

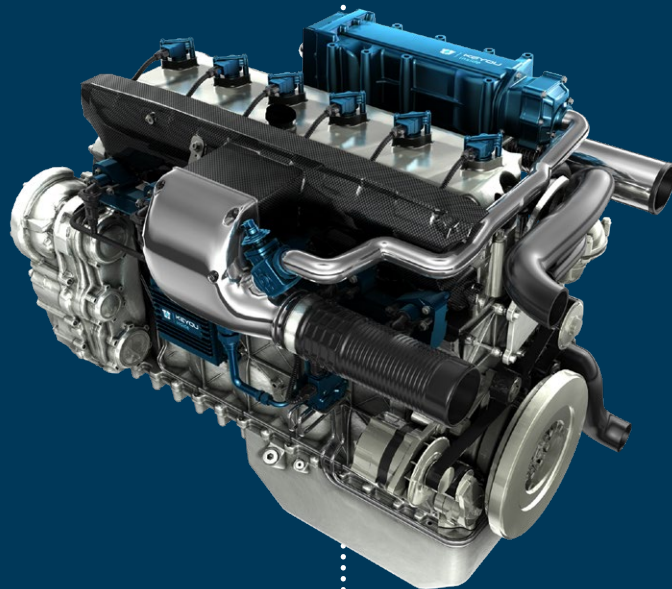
**KEYOU**  
emission-free technology.



Sustainable. Clean. Uncompromising.

**KEYOU-inside**  
for Hydrogen Engines and Vehicles

“Our goal is to roll out emission-free hydrogen engines which are suitable for everyday use and economically viable at the same time”



# KEYOU – Innovative Strength for Sustainable Mobility

## Vision

Hydrogen produced from renewable energies is essential for the transition to a new, more sustainable energy paradigm and greener future. KEYOU's vision is to facilitate sustainable transport by road, rail, sea and air, today by developing zero-emission, low-cost H<sub>2</sub> combustion engine and vehicle technologies.

## Company

KEYOU is YOUR KEY to innovative solutions for sustainable energy and clean mobility. Since 2015, we have been developing core components in drive technology; we are already presenting the engine of tomorrow today – the zero-emission hydrogen engine with KEYOU-inside!

## Founder

KEYOU owes its innovative strength to the three founders: Thomas Korn, Alvaro Sousa and Ivo Pimentel. Thomas Korn and Alvaro Sousa are both engineers, with over 10 years of research and development of alternative drives at BMW. Ivo Pimentel completes the team's know-how, with his expertise in alternative energies. Together, they strive forward by exploring creative synergies and innovative concepts.



● Thomas Korn



● Alvaro Sousa



● Ivo Pimentel

Maximum  
**Performance.**



Zero  
**Emission.**

# KEYOU-inside – Zero Emission Combustion Engines

## **Sustainable. Clean. Uncompromising.**

KEYOU-inside combines the use of hydrogen as a sustainable fuel, with the proven and economical technology of the combustion engine, to create a quantum leap in drivetrain development. For the first time, there is an engine that is emission-free, cost-efficient and powerful at the same time – a technology with no compromises!

## **From concept to reality.**

Today the public demands clean cities and affordable public transport. With KEYOU-inside for hydrogen engines, emission-free commercial vehicles are within reach and will soon become a reality on our streets. This emission-free technology has all the advantages of existing drive systems:

### **KEYOU-inside for your bus means:**

- + **Similar driving ranges**
- + **High performance**
- + **High availability**
- + **Fast refueling**
- + **Proven suitability for everyday use**
- + **Convincing cost efficiency**
- + **Long service life**
- + **Zero Emissions**



“Diesel is the benchmark.  
And we need to surpass it”

# Groundbreaking – our Drivetrain Technology for Clean Mobility

## Everyone is talking about climate protection – we are doing something about it

Climate protection is now also a public-health issue. It is no coincidence that discussions about driving bans and CO<sub>2</sub> reduction are so controversial. Urban and regional transport companies, fleet operators and politicians face a very difficult challenge: the search for affordable, ecological and everyday alternatives. However, the current focus on battery electric and fuel cell vehicles show clear weaknesses in affordability, range, availability or environmental balance. This is exactly what KEYOU is aiming to resolve.

## KEYOU-inside technology profitably applied

We build on the robust and proven technology of the diesel engine. We then modify and transform it into an emission-free hydrogen engine. The engine base remains the same, but we increase efficiency and customer value. What makes the difference is our unique patented technology "KEYOU-inside" that enables clean and sustainable propulsion using hydrogen.

## Convincing data – meaningful investment in the future

Our affordable KEYOU-inside technology guarantees high availability, ranges typical of commercial vehicles with correspondingly low consumption and the familiar heating and climate comfort control throughout the year.

### Utility profile

using the example of a 12m bus with KEYOU-inside

Range:	> 350 km
Output:	210 kW
Availability:	> 95 %
Service life:	> 700,000 km
Refueling time:	ca. 15 minutes
Passenger numbers:	≈ Diesel vehicle
Heating and climate comfort:	≈ Diesel vehicle
Costs over service life:	≈ Diesel level
Emissions:	Only water vapor, no CO <sub>2</sub>
Noise emission	-20 % compared to diesel bus

# Mobility and the Environment – New CO<sub>2</sub>-Regulations by Law

## CO<sub>2</sub> limits – EU targets create facts

Dream or reality, what about the climate targets for 2030 and 2050? It is a fact that the EU wants to limit CO<sub>2</sub> emissions not just from cars alone, but is now setting new limits for lower emissions from buses and trucks.

Target for 2025: -15 % CO<sub>2</sub> emissions vs. 2019

Target for 2030: -30 % CO<sub>2</sub> emissions vs. 2019

## Achievable with effective drivetrain technology

These goals can only be achieved with state-of-the-art technology, with alternative drive technologies that are sustainable and convince end consumers, fleet operators and manufacturers alike. ZERO EMISSION – locally emission-free, but also environmentally friendly during production and recyclable.

## Advantage KEYOU-inside – meets ZERO EMISSION requirements 100 %

At approx. 0.1 g/kWh, hydrogen engines with KEYOU-inside are massively below the ZERO EMISSION limit defined by the EU. Your bus will, therefore, be able to operate under the „ZERO EMISSION“ label in the future.

## Official since June 20, 2019: EU-commission adopts CO<sub>2</sub>-limits for utility vehicles (Regulation (EU) 2019/1242)



“zero emission heavy-duty vehicle’ means a heavy-duty vehicle without an internal combustion engine, or with an **internal combustion engine that emits less than 1 g CO<sub>2</sub>/kWh** as determined pursuant to Regulation (EC) No 595/2009 and its implementing measures, or which emits less than 1 g CO<sub>2</sub>/km as determined pursuant to Regulation (EC) No 715/2007 and its implementing measures;”

## KEYOU-inside officially reduces your carbon footprint:

- Save CO<sub>2</sub> certificates
- Reduces the CO<sub>2</sub> fleet balance
- Reduces your company’s CO<sub>2</sub> footprint with KEYOU-inside





# Hydrogen – More Efficient than Batteries will ever be

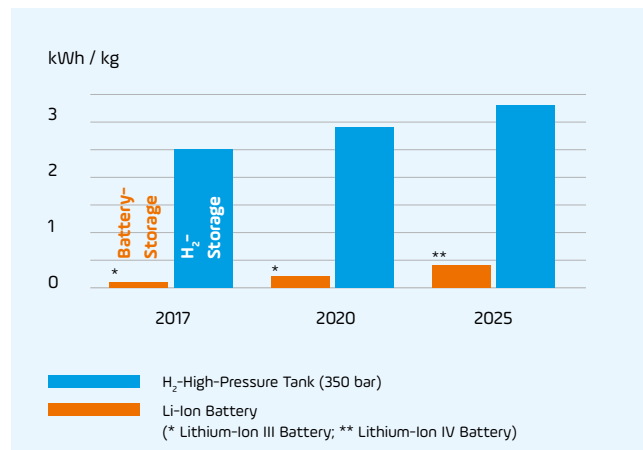
## Hydrogen storage is decades ahead of the electric battery solution

Sustainable technology does not only focus on the type of drive, but also on the type of energy storage. For KEYOU this is an additional reason to focus on hydrogen engines.



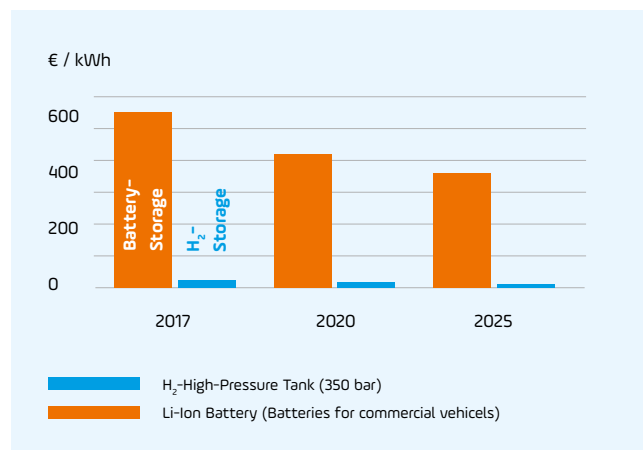
### Advantage: Gravimetric Energy Storage Density (energy per mass)

Already today, the 350 bar H<sub>2</sub> high-pressure tanks currently available, have an **energy storage density that is 25 times** higher than that of lithium-ion batteries used in the bus sector.



### Advantage: Costs

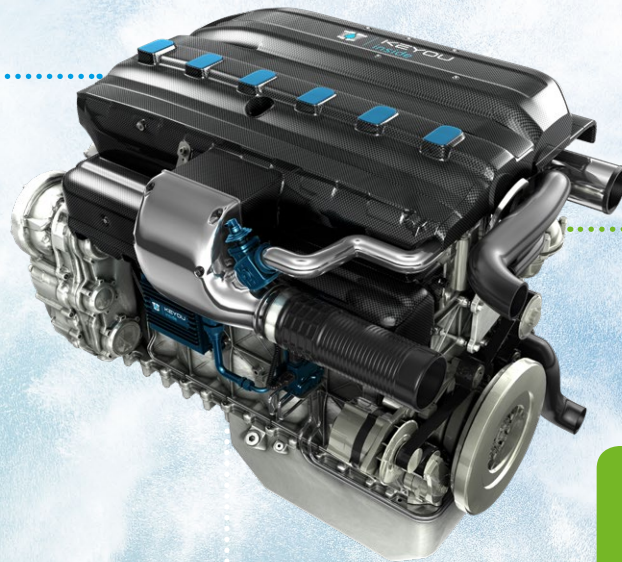
Another advantage – costs: The price difference is significant. Hydrogen storage is about **23x cheaper** than battery storage. The cost-advantage of hydrogen storage compared to electric storage is, among other things, the low material cost of the tanks.



## Hydrogen – is Safe!

Safety is also a top priority for the hydrogen engine. It requires additional safety measures, but there is no need to rethink the risk awareness. On the contrary, the danger of a fire, e.g. in the event of an accident, is higher if gasoline escapes. Hydrogen storage tanks are very robust. If hydrogen is actually released after an accident, the light gas escapes upwards and the fuel does not collect on the ground, unlike petrol.

Maximum  
**Performance.**



Zero  
**Emission.**

“Thanks to our innovative hydrogen technology, the combustion engine is turning green.”

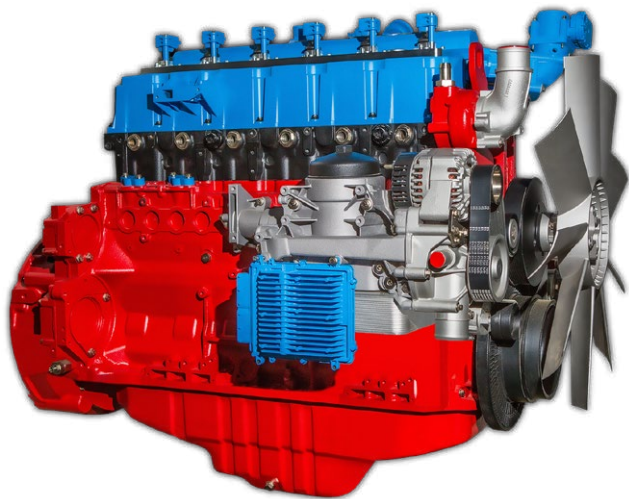
# Hydrogen and the Combustion Engine – A truly “GREEN” Combination

## Internal combustion engines – a mature technology with weak points

Everyone knows it, everyone appreciates it, the reliable and powerful combustion engine. The downsides of the mature diesel or gasoline drive: high emissions of pollutants and the related damage to the environment and public health. Solutions using emission-free electric drives and fuel cells are promising, but they show weaknesses in range and suitability for everyday use and cost many times more than diesel vehicles. In addition, current environmental studies have shown that the eco-balance of these approaches must be viewed critically.

## Hydrogen engines – sophisticated technology with ZERO EMISSION

KEYOU has used the optimized technology of the diesel engine as a basis to develop a new generation of emission-free hydrogen engines: Sustainable. Clean. Uncompromising.



Prototype engine DEUTZ TCG 7.8 with KEYOU-inside technology

## Emission-free – no CO-, CH-, CO<sub>2</sub>- and NO<sub>x</sub> with hydrogen

The main advantage of hydrogen compared to fossil fuels is the lack of carbon. Exhaust gases such as CO, CH and climate-damaging CO<sub>2</sub> cannot be produced in the first place. NO<sub>x</sub> formation is also completely avoided by the lean combustion capability of hydrogen in conjunction with the innovative EGR strategy. In order to increase the power density, an SCR catalyst, that works with hydrogen, can be considered instead of AdBlue.

## Efficiency potential – greater than that of diesel engines

This means that the hydrogen engine scores several times over:

- 6 x faster flame burning speed compared to gasoline
- Largest flammability range of all fuels (4-75 %)
- De-throttled motor operation for high efficiency
- With the KEYOU Port Fuel Injection (PFI) engine:
  - > 45 % peak efficiency
  - > Additional increase in efficiency through H<sub>2</sub> direct injection

## Power – highest potential at power density and torque

In future generations of the engine, power density and torque can be further increased. The hydrogen-powered engines offer the greatest development potential compared to gasoline and diesel engines.

# KEYOU-inside – the New Generation of H<sub>2</sub> Engines

## Robust base and innovative technology

The special feature of KEYOU's hydrogen engine is its patented coherent technology approach: efficient injection, exhaust gas recirculation, turbocharging and a special hydrogen catalyst. By using the conventional diesel engine as the base, KEYOU has succeeded in doing something that others have failed to do so far – developing an efficient and economical zero-emission engine with high efficiency and significant customer benefits.

## H<sub>2</sub>-Combustion concept of KEYOU

### H<sub>2</sub>-Lean Combustion with EGR

- ✓ No NO<sub>x</sub> problem
- ✓ High efficiency

### Turbocharged

- ✓ Maximum performance

### H<sub>2</sub>-Direct Injection

- ✓ High power and torque
- ✓ High efficiency

### H<sub>2</sub>-Reduction Catalytic Converter

- ✓ Optional upgrade as "KEYOU Air Clean Technology"



### Highest Power/Torque Density

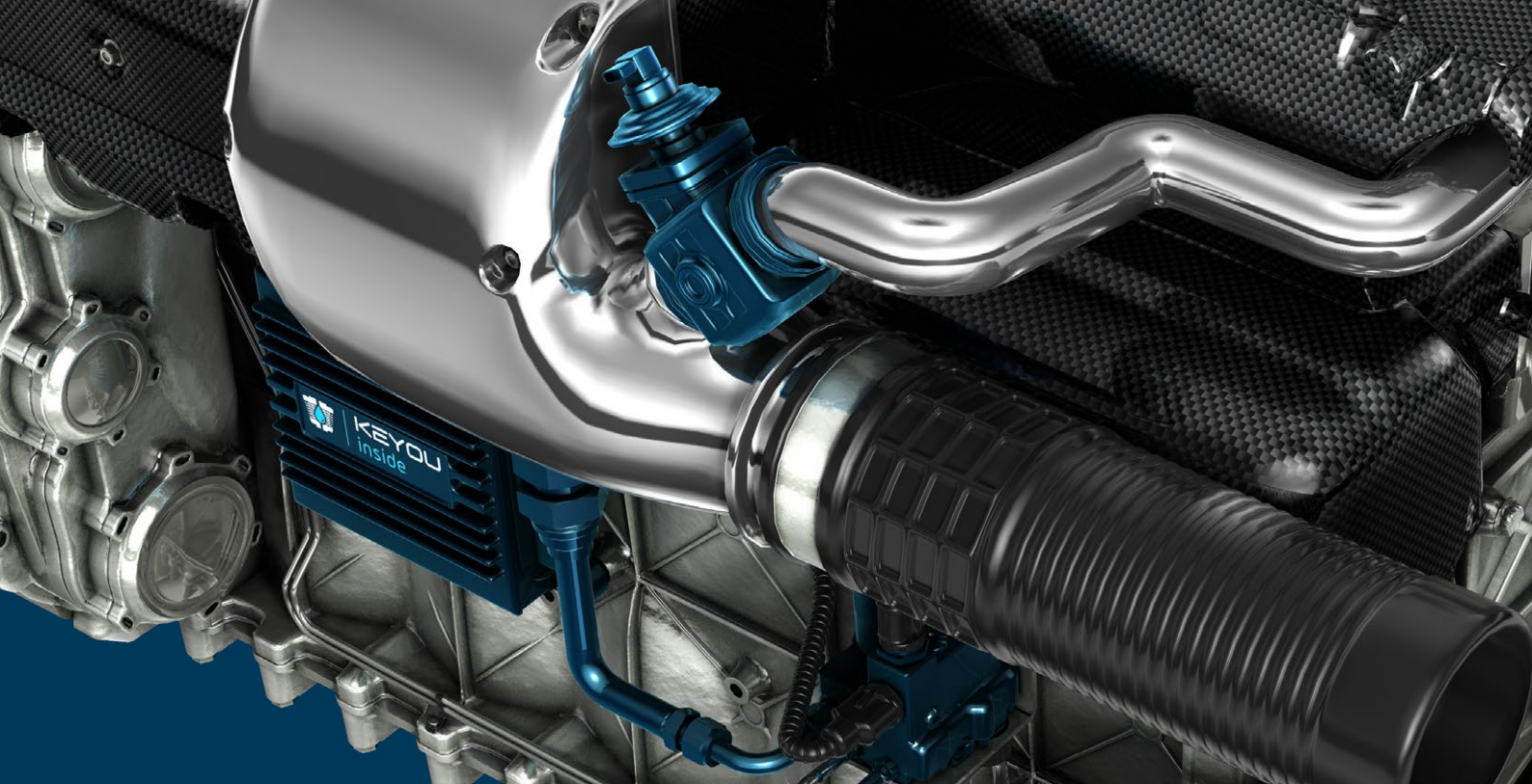
- 27 kW/L Engine
- 140 Nm/L Engine

### Highest Efficiency

- Higher than basic diesel engine
- Effective peak value of 45 %

### Sustainable Air Purification

- 0,0 g CO<sub>2</sub> emissions
- 0,0 g CO<sub>x</sub>
- 0,0 g NO<sub>x</sub>
- 0,0 g other impurities



### **Engines with KEYOU-inside – in lean operation on the fast lane**

The zero-emission hydrogen engine builds on the robust diesel engine and is modified into a turbocharged, lean, spark-ignited hydrogen internal combustion engine, with high efficiency and high-power density. Using hydrogen as a fuel, engines can operate efficiently up to an air-fuel ratio of  $\lambda 5$ . KEYOU operates the engine via an air-fuel map that is always larger than  $\lambda 2$ . In conjunction with an innovative EGR strategy,  $\text{NO}_x$  formation is completely prevented.

### **Prevention of $\text{NO}_x$ formation – with sophisticated exhaust gas recirculation (EGR)**

Compared to diesel engines, hydrogen-powered engines have low EGR usage restrictions because there is no carbon in the fuel. This, together with the fast combustion properties of hydrogen, allows the engine to operate at high EGR rates without compromising efficiency. The formation of  $\text{NO}_x$  is thus already avoided in the first place.

### **More power – through turbocharging**

In order to compensate for performance losses caused by lean combustion, KEYOU integrates an air charging system tuned to hydrogen. This also provides the required torque in the lower speed range with perfect calibration.

### **High efficiency – with external mixture formation and direct injection**

With KEYOU's current technology, hydrogen is injected sequentially, directly in front of the intake valve. With this technology, engines with intake manifold injection can already achieve a very good efficiency of 45 %. In the next generation of KEYOU's technology, direct injection will be used in order to achieve higher efficiencies and performances.

### **Zero-emissions and powerful thanks to an $\text{H}_2$ -SCR catalytic converter**

Hydrogen engines, with the first-generation KEYOU technology, are already zero-emission vehicles today – without after-treatment of exhaust gases! We are currently developing a special  $\text{H}_2$ -SCR catalytic converter, which exclusively uses hydrogen as a reducing agent and allows to increase the power density without compromising on emissions. The fundamentally new catalytic design eliminates the need for additional consumables such as AdBlue.

“We believe in hydrogen as the fuel of the future.”

# KEYOU-inside – a Solution for Humanity and the Environment

## Harmless water vapor as exhaust gas – 0.0 emissions in all areas

Due to KEYOU’s special operating strategy, only small amounts of nitrogen oxides are produced, far below the strict Euro 6 emission limits, even without exhaust gas aftertreatment. In the life cycle assessment of electric vehicles, the KEYOU technology is superior to CO<sub>2</sub> in terms of the German electricity mix and the current state of studies on the production and service life of battery systems (Please see the graph on page 16).

In a nutshell: Every vehicle with KEYOU-inside and H<sub>2</sub>-SCR is not only environmentally friendly, it also cleans the heavily polluted air of city centers.

Bus 12m		Diesel Motor Euro VI <sup>***</sup>	H <sub>2</sub> -Motor by KEYOU
CO <sub>2</sub>	[g/kWh]:	1.000	0,08
NO <sub>x</sub>	[g/kWh]:	0,46	0,04
PM*	[g/kWh]:	0,01	0,002
HC**	[g/kWh]:	0,16	0,01
CO	[g/kWh]:	4	0,01

\* Particulate Matter, description / unit / standard for fine dust

\*\* Volatile organic substances such as hydrocarbons

\*\*\* Legal requirements

## Environmentally friendly – from production to recycling

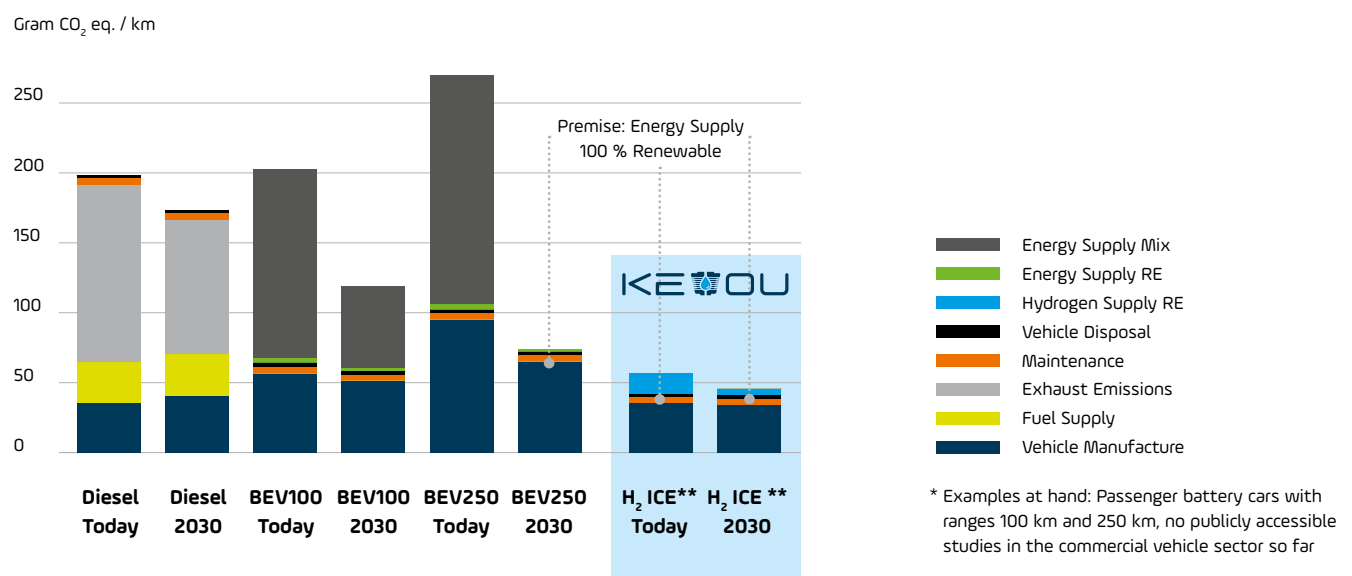
The planet’s raw materials are finite, especially when it comes to precious, rare earth elements. The extraction, use and recycling of toxic raw materials is also highly problematic. Unfortunately, these same materials are produced in much greater quantities during the production of electric vehicles, which also leads to an increased dependency on certain raw materials or producing countries. By contrast, steel, aluminum as well as plastics dominate the market for combustion engines and classic transmissions. A clear plus for sustainability.

# KEYOU-inside also stands for the Cleanest Drive Technology over the Life Cycle

## Sustainability impact: Clear advantages for KEYOU in the life cycle assessment

Powered by H<sub>2</sub> from renewable energies, a KEYOU drive system has the lowest CO<sub>2</sub> emissions over its life cycle compared to fuel cell or pure electric vehicles. In addition, no rare earth elements such as cobalt are needed for the hydrogen combustion engine.

## Greenhouse gas emissions from diesel and battery electric vehicles\*



Sources:  
 Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety  
 ifeu Institute for Energy and Environmental Research of Heidelberg  
 \*\* KEYOU own calculations, ICE = Internal Combustine Engine







# Refueling? No problem – if required, Hydrogen Bus and Infrastructure are available as a Package

## Hydrogen is already sufficiently available today

Hydrogen, as an industrial by-product, is available in large quantities in many regions. At the same time, H<sub>2</sub> production is becoming increasingly environmentally friendly and cost-effective thanks to new processes. Produced with the help of regenerative energies, hydrogen can be offered almost CO<sub>2</sub>-neutral. Additional sources can be tapped in waste management through the generation and subsequent reforming of biogas.

## Simple refueling

The refueling process and infrastructure requirements of an H<sub>2</sub> filling station are comparable to conventional filling stations. While electric vehicles have a huge variety of charging systems and standards, today there is already a worldwide standard for H<sub>2</sub> tank nozzles. The refueling process is comparable to conventional refueling and takes between 10 and 15 minutes, depending on the storage tank and tank size. Hydrogen refueling is safe. Refueling is only permitted if the tank nozzle and coupling are locked pressure-tight.

## No dependence on a nationwide network of filling stations

Fleet operators, public transport and companies, with regular schedules or route operations, usually refuel their vehicles centrally in their own depot. This eliminates the need for a nationwide network of filling stations. Nevertheless, around 100 new H<sub>2</sub> filling stations, with an investment value of around € 100 million are planned in Germany alone by 2020.

## H<sub>2</sub>-filling stations as an attractive investment

While the lack of capacity utilization and high hydrogen prices in the passenger car sector have so far been the root cause of gaps in the filling station network, a KEYOU H<sub>2</sub> filling station can offer attractive fuel prices starting from a fleet of 15 to 20 KEYOU buses, through guaranteed daily distances and central refueling at its own depot. This ensures shorter payback times and opens up opportunities for intelligent H<sub>2</sub> operator concepts. KEYOU is already working with partners on various solution models in the field of H<sub>2</sub> infrastructure.



H<sub>2</sub> as a by-product of the chemical industry, via electrolysis or biogas reformer from renewable energies

## The KEYOU H<sub>2</sub> mobility concept for end customers is already in preparation today

KEYOU is more than an innovative drive technology. When entering the market, KEYOU will also offer H<sub>2</sub> infrastructure solutions together with partners. Don't worry about filling stations and H<sub>2</sub> procurement. KEYOU supports you in the analysis, planning and construction of your H<sub>2</sub> infrastructure.

- ✔ "Emission-free vehicle plus fuel" as a package solution
- ✔ Turnkey filling station concepts for different fleet sizes
- ✔ Consideration of H<sub>2</sub> availability for the end customer

# Sustainable. Clean. Uncompromising.

## The first hydrogen bus – powered by KEYOU

Its diesel-typical robustness, high efficiency and emission-free operation without exhaust gas aftertreatment, make the hydrogen engine the superior drive unit in commercial vehicles. On top of this is the extremely attractive price/performance ratio compared to other emission-free alternatives currently available.

## Unique competitive advantage through KEYOU-inside

Whether diesel, electric or fuel cell buses – KEYOU offers a unique competitive advantage. Hydrogen engines, with KEYOU-inside, empowers vehicles with maximum performance, zero emissions and all at an affordable price. This makes clean mobility affordable for the customer himself for the first time. All this with the same customer benefits in terms of range, availability, number of passengers or climate control common in diesel buses. The big winners are people and nature alike.

## KEYOU-inside hydrogen engines – the new world of mobility

With KEYOU-inside manufacturers can offer the world's first emission-free hydrogen combustion engine with performance characteristics suitable for everyday use, on economically attractive terms. Already with the market launch prices, the first buses with KEYOU-inside can be operated at costs significantly below battery and fuel cell buses without subsidies. Once successfully launched on the market, buses can reach the price of natural gas vehicles in large quantities (approx. 270,000 €) and, depending on the locally available hydrogen source, can even be operated today at diesel-like total costs. This already allows fleet operators to replace current diesel buses 1:1 by H<sub>2</sub> buses with KEYOU-inside today.

## KEYOU by Comparison: Case 12 m Bus

Assumptions: Lifecycle: 720.000 km (60.000 km p.a.) H <sub>2</sub> -Price: 5 €/kg (equivalent: 1,51 €/l Diesel)	Alternative Propulsion Technologies			
	Diesel Euro 6	Battery E-Bus	Fuel Cell H <sub>2</sub> -Bus	H <sub>2</sub> -ICE KEYOU-inside PFI
Range:	> 350 km	< 200 km	> 350 km	> 350 km
<b>Purchasing Price:</b>	<b>226.000 €* </b>	<b>475.000 €* </b>	<b>650.000 €* </b>	<b>350.000 €** </b>
<b>TCO (Basis: 720.000 km)***</b>	<b>750.000 €</b>	<b>1,02 Mio. €</b>	<b>1,35 Mio. €</b>	<b>896.000 €</b>
Heating/Air Conditioning	Diesel	Diesel	Battery	H <sub>2</sub>
Payload capacity	100 %	80 %	85 %	95 %
Operational lifetime (years):	12	5 (Battery)	4 (FC Stacks)	12
Consumption (100 km):	36 l	158 kWh	8 kg H <sub>2</sub>	ca. 11 kg H <sub>2</sub>

Assumptions fuel prices: diesel: 1,16 €/L – AdBlue: 40 ct/L – battery: 19 ct/kWh (storage: 100 Wh/kg; storage costs: 500 €/kWh) – hydrogen: 5 €/kg

\* Current market price average

\*\* Prospective (calculated) price at market introduction (series production ca. 270.000.- €)

\*\*\* Including purchasing price, maintenance, fuel

For high-volume production, the H<sub>2</sub> engine, which is suitable for everyday use, is even cheaper than a diesel engine of the same design, since OEMs can make use of existing production capacities and infrastructure. Furthermore, it is to be expected that the total cost of ownership (TCO) of the hydrogen combustion engine will continue to decline, partly due to rising diesel prices, which, according to Deloitte, could amount to up to +30 % by 2026, while at the same time H<sub>2</sub> prices are expected to fall.



## Do you also want to be at the Cutting Edge? Secure all the Advantages for you and your Company – now!

### 12m Bus with KEYOU-inside – Generation I

Length:	12.000 mm
Widths:	2.500 mm
Cylinders:	6
Displacement:	7,8 Litres
Charge:	Turbocharged
Power:	210 kW
Torque:	1.000 Nm
Combustion Concept:	lean
NO <sub>x</sub> -control:	AGR + H <sub>2</sub> SCR
Consumption:	ca. 11 kg H <sub>2</sub> / 100 km
Range with 350 bar/40 kg Tank:	> 350 km
Refueling:	ca. 15 minutes

**KEYOU and its OEM partners are planning to deliver the first 12m H<sub>2</sub> buses with KEYOU-inside technology.**

There is great interest in the first pilot vehicles. To be part of the first group to drive zero-emission hydrogen buses, reserve now for your vehicle of tomorrow.

**Do you wish to know at what price hydrogen can be offered to your location with your usage profile?**

We offer to support you in your personalised location and economic analysis. Contact our project developers, they will be happy to help you.

**Talk to us or contact us at [info@keyou.de](mailto:info@keyou.de)**

#### Legal notice

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Agentur für Markenidentität.



KEYOU GmbH  
Gutenbergstr. 3  
85716 Unterschleißheim  
Munich, Germany

T +49 89 327 08 89-42  
E [info@keyou.de](mailto:info@keyou.de)  
W [www.keyou.de](http://www.keyou.de)