

# **BMW CleanEnergy.**

## **CARB ZEV Technology Symposium.**



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

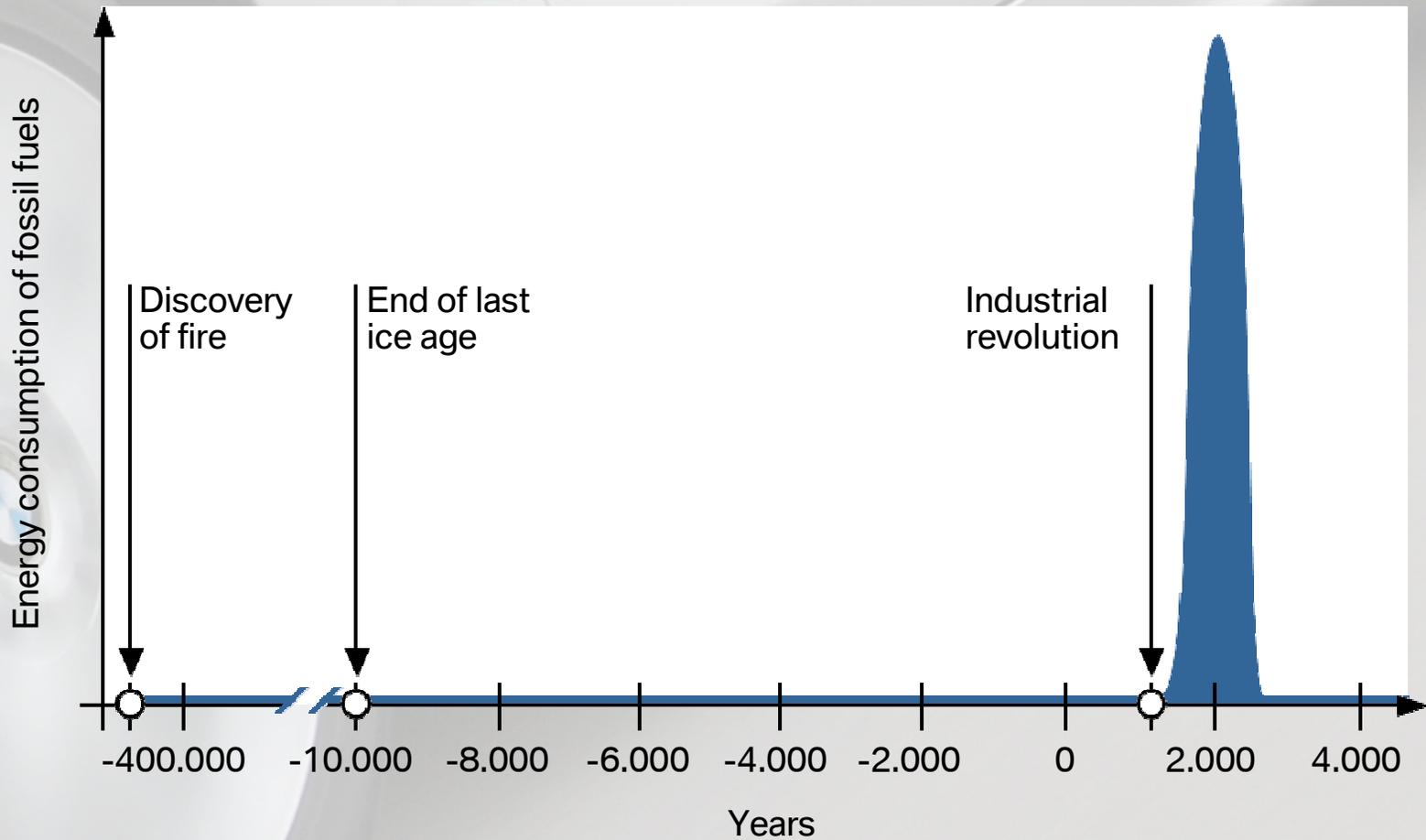
**Dr. Edgar Berger.**

**BMW Group**



# BMW CleanEnergy.

## Fossil fuels as momentary event.



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

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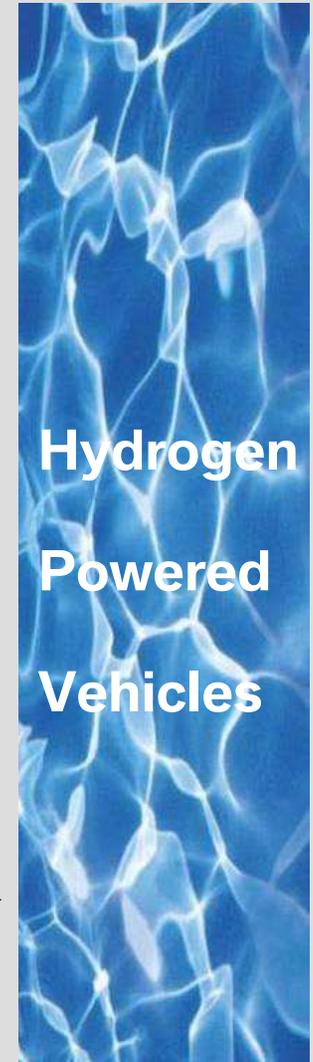
**Air Quality**  
⇒ ZEV Mandate



**Global Warming**  
⇒ Kyoto Protocol



**Energy Security**



# BMW Energy Strategy.

## Short-term and long-term solutions.

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CO<sub>2</sub>

Today

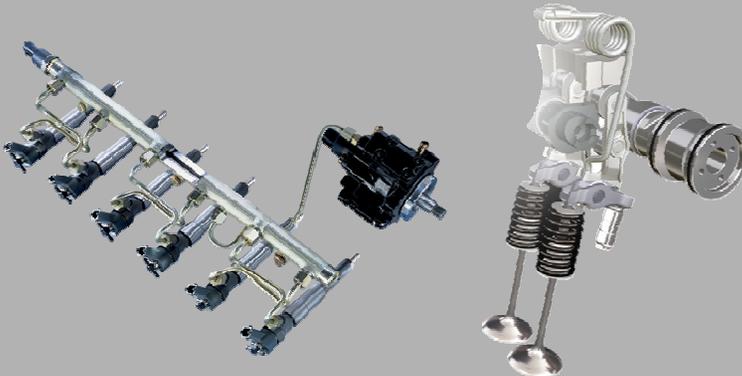


crude oil:  
ratio H:C = 2.2-2.6

**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 → H<sub>2</sub>-vehicles



# BMW CleanEnergy: H<sub>2</sub> ICE.

## Targets H<sub>2</sub> powertrain development.

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### Efficient dynamics:

- efficiency
- power output
- weight/volume



- Near Zero Emissions
- cost efficient engine production
- open issue: H<sub>2</sub> storage



# Hydrogen internal combustion engine. Engine concepts and power output potentials.



	Gasoline PFI	H <sub>2</sub> -PFI	H <sub>2</sub> -DI	charged H <sub>2</sub> -PFI	charged H <sub>2</sub> -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: H<sub>2</sub> ICE.

## Technical data H<sub>2</sub> 7 series.



### Engine and performance



Power [kW]

Torque [Nm]

Emission level

**6l-V12 bi-fuel**

190 kW

390 Nm

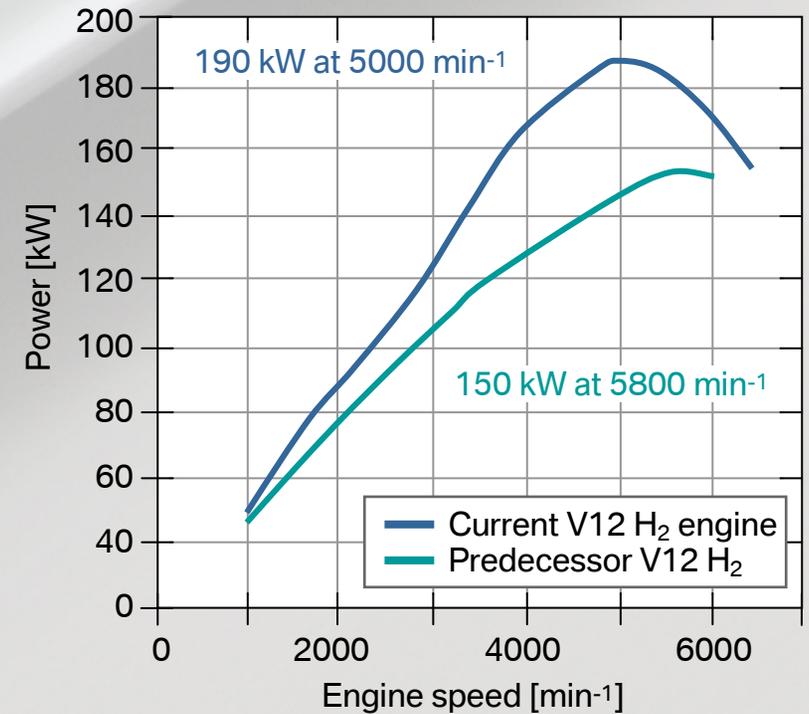
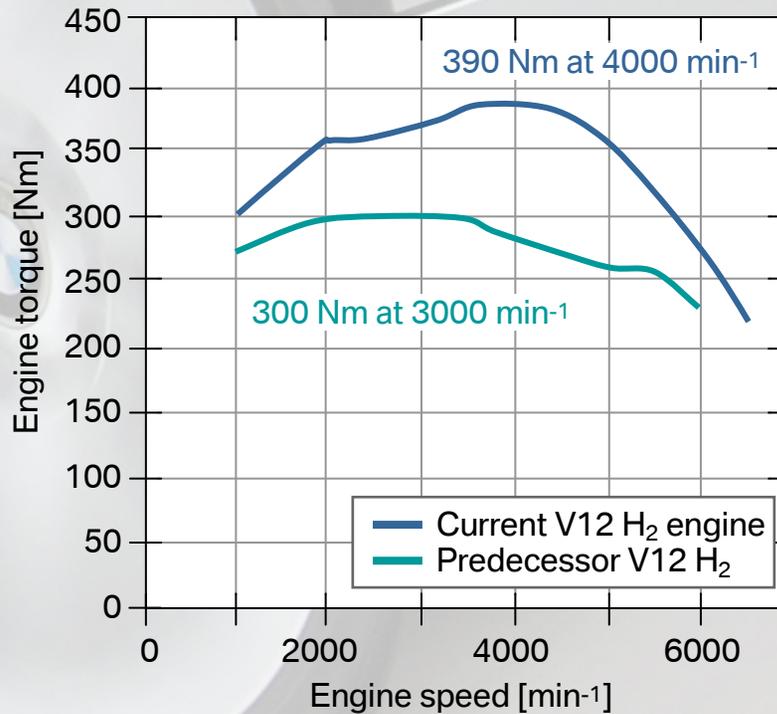
EU 4

**6l-V12 mono-fuel**

> 190 kW

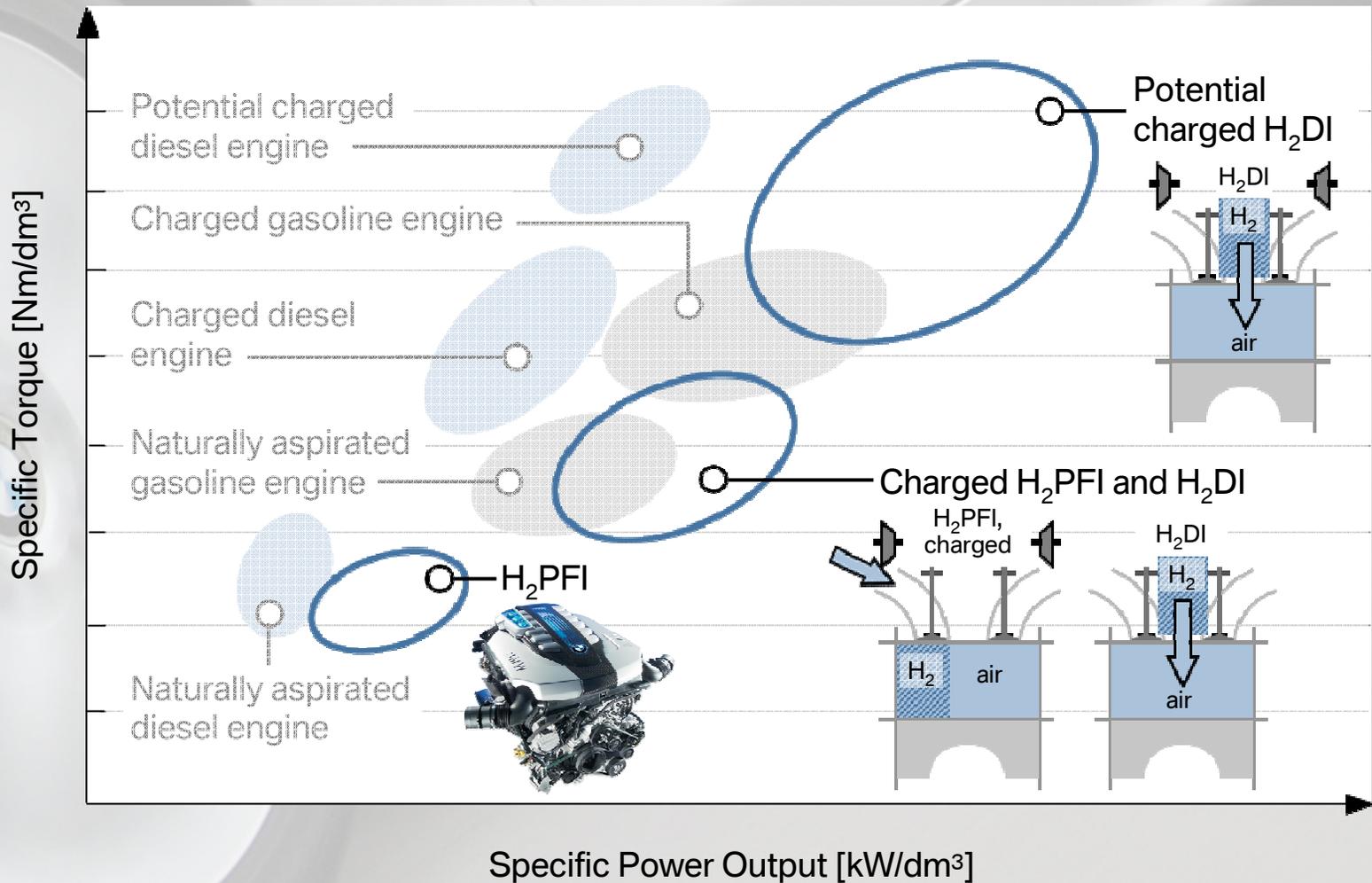
> 390 Nm

„NZEV“



# BMW CleanEnergy: H<sub>2</sub> ICE.

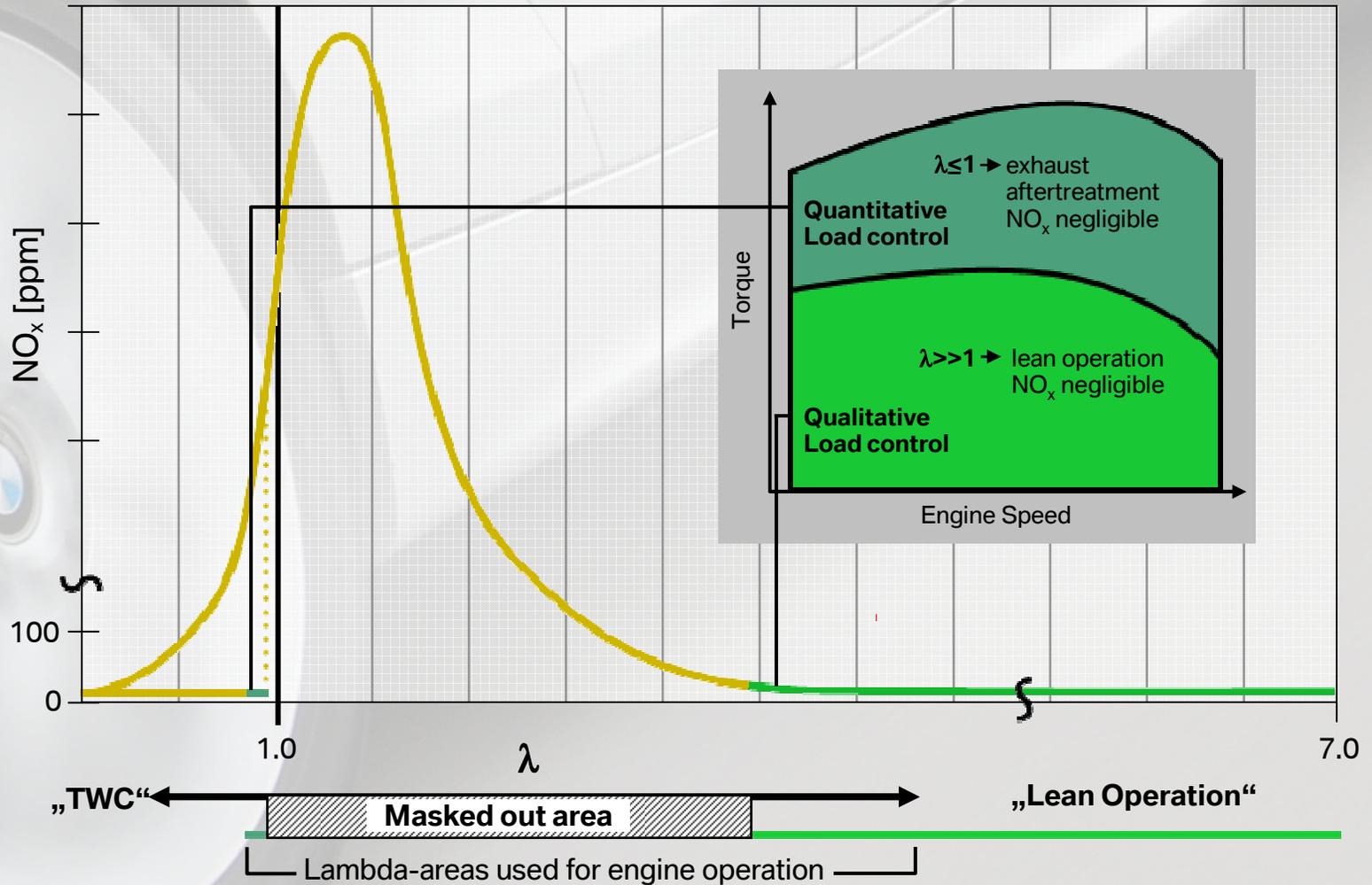
## Potentials specific power output / torque.



# BMW CleanEnergy: H<sub>2</sub> ICE. Operating strategy V12 H<sub>2</sub>-mode.



NO<sub>x</sub>-Emissions with Hydrogen (lambda-range)



# BMW CleanEnergy: H<sub>2</sub> ICE. Emissions 7 series H<sub>2</sub> V12.



Operating points

full load  $\lambda = 1$

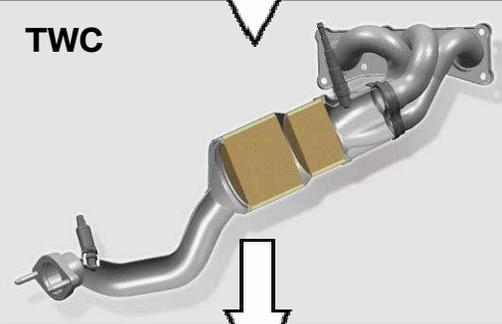
part load  $\lambda \gg 1$

Exhaust gas  
emissions  
before catalytic  
converter

	HC [ppm]	CO [ppm]	NO <sub>x</sub> [ppm]
H <sub>2</sub> ( $\lambda=1$ )	5	0	2000

	HC [ppm]	CO [ppm]	NO <sub>x</sub> [ppm]
H <sub>2</sub> ( $\lambda \gg 1$ )	< 1	0	< 1

TWC



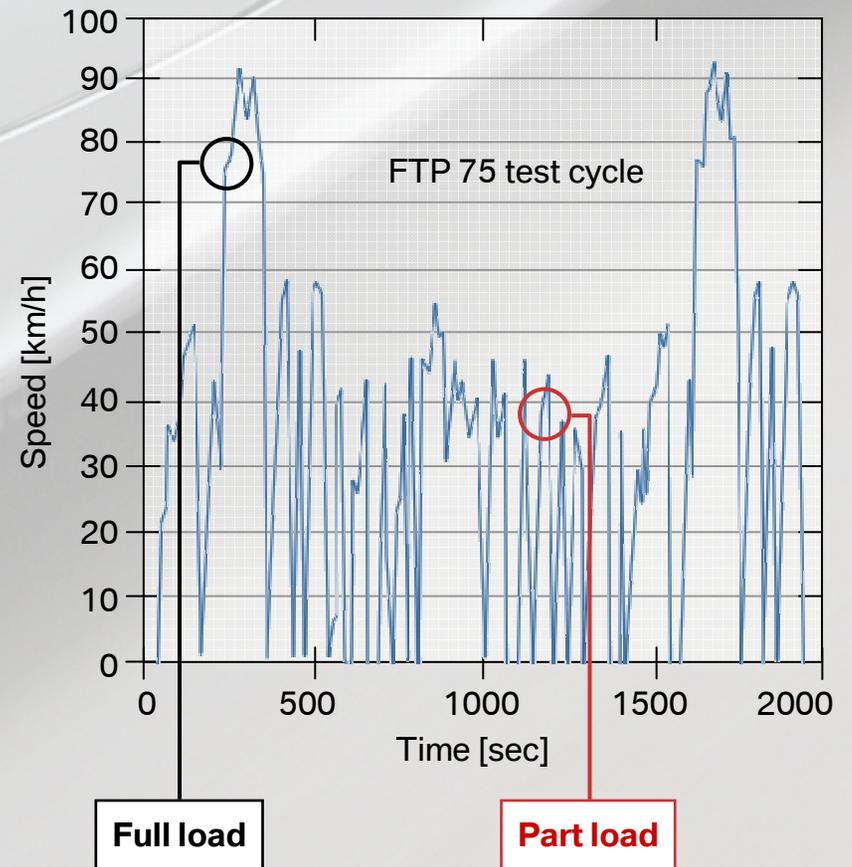
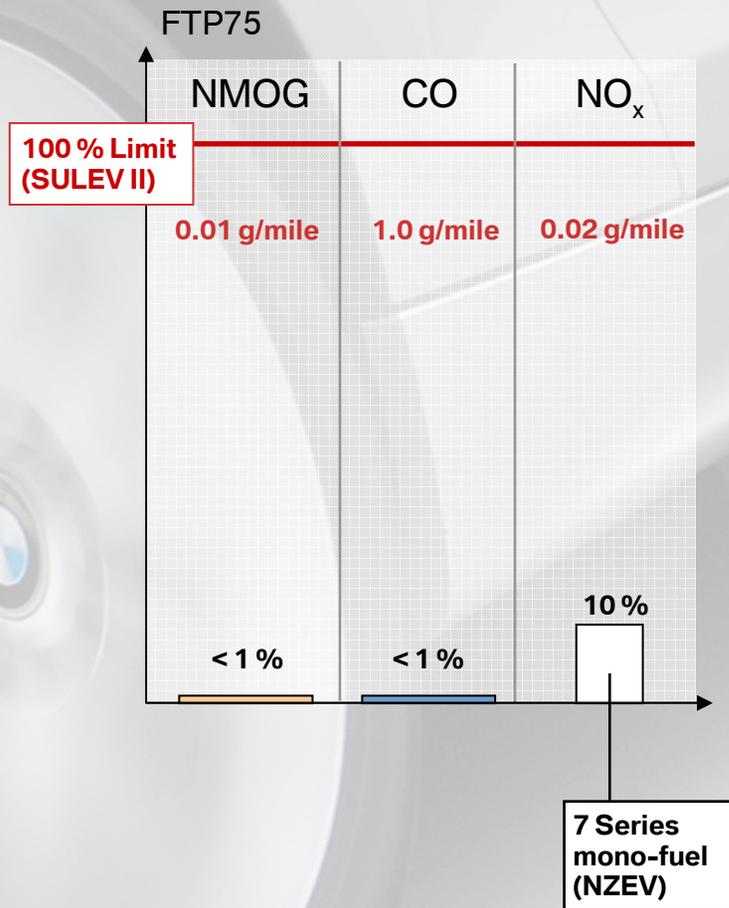
Tailpipe  
emissions

	HC [ppm]	CO [ppm]	NO <sub>x</sub> [ppm]
H <sub>2</sub> ( $\lambda=1$ )	< 1	0	< 1

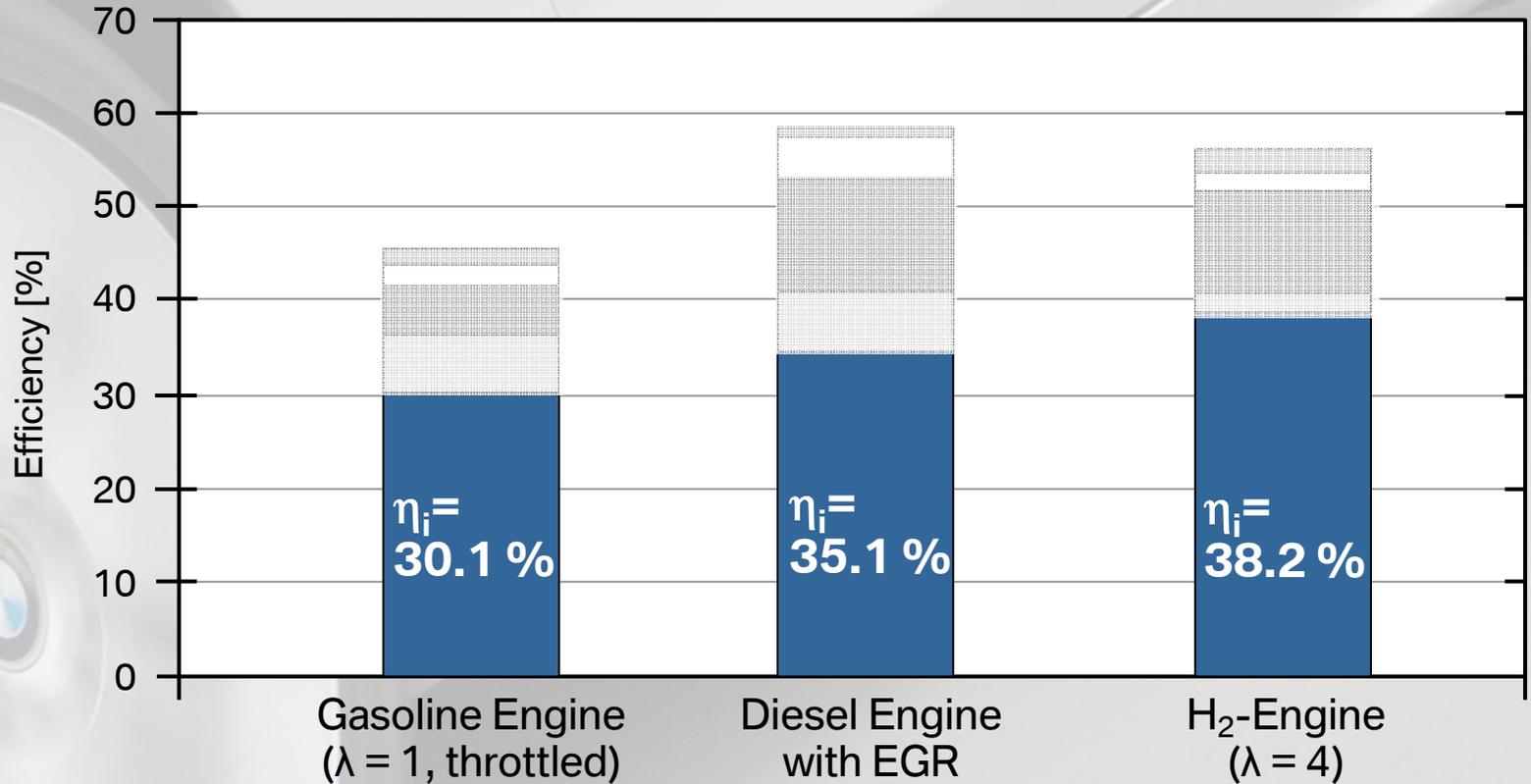
	HC [ppm]	CO [ppm]	NO <sub>x</sub> [ppm]
H <sub>2</sub> ( $\lambda \gg 1$ )	< 1	0	< 1

# BMW CleanEnergy: H<sub>2</sub> ICE.

## Tailpipe emissions 7 Series H<sub>2</sub> in FTP 75 drive cycle.

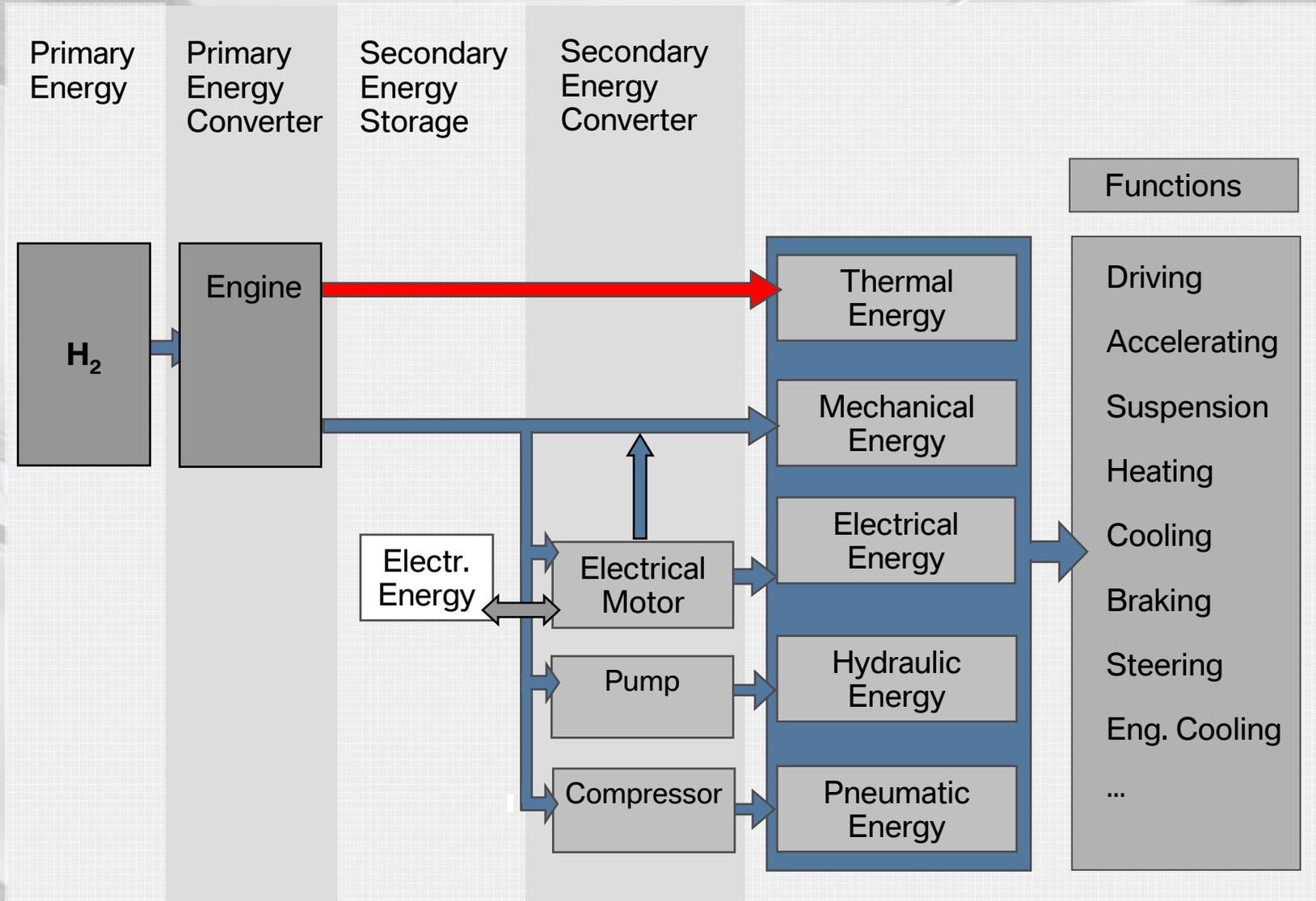


# BMW CleanEnergy: H<sub>2</sub> ICE. Efficiency at partial load.

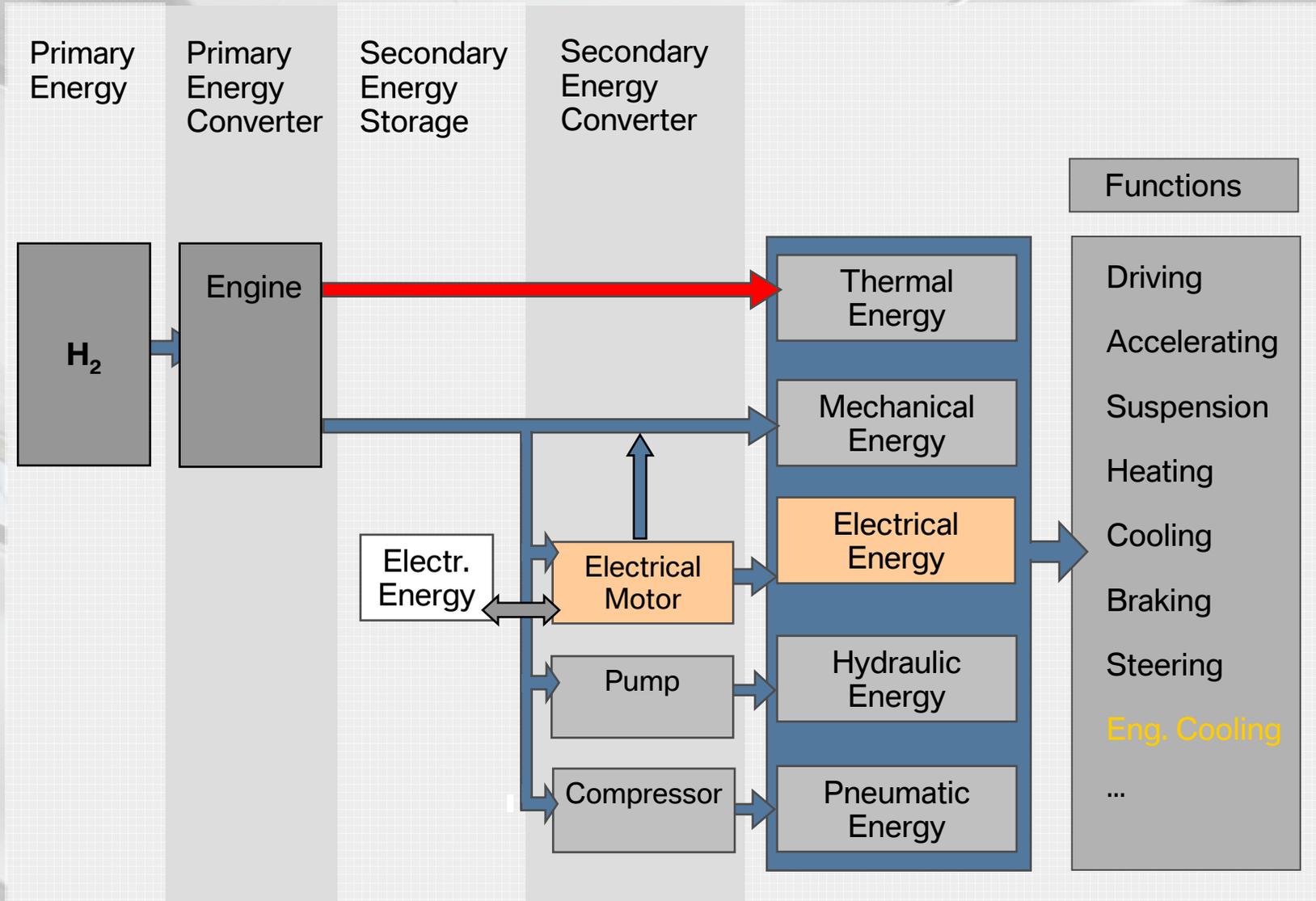


- unburned fuel
  - charge exchange
  - non-ideal heat release
  - indicated efficiency
  - wall heat
- $n = 2000 \text{ min}^{-1}$ ,  $w_i = 0.27 \text{ kJ/dm}^3$

# Electrification of H<sub>2</sub> drivetrains. Energy management.

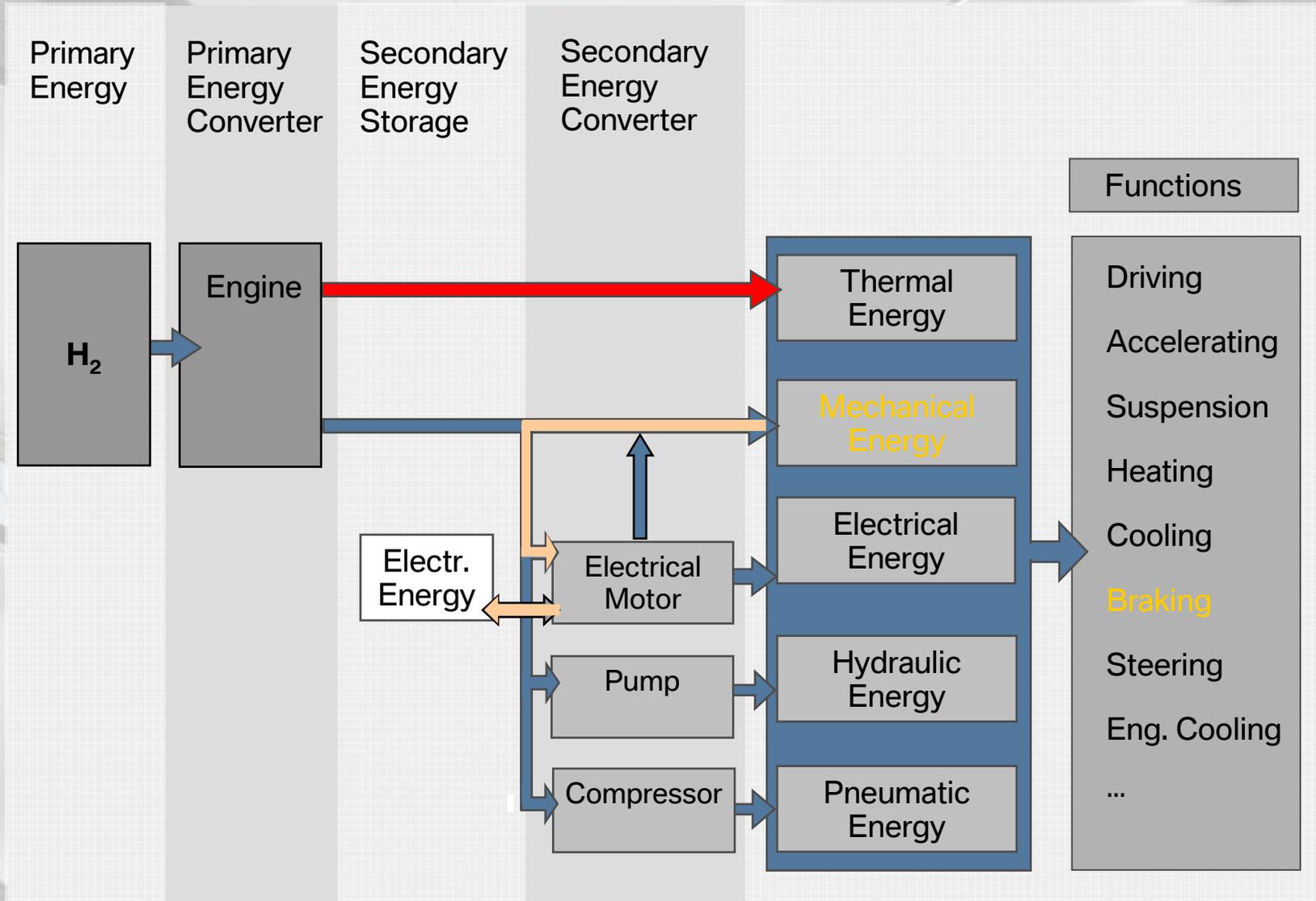


# Electrification of H<sub>2</sub> drivetrains. Energy management.



# Electrification of H<sub>2</sub> drivetrains.

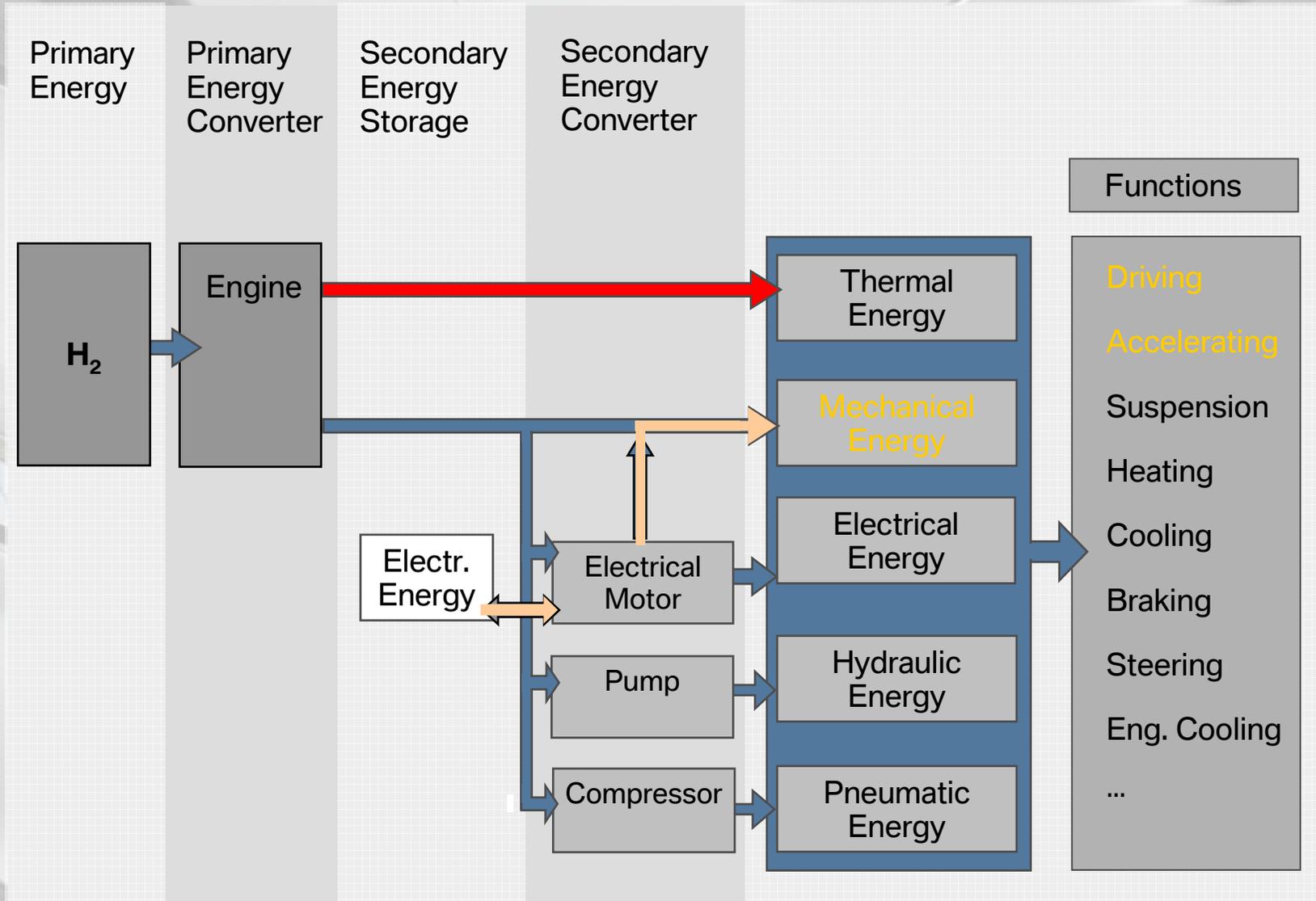
## Hybrid powertrain systems: Recuperation.



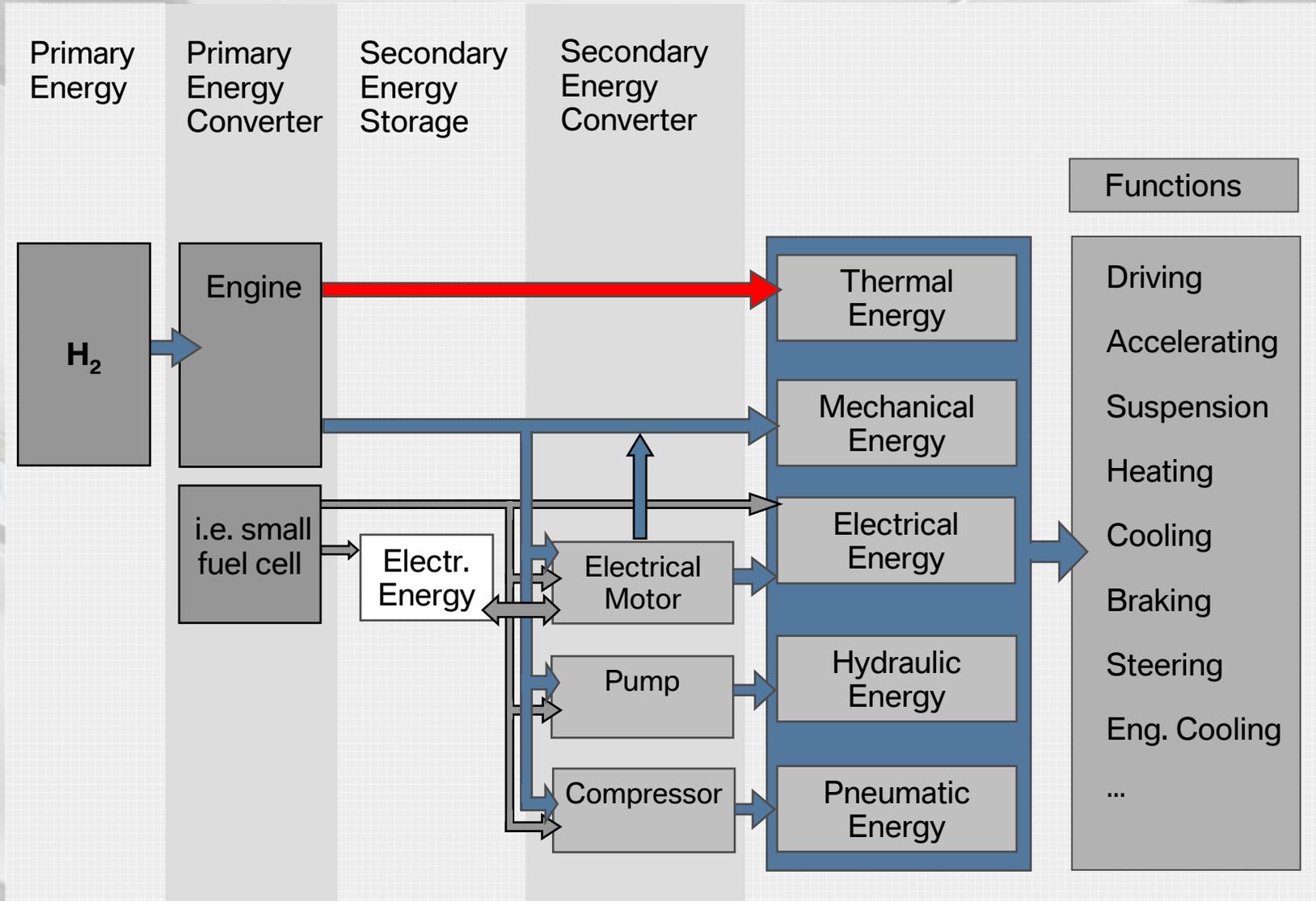


# Electrification of H<sub>2</sub> drivetrains.

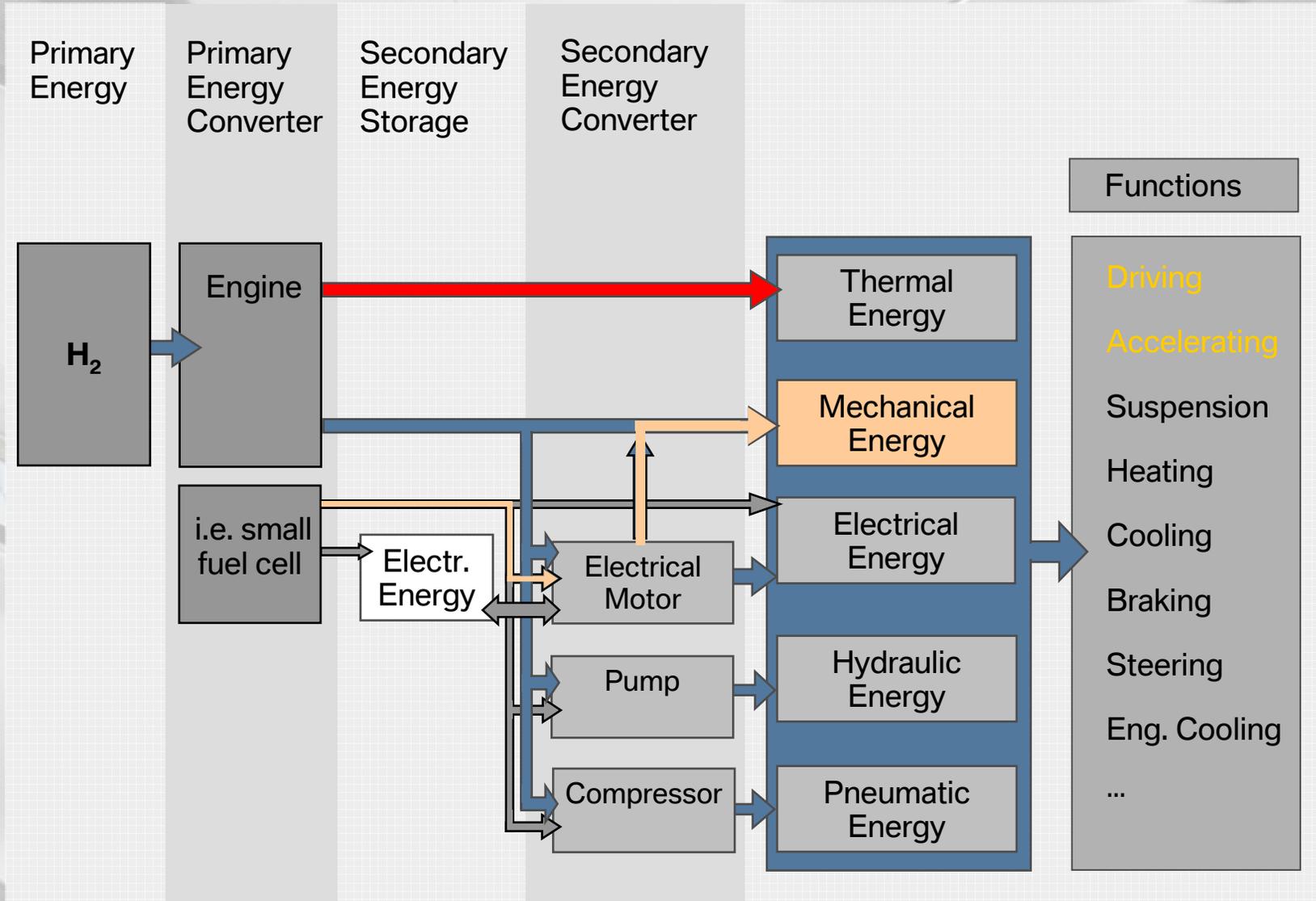
## Hybrid powertrain systems: Assisting/Electric driving.



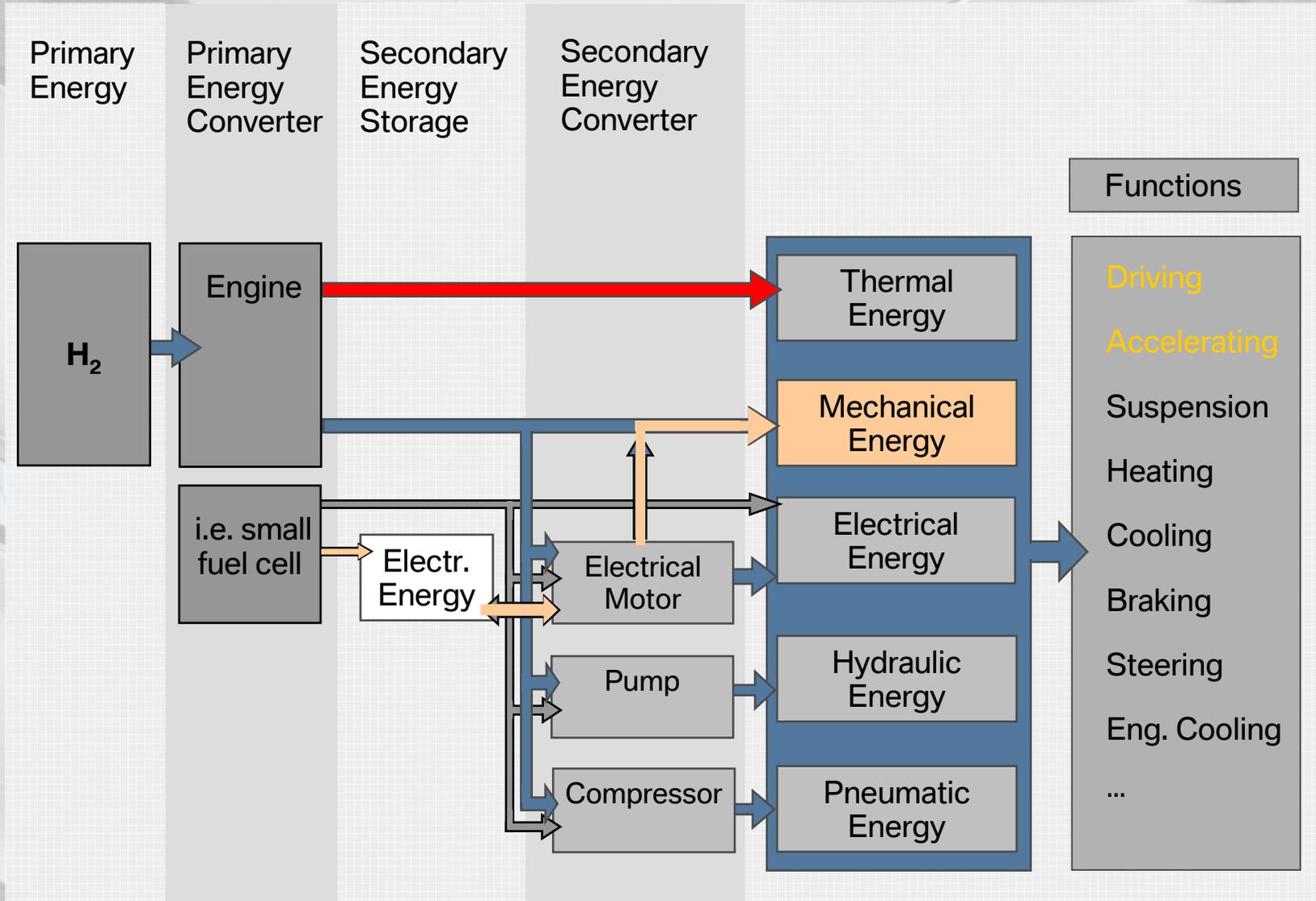
# Future option for electrification of drivetrains. Advanced energy management.



# Electrification of H<sub>2</sub> drivetrains. Advanced energy management.



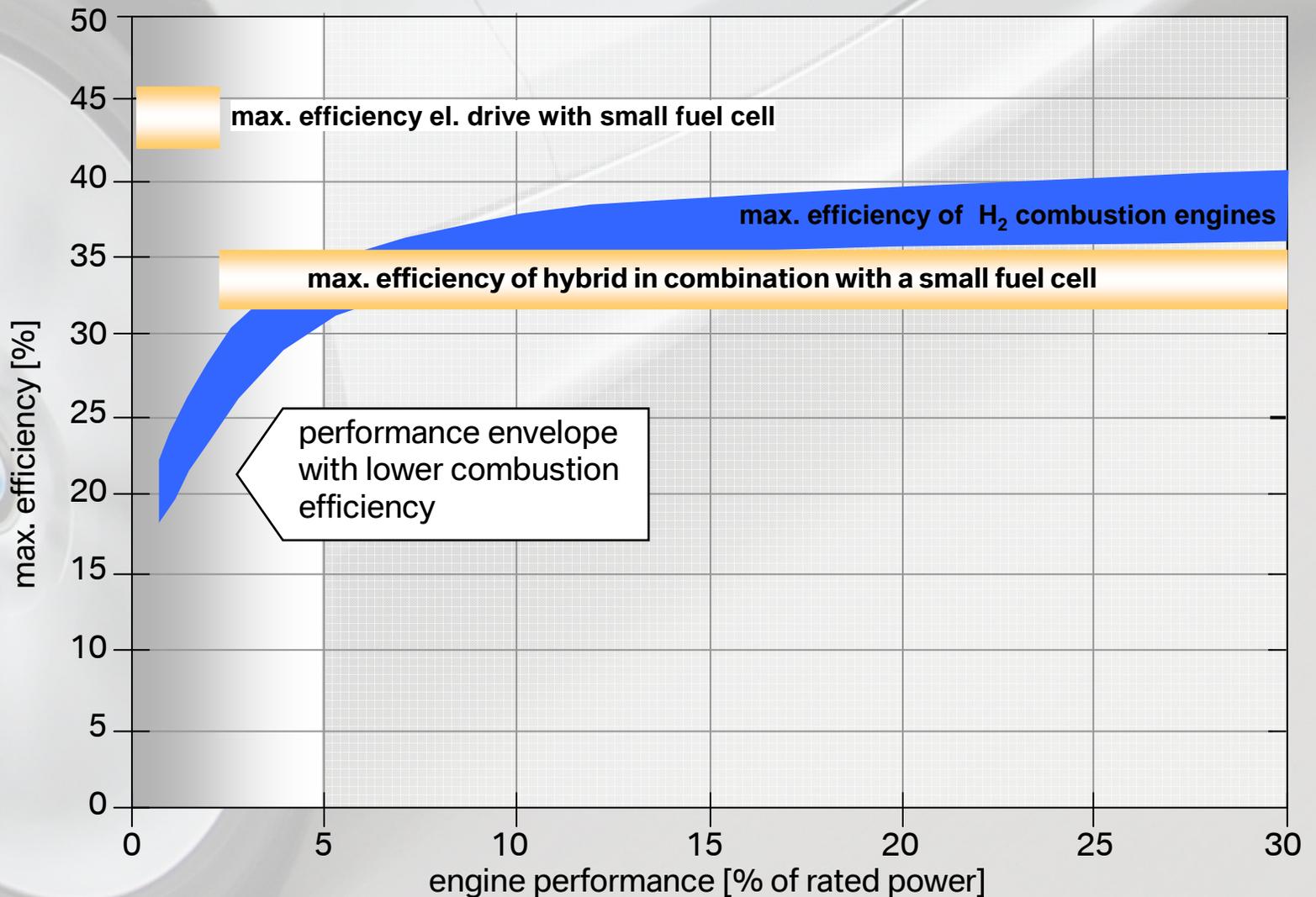
# Electrification of H<sub>2</sub> drivetrains. Advanced energy management.





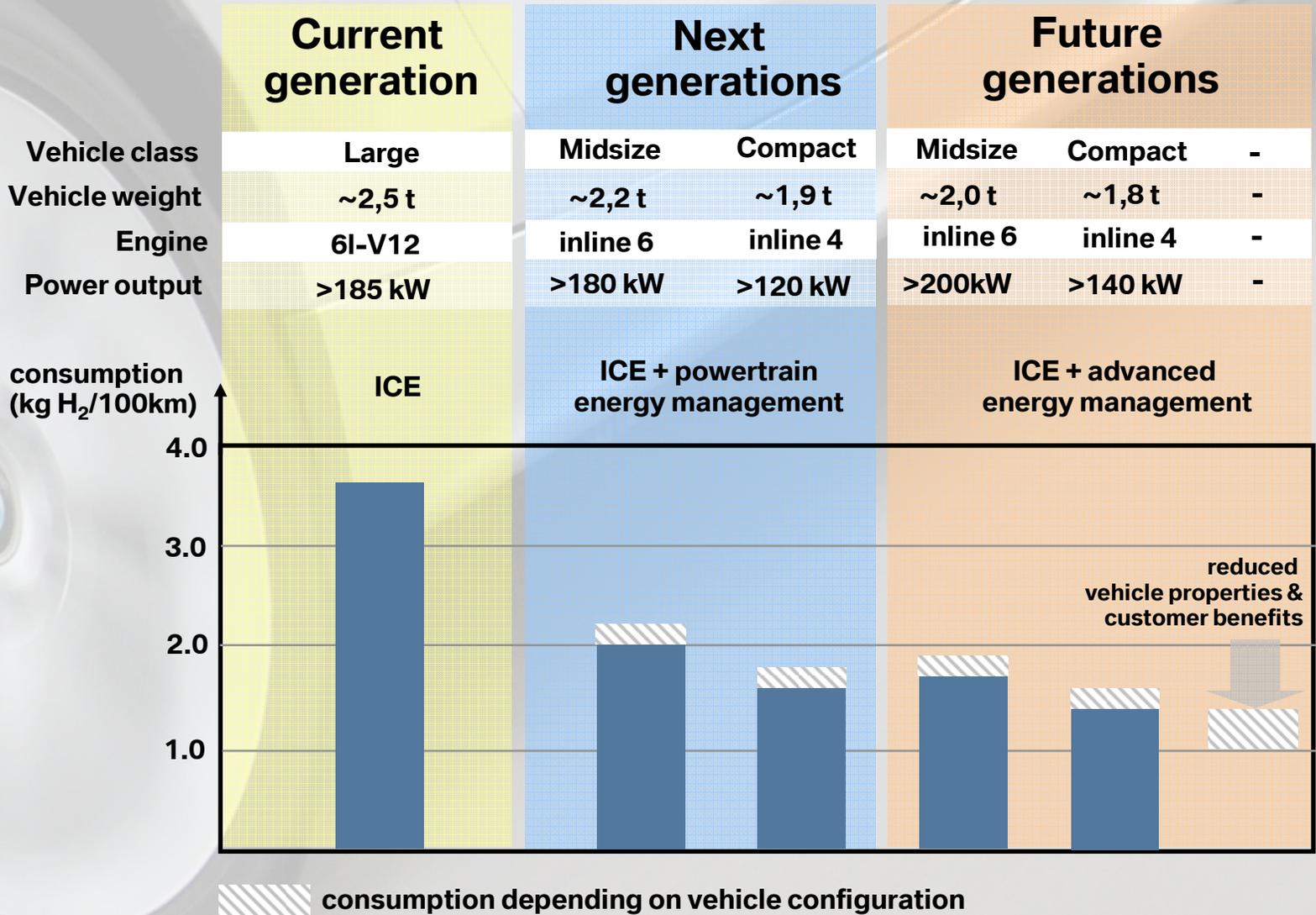
# Electrification of H<sub>2</sub> drivetrains.

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



# BMW CleanEnergy: H<sub>2</sub> ICE.

## Potential fuel consumption of NZEVs in NEDC.

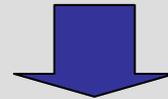


# BMW Powertrain Strategy.

## ZEV gold standard - chances and barriers.

### New challenges for ZEV

**Air Quality**      **Global Warming**      **Energy Security**  
⇒ ZEV Mandate      ⇒ Kyoto Protocol



**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.

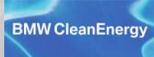
ZEV-Technology requirements	H <sub>2</sub> ICE powertrains
(Near) Zero Emission Vehicle	✓
high fuel economy*	✓
high power density	✓
relatively low costs of production	✓
proven durability	✓

- **Broadening the scope of ZEV mandate to facilitate different technology options**
  - **Future challenge: build-up a H<sub>2</sub> infrastructure**
- need to review ZEV mandate



\*H<sub>2</sub> ICE + advanced energy management

# BMW CleanEnergy: H<sub>2</sub> ICE. Conclusion.



- **7 Series with bi-fuel engine:**
  - first H<sub>2</sub> vehicle in production development
  - customer oriented vehicle concept with fall back gasoline mode
  
- **7 Series mono-fuel as NZEV:**
  - emissions far below SULEV70 level
    - very low emissions in  $\lambda \gg 1$  operation
    - very low emissions after TWC in  $\lambda = 1$  operation
  - potential: near zero emission with H<sub>2</sub> 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.

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# Material properties of Hydrogen.

## Comparison with gasoline.

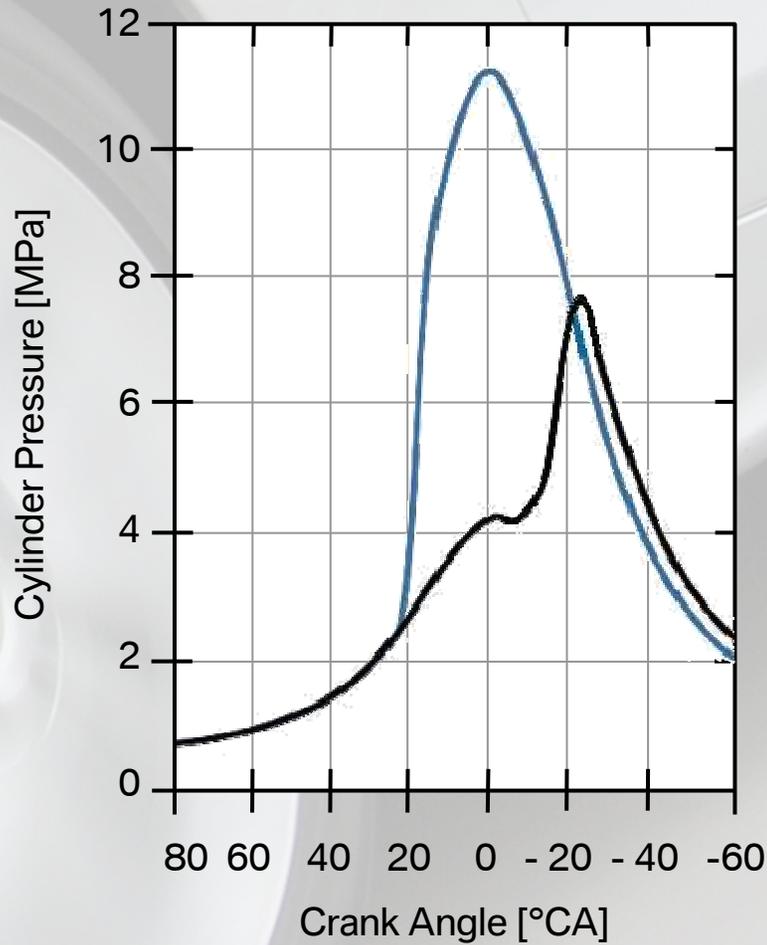


	Gasoline	Hydrogen
Heating value $H_l$ (MJ/kg)	43	120 (=2.8-fold)
Energy density (MJ/dm <sup>3</sup> )	31.4 (=3.8-fold)	LH <sub>2</sub> : 8.5
Laminar flame velocity* (cm/s) <i>(normal conditions)</i>	30	250
Flammability limit (Vol.%) Flammability limit (Lambda)	1-7.6 1.65 - 0.2	4-75 10 - 0.14
Ignition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

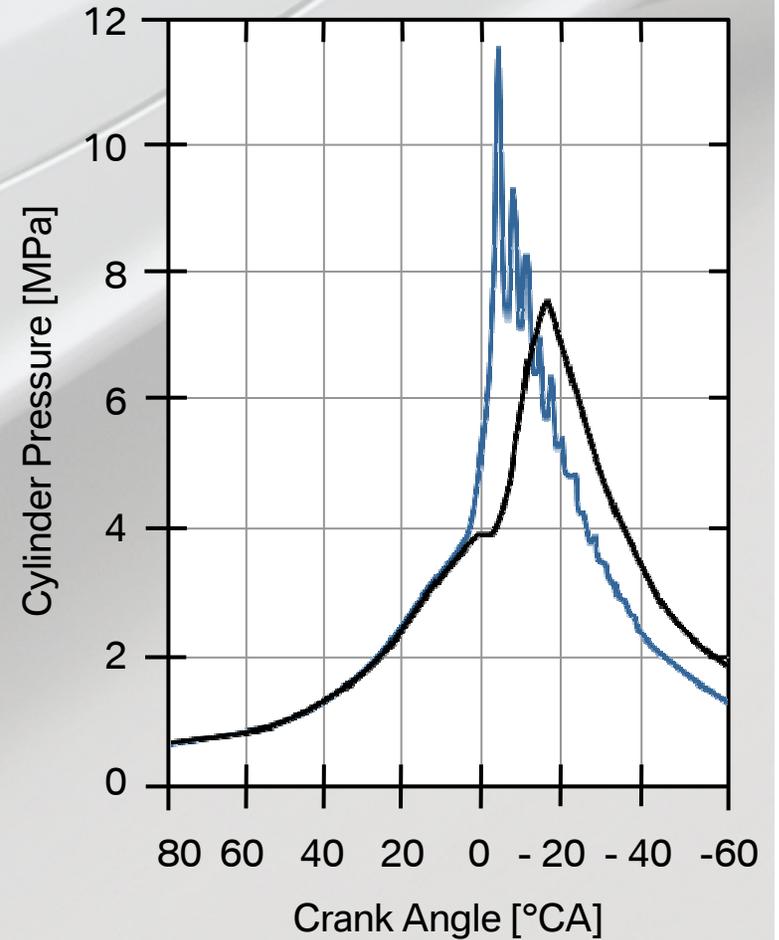
\*stoichiometric air/fuel ratio

# H<sub>2</sub> combustion process.

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



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

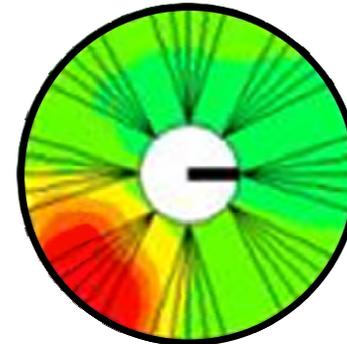
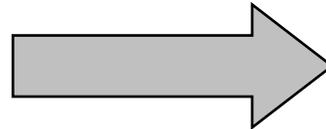
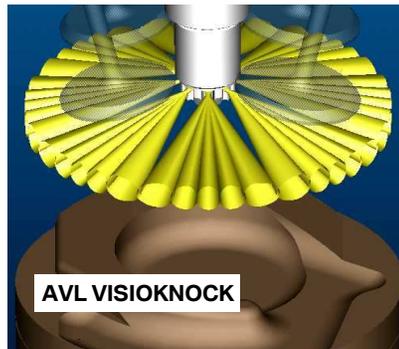


 **engine knock**  
 **regular combustion**

# H<sub>2</sub> combustion process.

## Combustion process development.

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pre-ignition

### Measures:

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

➔ **Regular engine operation**

