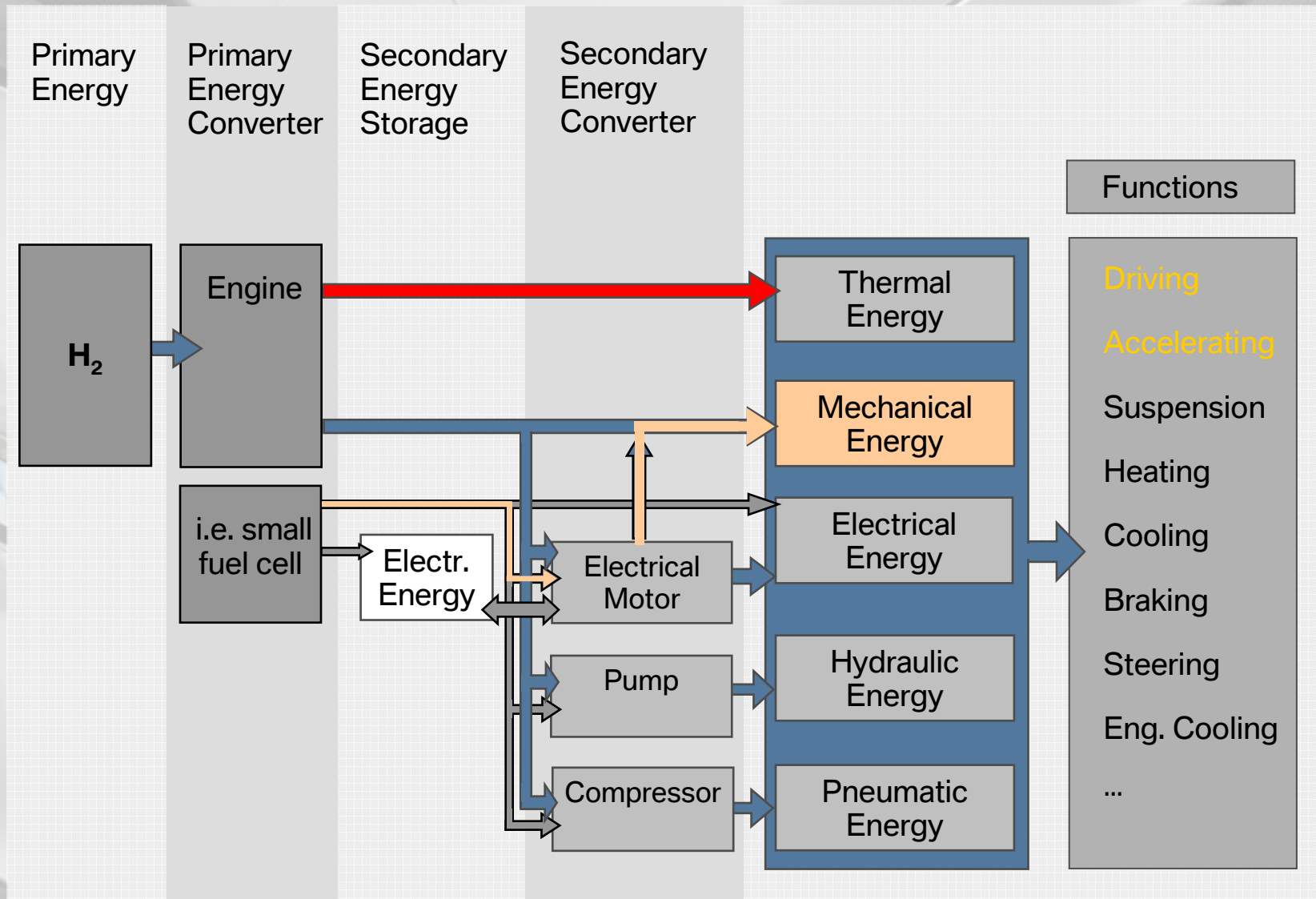
Future option for electrification of drivetrains.

Advanced energy management.



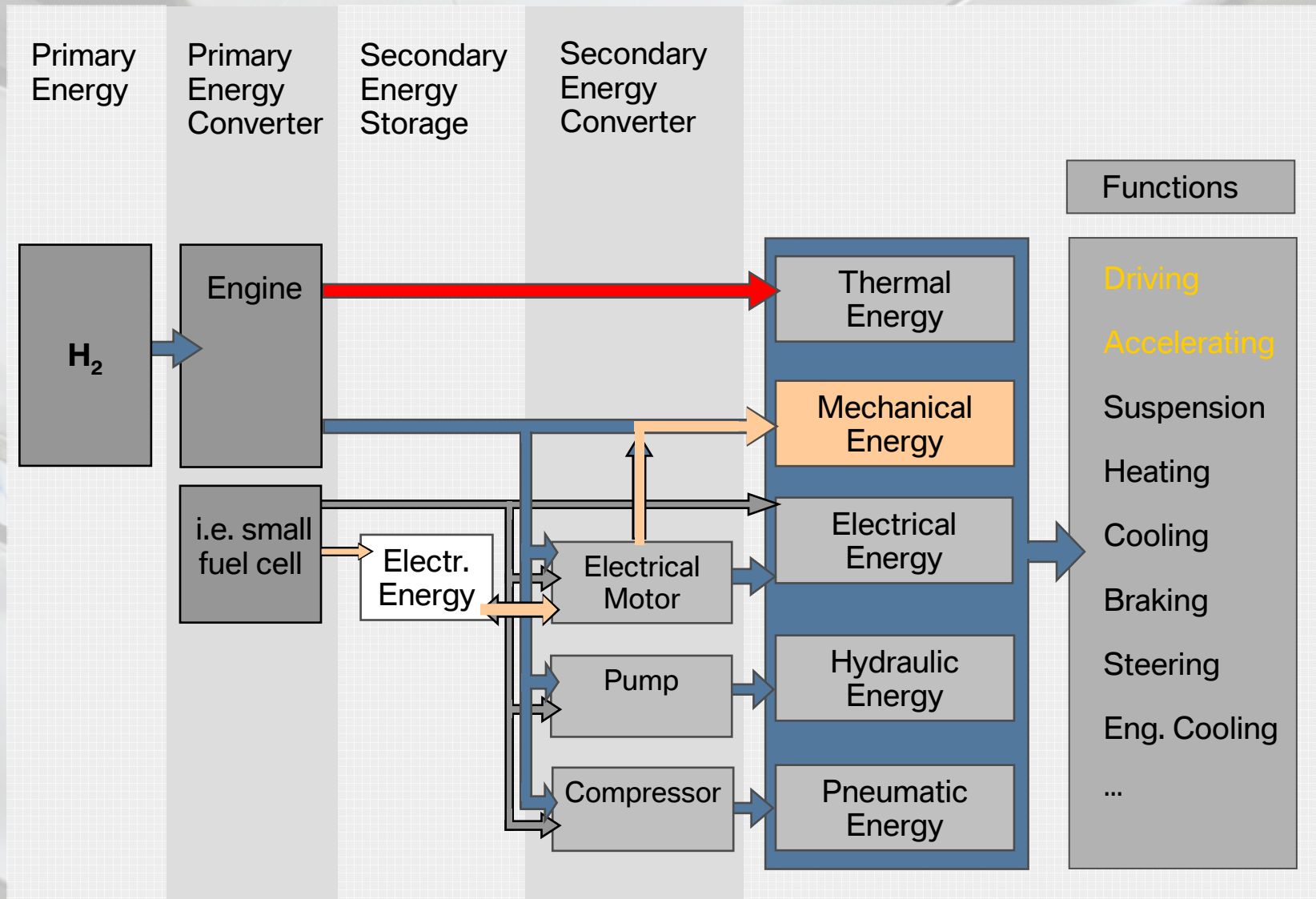


Electrification of H₂ drivetrains. Advanced energy management.





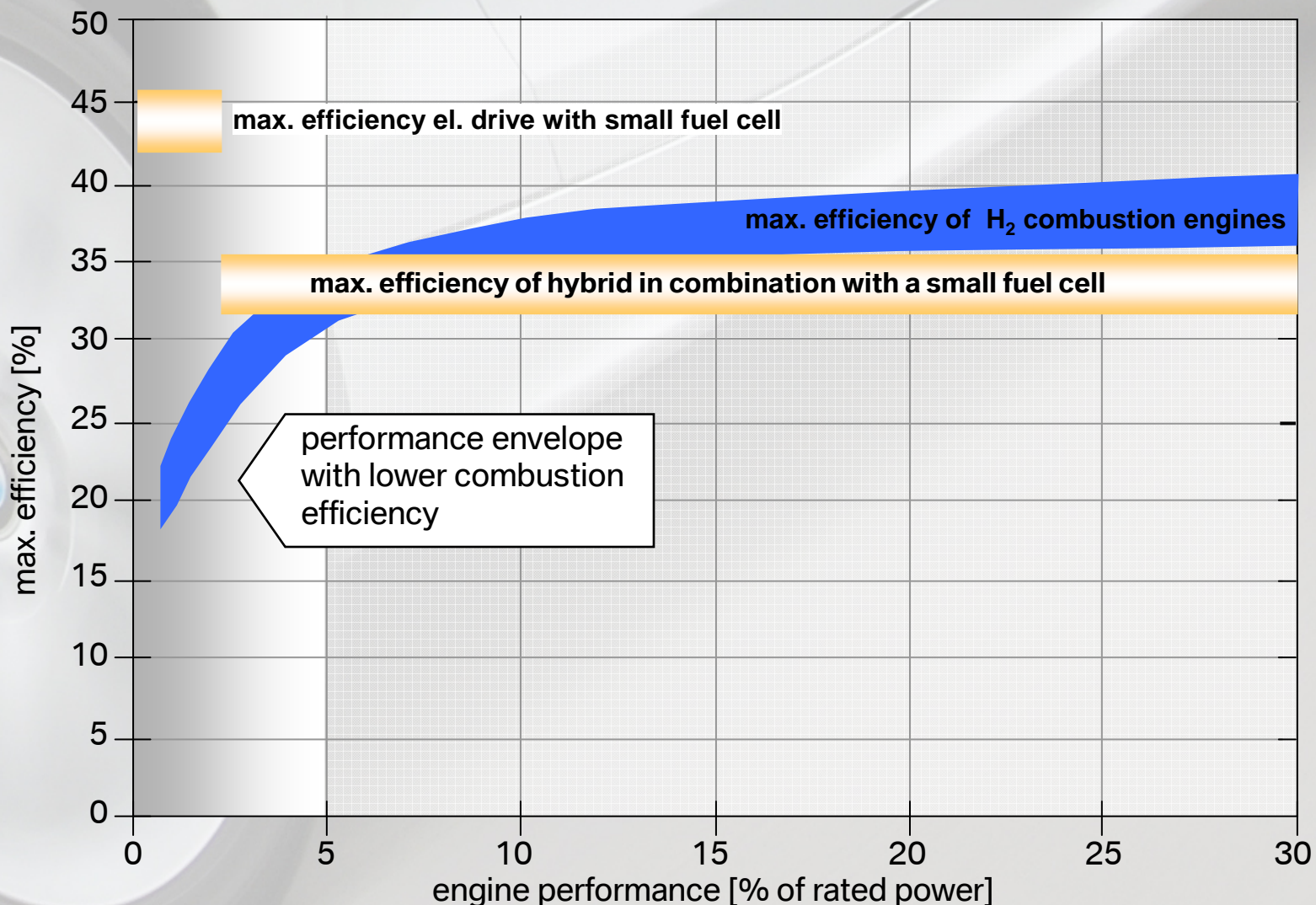
Electrification of H₂ drivetrains. Advanced energy management.





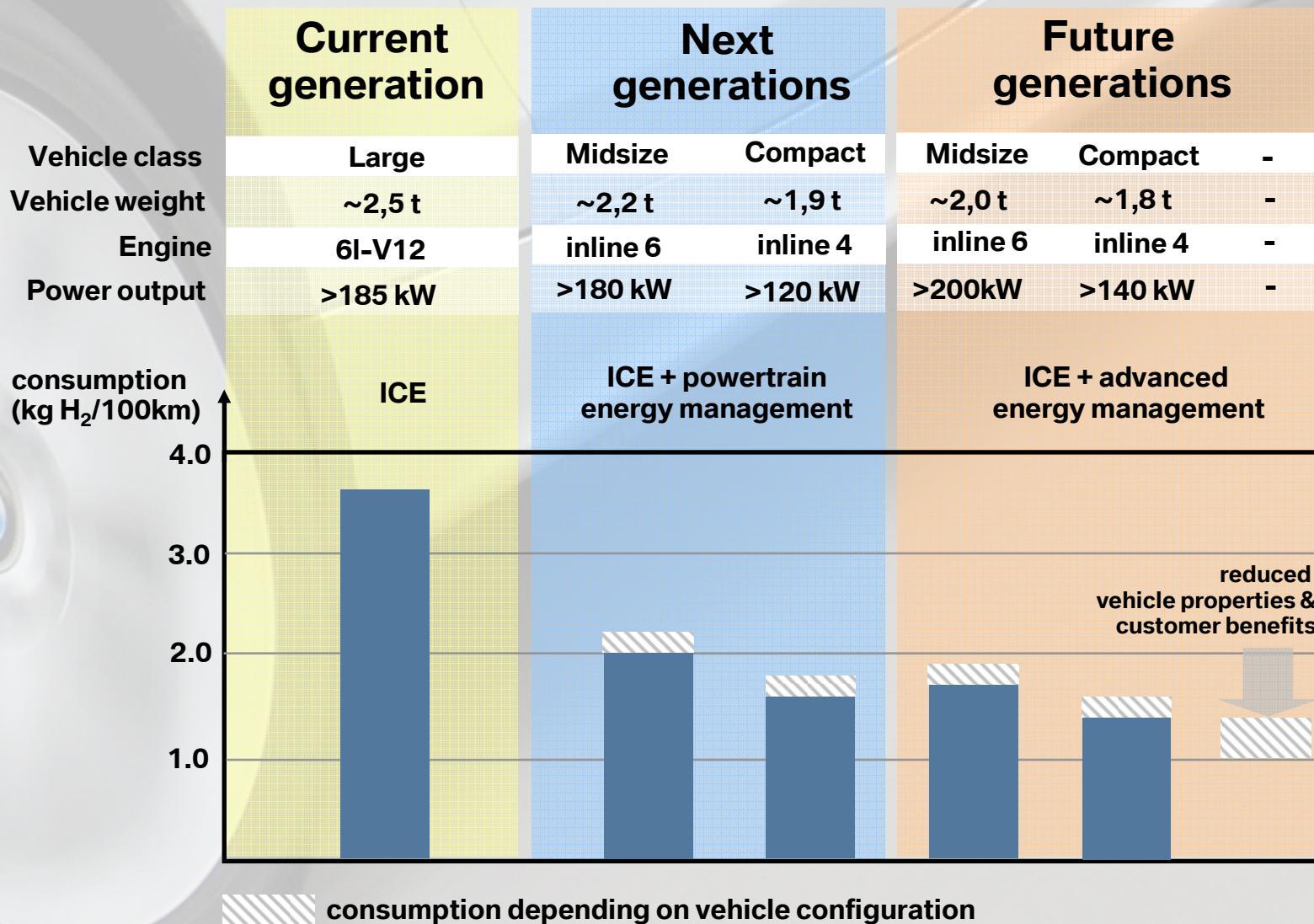
Electrification of H₂ drivetrains.

Efficiency characteristics for advanced energy management example with small fuel cell.



BMW CleanEnergy: H₂ ICE.

Potential fuel consumption of NZEVs in NEDC.





BMW Powertrain Strategy.

ZEV gold standard - chances and barriers.

New challenges for ZEV

Air Quality

⇒ ZEV Mandate

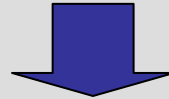


Global Warming

⇒ Kyoto Protocol



Energy Security



requires broader long-term view for solutions that meet:

- wide market acceptance and affordability
- clean air goals and provide a sustainable mobility future
- efficient usage of all available resources

The development of a viable future hydrogen infrastructure corresponding with customer-acceptable hydrogen vehicle population can meet these requirements, but hydrogen is not yet sufficiently available.



BMW Powertrain Strategy.

ZEV-Technology Hydrogen Vehicle Powertrain Option.

ZEV-Technology requirements	H ₂ ICE powertrains
(Near) Zero Emission Vehicle	✓
high fuel economy*	✓
high power density	✓
relatively low costs of production	✓
proven durability	✓

- Broadening the scope of ZEV mandate to facilitate different technology options
 - Future challenge: build-up a H₂ infrastructure
- need to review ZEV mandate



*H₂ ICE +
advanced energy
management

BMW CleanEnergy: H₂ ICE. Conclusion.



- **7 Series with bi-fuel engine:**
 - first H₂ vehicle in production development
 - customer oriented vehicle concept with fall back gasoline mode
- **7 Series mono-fuel as NZEV:**
 - emissions far below SULEVII level
 - very low emissions in $\lambda \gg 1$ operation
 - very low emissions after TWC in $\lambda = 1$ operation
 - potential: near zero emission with H₂ mode
- **Next generations hydrogen vehicles:**
 - customer friendly integration of storage system
 - near zero emission
 - increased power density and fuel efficiency
 - advanced hydrogen vehicle energy-management

Thanks for your attention.





Material properties of Hydrogen.

Comparison with gasoline.

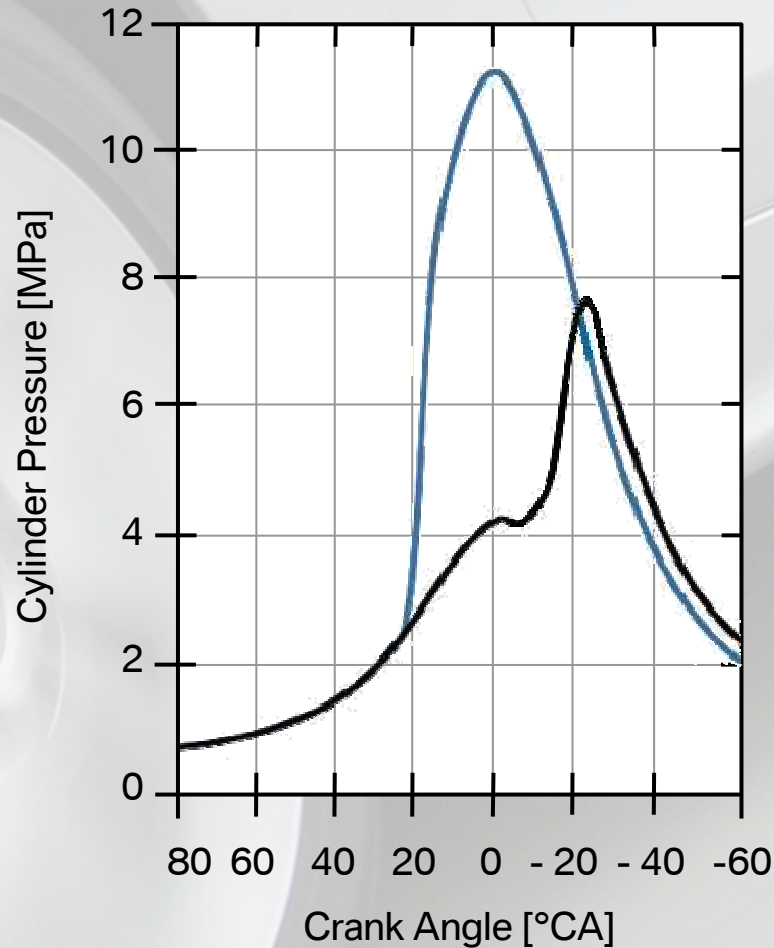
	Gasoline	Hydrogen
Heating value H_l (MJ/kg)	43	120 (=2.8-fold)
Energy density (MJ/dm ³)	31.4 (=3.8-fold)	LH ₂ : 8.5
Laminar flame velocity* (cm/s) (normal conditions)	30	250
Flammability limit (Vol.%) Flammability limit (Lambda)	1-7.6 1.65 - 0.2	4-75 10 - 0.14
Ignition energy* (mJ)	0.24	0.017
Flame temperatur (°C) (30 bar and 650K at TDC)	2630	2770



*stoichiometric air/fuel ratio

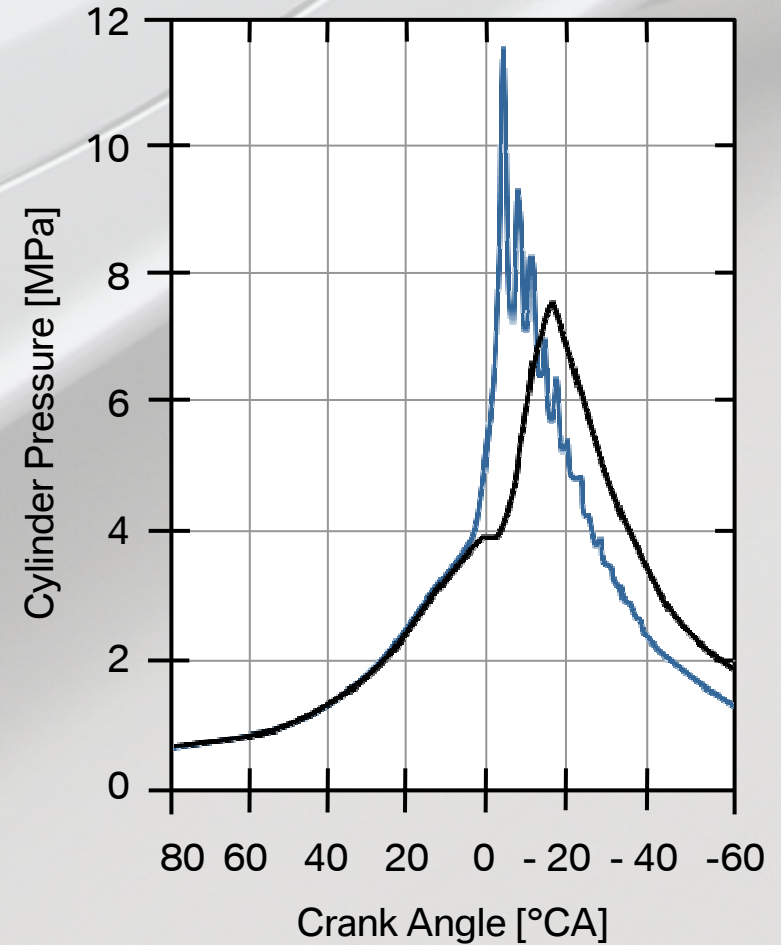




H₂ combustion process.

Examples for irregular Combustions at $\lambda=1$.



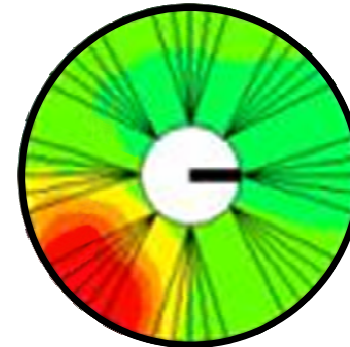
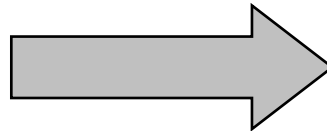
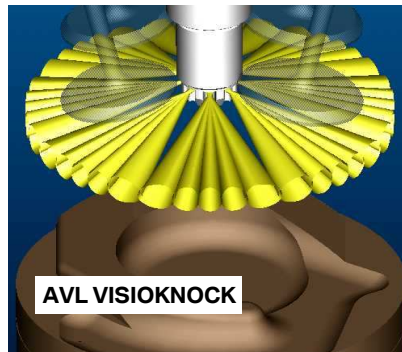
 **Pre-ignition**
 **regular combustion**



 **engine knock**
 **regular combustion**

H₂ combustion process.

Combustion process development.



pre-ignition

Measures:

- engine design
- minimisation of residual gas
- choice of materials
- injection timing and duration
- ignition timing

➡ **Regular engine operation**

