Making our world more productive

Sustainable and Efficient

Hydrogen-powered Fuel-cell Buses Win Through in Public Transport

Zero-emissions Urban Transport

Beyond diesel

Stricter legislation and emissions regulations are putting growing pressure on fleet operators to decarbonize public transport. In Europe, for instance, EU legislation mandates that 65 percent of all new buses must be zero-emission vehicles by 2025.

In many parts of the world, public transport has already evolved beyond the early diesel-heavy models – driven largely by concerns around noise, nitrogen oxide (NOx), sulfur and particulate emissions. In the first step, many of these diesel buses transitioned to quieter electric drivetrains as these offered zero tailpipe emissions.

Combining sustainability with efficiency

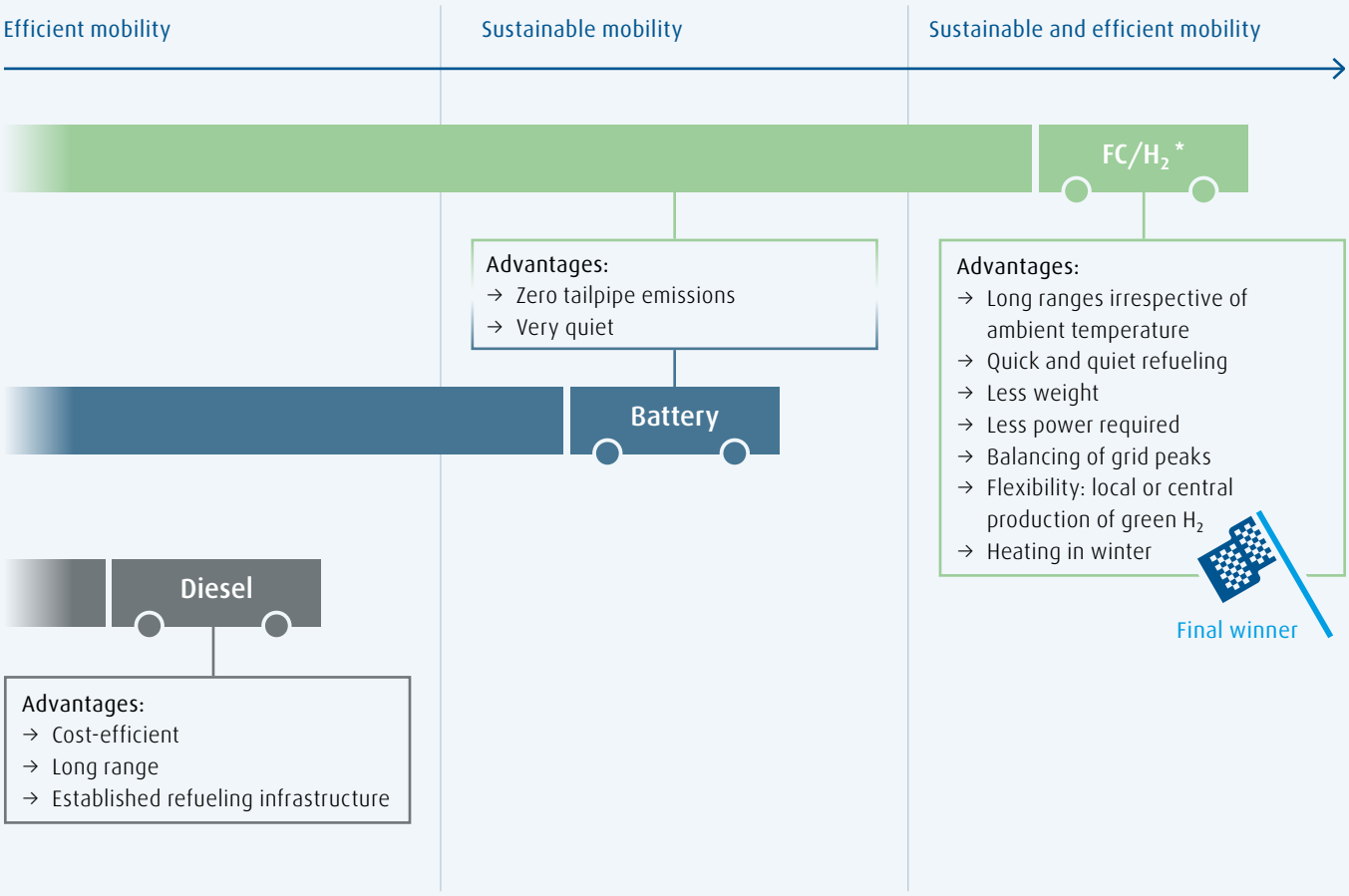
Although battery-powered electric cars offer certain advantages particularly in urban settings, the balance clearly shifts towards hydrogen-powered drivetrains as the size of vehicles/fleets and their ranges increase. This makes hydrogen fuel-cell buses an increasingly popular contender in the race to decarbonize urban transport and meet new policy and regulatory demands.

Many regions around the world are already investing in hydrogen (H_2) initiatives, developing concrete hydrogen projects and building out climate-friendly infrastructures. China already has over 5,000 fuel-cell buses in operation.

Japan plans to get 1,200 fuel-cell buses on the road by 2030. To serve these vehicles, Japan aims to build a H_2 supply chain producing 300,000 tons of H_2 every year by 2030.

Technology leader Linde is already actively involved in many hydrogen bus projects, supporting customers with its proven expertise along the entire hydrogen value chain – from gas production, supply and storage to fueling station systems featuring state-of-the-art compression and dispensing technologies. Our end-to-end offering even extends to the operation and maintenance of hydrogen refueling stations (HRS) on behalf of our customers.

Why H_2 mobility will win the race – range, refueling, payload and flexibility



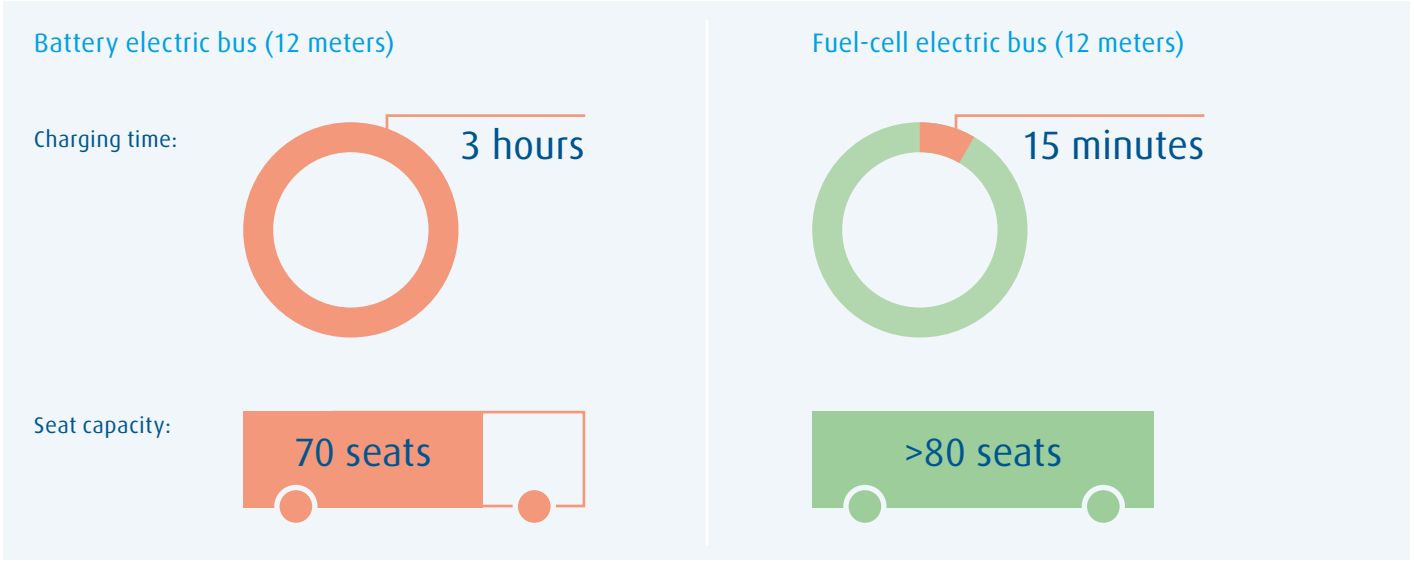
* Fuel cell / hydrogen

Compelling Advantages of Hydrogen

Here at Linde, we firmly believe that hydrogen (H_2) is a more compelling prospect for urban transport as it combines sustainability with the efficiency needed for widespread commuter acceptance.

It is common knowledge that battery-operated buses have a number of drawbacks. These include limited range, especially on hilly terrain and in colder or warmer climates – where air conditioning and heating can drain up to 50 percent of the battery capacity. In cold temperatures especially, this can even make the bus inoperable.

In addition, the infrastructure costs for battery-operated buses are prohibitive as each bus needs its own charging point and these may need to be distributed over wide rural areas depending on the bus route. This lack of flexibility means that fleet expansions typically entail high infrastructure investment costs. Plus it can take up to three hours to charge an electric bus. During this time, these buses are out of service, which means that operators may have to invest in a larger fleet to ensure that the requisite number of vehicles are charged and operational at any given time. Not only is battery charging a slow and often loud process, it can also strain the grid, particularly during peak hours. Last but not least, the battery in electric buses is extremely heavy and bulky, limiting seating accommodation. This can further contribute to fleet oversizing.



H_2 stacks up – in every sense of the word

H_2-powered fuel-cell buses overcome these challenges. First and foremost, they offer a longer range than battery electric models. In addition, they are robust to changes in temperature as heat from the fuel cell warms the bus in colder months, thus reducing the energy drain for heating. The absence of a heavy battery further increases fuel efficiency and creates added space for passengers, thus potentially reducing the number of buses required on the road.

Speed is another key advantage. H_2 buses can refuel in as little as 15 minutes or less. This means that one single dispenser can serve a large fleet over the course of a day.

Scaling Smoothly to Meet Growing Demand

The cost-efficient, scalable choice – on a compact footprint

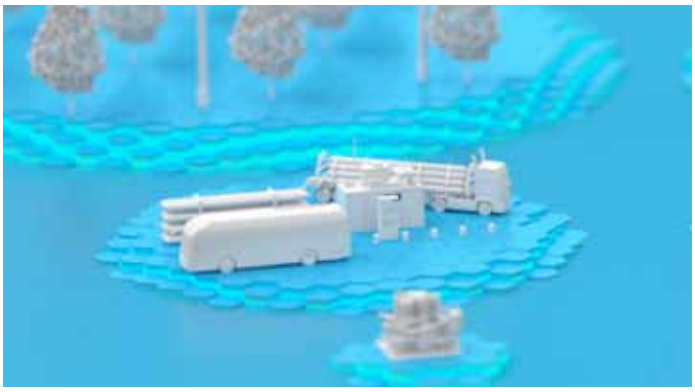
Perhaps the most compelling advantage of H_2 buses is the overall cost factor. Unlike battery electric buses, the infrastructure and relative costs of a H_2 bus station drop per kilogram of H_2 as the fleet expands. For instance, our Twin IC-P solution has a power rating of less than 230 kW and can refuel more than 60 buses per day. By comparison, each individual electric charging point for a battery bus has a power rating of about 600 kW.

Fast refueling speeds also mean that operators can expand their fleet without having to contend with additional infrastructure CAPEX for each new bus. If additional capacity is required, modular, containerized designs of key components enable easy scaling of H_2 refueling stations.

Furthermore, hydrogen refueling stations offer a more compact footprint. Our Twin IC-P requires about 20 m^2, and can serve up to 60 buses.

Extremely efficient H_2 refueling depots for gaseous and liquid supply modes

Cryo Pump technology enabling large, efficient bus depots



Ionic Compressor for highly efficient trailer-supplied refueling stations

Twin CP 50/100 for liquid H_2 supply

- More than 100 buses per day
- Less than 400 kW required to power station
- Less than 1.6 kWh per kg H_2
- Less than 60 m^2 required for pump

Twin IC-P 50/100 for gaseous H_2 supply

- More than 50 buses per day
- Less than 225 kW required to power station
- Less than 3.7 kWh per kg H_2
- Less than 20 m^2 required for compressor

Service and Support Every Step of the Way

Benchmark performance backed by global service and support

Our refueling technologies offer leading performance – both in terms of capacity and energy efficiency – over the broadest inlet pressure range available on the market. Highlights include optimized total cost of ownership (TCO), enabled by low operating costs combined with efficient services such as preventive maintenance, express spare part deliveries, remote troubleshooting and ongoing support.

Customers can also rely on us for benchmark reliability as measured through system availability and the success rate for first fueling attempts. In addition, modularized designs, choice of reliable supply modes (trailer, tank or pipeline), and support for both 350- and 700-bar refueling pressures all take flexibility and scalability to the next level. Low noise and small footprints enhance flexibility further through ease of integration into urban environments. Last but not least, all our compressors and pumps are designed, built and operated to the highest safety standards, reflecting our long-standing operational experience and type-testing history, our robust safety philosophy and our active role in advancing safety standards.

Complementing our standardized, modularized fueling station systems, our consultants also team up with our customers to realize individual or special requests – whether that be for larger fueling capacities, combined gaseous and liquid fueling models or integration into existing fueling stations.

In short, customers can rely on us for everything from the manufacture of dispensers to end-to-end execution of complete fueling stations for H_2 bus fleets. Thanks to our global footprint, these services are available worldwide.

H_2 refueling technology for optimized TCO

- → Highest safety standards
- → Leading performance
- → Benchmark reliability
- → Fast delivery times

Efficient scalability

15–30 buses per day

- 1 × single Ionic Compressor container (28 or 52 kg/hour)
- 1 × electric container
- 3 × 550-bar tube (each 1,200 l)
- 1 × dual dispenser

30–60 buses per day

- 2 × single Ionic Compressor container (28 or 52 kg/hour each)
- 1 × electric container
- 9 × 550-bar tube (each 1,200 l)
- 1 × dual dispenser

40–90 buses per day

- 3 × single Ionic Compressor container (28 or 52 kg/hour each)
- 2 × electric container
- 9 × 550-bar tube (each 1,200 l)
- 2 × dual dispenser

Experience Matters

Having engineered and built more than 200 hydrogen fueling stations worldwide, we have the most experience and largest installed base worldwide. Today, the world's biggest hydrogen bus depot in California relies on our technologies. We also have the world's most extensive liquid hydrogen production and distribution capacity in the world.

Flagship projects

Large public H_2 fueling station in Oakland, USA

- Cryo Pump CP 90 for LH_2 supply with a fueling capacity of 40 kg/hour
- Fully integrated into existing conventional fueling station
- Very small footprint (10 m × 3 m)
- Simultaneous refueling on a dual dispenser offering 350 bar for buses and 700 bar for cars

Linde H_2 station uses electrolysis to serve local bus fleet in Sarawak, Malaysia

- Twin IC 90 for GH_2 supply with a fueling capacity of 52 kg/hour or 1,200 kg/day
- Serves local bus fleet with 350-bar vehicles and 700-bar passenger cars
- On-site production of green H_2 with integrated electrolysis

One of Europe's most reliable H_2 refueling stations in Aberdeen, Scotland

- Twin IC 90 for GH_2 supply with fueling capacity for up to 15 buses, each traveling up to 200 km a day
- More than 150,000 kg hydrogen dispensed (Europe's most reliable HRS*)
- On-site production of green H_2 with integrated electrolyzers
- Dual dispenser with 350 bar for buses and 700 bar for cars and road sweepers

*HyTransit, "European Hydrogen Transit Buses in Scotland", final report (01.01.13–31.03.19), eupopa.eu

Bus fueling depot supplied with green H_2 in Rhein-Main area, Germany

- Twin IC 50 for GH_2 supply (one IC 50 in operation, one as backup) serving eight buses
- Green H_2 supplied from the power-to-gas plant in nearby Mainz
- Station capacity: 300 kilograms of H_2 in eight hours

Highly redundant station in Cologne, Germany, serves Europe's largest H_2 bus fleet

- Two Twin IC 50 compressors for GH_2 supply with a fueling capacity of 100 kg/hour
- Refueling of Europe's largest fuel-cell bus fleet consisting of 20 buses
- Very high system redundancy

700-bar bus refueling for the 2020 Olympics in Tokyo, Japan

- Cryo Pump CP 90 for LH_2 supply with a fueling capacity of 100 kg/hour
- Large capacity on small footprint with LH_2
- Serving 700-bar buses

Connecting the World of Hydrogen – from Source to Service

Think hydrogen. Think Linde.
The hydrogen future is here now. And Linde can deliver it. The company covers every link in the hydrogen value chain from production and processing through distribution and storage to everyday industrial and consumer applications. Building on decades of research and countless real-world projects, Linde's hydrogen capabilities demonstrate its innovative power and proven expertise in delivering workable, economically viable hydrogen technologies suited to mass deployment.

Demand for these technologies is set to rise given that hydrogen is ideally positioned to accelerate the transition to more sustainable forms of energy while still supporting current energy models and regional variations. Hydrogen is a zero-emissions source of fuel for trains, buses and cars.

Do you want to get your hydrogen project off the ground quickly, safely and based on state of-the-art technology?
Then you should team up right from the start with a partner who covers all areas of hydrogen expertise.

Get in touch with our team of experts:
www.linde-engineering.com/contact

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