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European Demonstration Projects CUTE and HyFLEET:CUTE

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Objectives and Needs for CUTE / HyFLEET:CUTE

Motivation

- Develop a totally clean transport system for cities
- Making fuel cells competitive in costs and reliability
- Produce hydrogen economically and with no negative environmental impact
- Learn how to handle hydrogen safely
- Storing sufficient energy to achieve an adequate vehicle range

Needs for the Fuel Cell technology

- Gain field experience with fuel cell (FC) systems and electric engines in mobile applications
- Operability of on-site H_2 production facilities and high pressure filling stations
- Country specific certification of FC systems and high pressure H_2 storage systems
- Acceptance test of the new technology and of hydrogen as a fuel

What is CUTE / HyFLEET:CUTE?

CUTE:

- 2 year operation of 27 Fuel Cell Mercedes-Benz buses in regular service in 9 European cities
- Test in different topographical, climatical and operational settings
- Evaluation of different means of production, distribution and storage of hydrogen
- Identification of technical optimizations (buses and infrastructure)

ECTOS:

- 3 buses in Reykjavik

STEP:

- 3 buses in Perth (Western Australia)

HyFLEET:CUTE:

- Continued operation of 33 H_2 powered Fuel Cell Mercedes-Benz Citaro buses in 7 European cities, Perth (Western Australia) and Beijing (China)
- Operation of 14 H_2 powered Internal Combustion Engine MAN buses in Berlin (Germany)
- Design, Construction and Testing of "next generation" H_2 powered Fuel Cell buses and Internal Combustion Engine buses
- Continuous operation an optimization of existing filling stations
- Identification of technical optimizations (buses and infrastructure)

CUTE/HyFLEET:CUTE

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Success story CUTE/HyFLEET:CUTE

12 cities (Europe, Asia, Australia) – 36 Buses

Europe

Beijing

Perth

Situation January 2007

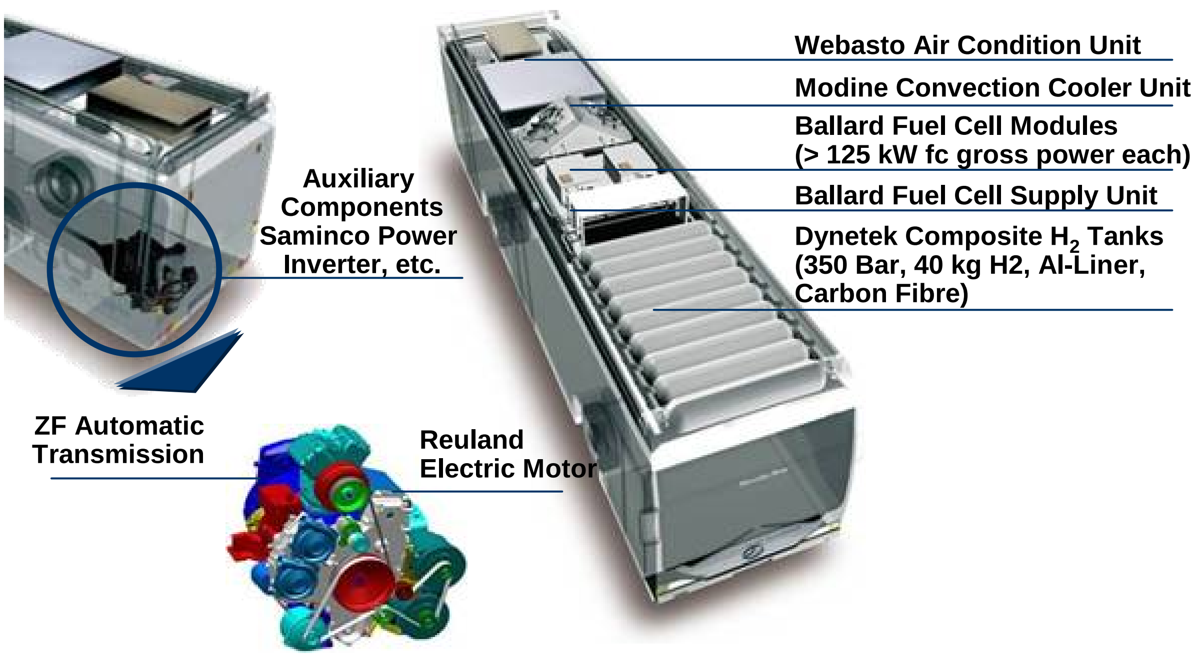
- More than **1.713.000 km**
- More than **115.200 hrs**
- Vehicle availability **90 – 95 %**
- More than **6 Mio. passengers**
- Fuel Cell Lifetime: up to 4000 hrs
- **Extension** in some selected cities: (Hamburg and Amsterdam in Europe, Perth in Australia an Beijing in China)

➡ The European Fuel Cell Bus Projects (CUTE/HyFLEET:CUTE) are the most successful Fuel Cell Bus projects world-wide.

➡ Demonstration that fuel cell technology is able to meet public transport requirements.

Technical Design of the Mercedes-Benz Fuel Cell Citaro

- The design is based on Standard Mercedes-Benz Citaro series model (12 m version)
- Outside dimensions stayed unchanged except height (3.70 m) due to roof mounted fuel cell drive train and fans of the cooling module.
- Additional 3 tons of extra load for the fuel cell drive system. Suspension has been adapted to accommodate higher weight and tendency to roll.

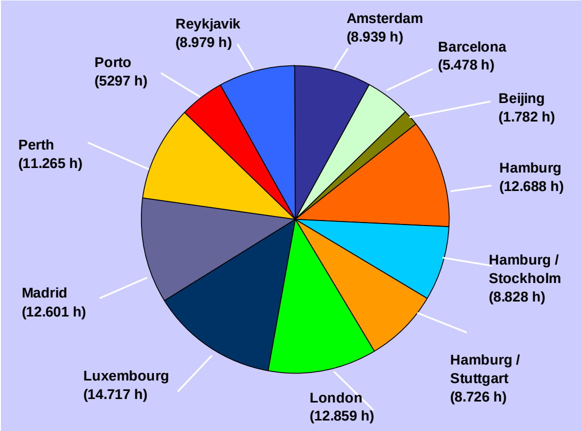


Specifications:

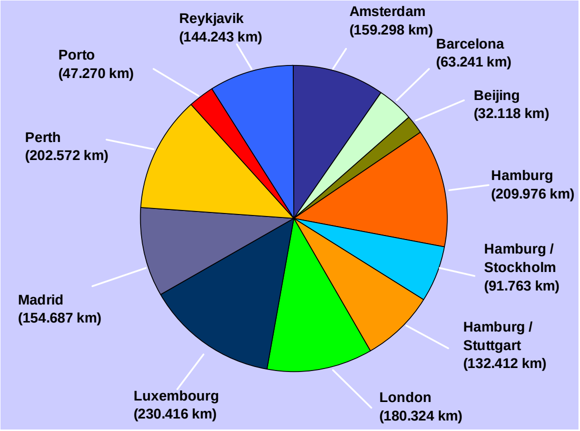
- Fuel cell gross power: > 250 kW
- Net Shaft power: 205 kW
- Transmission: 6 speed automatic transmission
- Tank Capacity: > 40kg H_2 at 35 MPa
- Range: > 200km
- V_{max}: up to 80 km/h (elec. ltd.)
- Weight empty / loaded: 14.2 tons / 18 or 19 tons
- Passenger capacity: up to 70

Lessons Learned: Fuel Cell Bus Operations

- The buses operated for more than **115.200 hrs** (incl. ECTOS & STEP)
- The 3 buses per site completed an average of **142.000 km** until now (Luxembourg 230.000 km; Barcelona 68.000 km due to infrastructure problems)

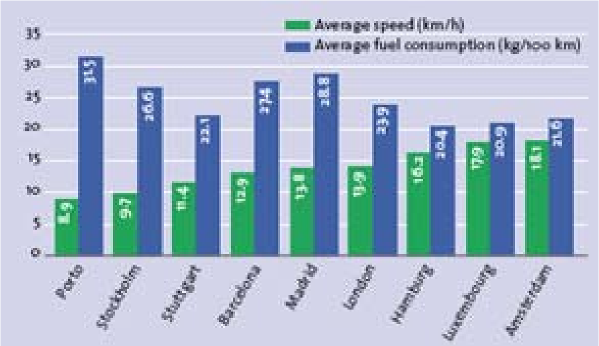


Total Hours

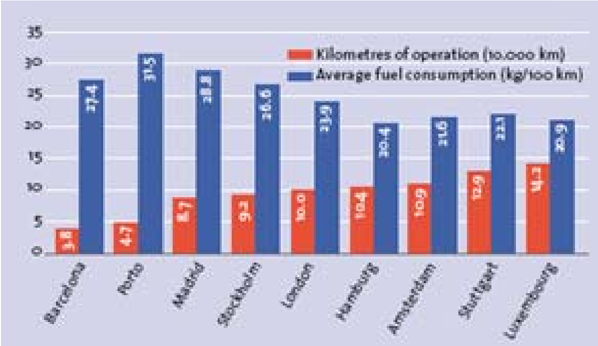


Total Kilometers

- The average speed of the buses differs from 19 km/h in Perth and Luxemburg to 9 km/h in Stockholm and Porto
- Fuel consumption tends to be higher for the cities with low kilometers driven



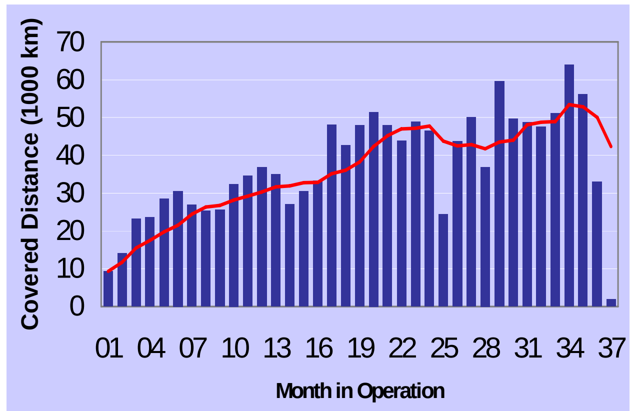
Average Speed/Fuel Consumption (CUTE)



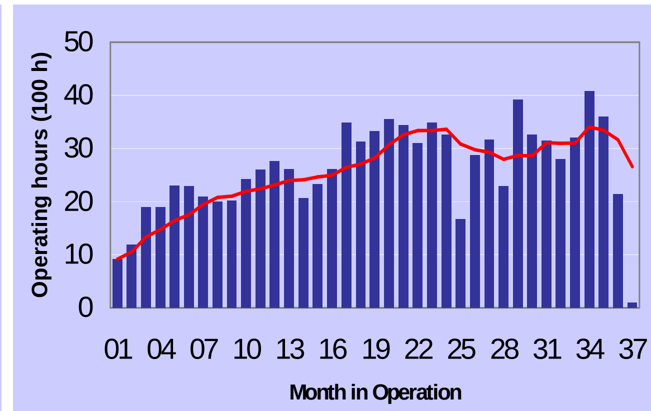
Kilometers/Fuel Consumption (CUTE)

Lessons Learned: Fuel Cell Bus Operations

- 20.000 km/month at beginning to 48.000 km at end of the trial (Sep 2006: 64.000 km).
- Daily operations from 8 hrs to 16 hrs a day at end of the trial.

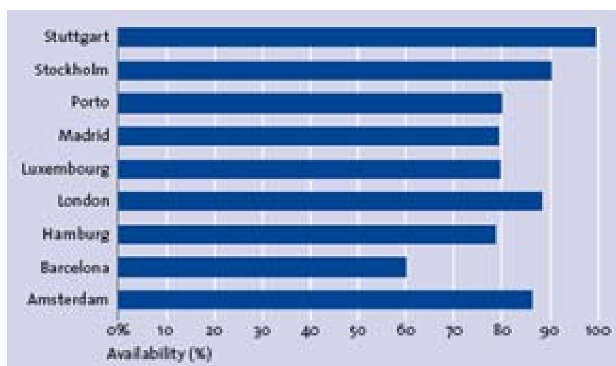


Monthly Kilometers

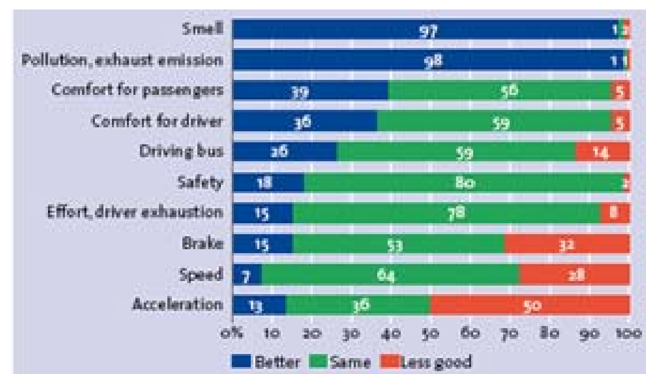


Monthly Hours

- Availability of the buses was 81.6% in average (Stuttgart: 99.6%; Barcelona: 60% due to contamination in hydrogen vessels)*.
- Drivers survey showed high acceptance for the buses.



Availability of Buses

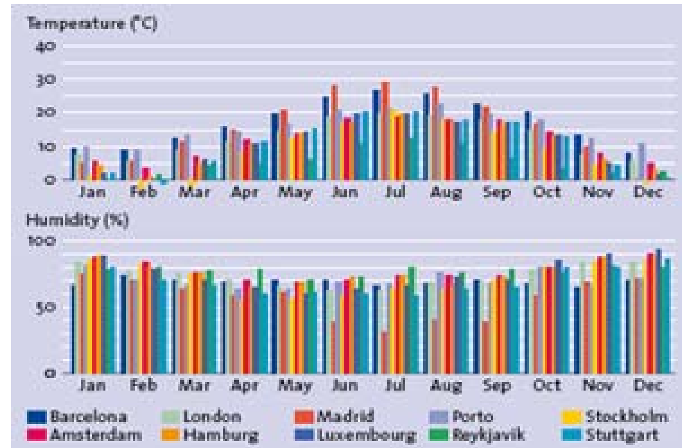


Drivers Opinion

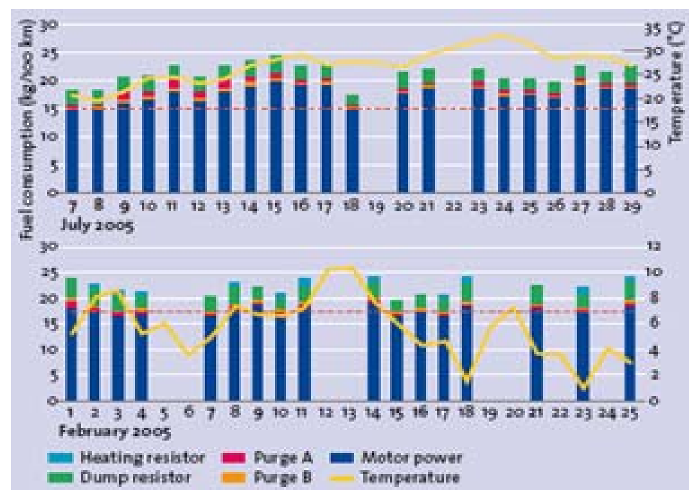
* Number of downtime days per month as proportion (%) of total number of days in month

Lessons Learned: Climate Effects
- CUTE -

- **The climate in the nine cities differs considerably (temperature, humidity).**
- **For reliability the fuel cell stacks were kept warm in cold conditions (below 5° C).**
- **Temperature dependency of fuel consumption was noticeable at temperatures below 0° or above 18°.**
- **Fuel consumption increase in warm periods due to increased draw of power caused by air-conditioning. Heating in cold periods consumed up to 5 kg/100 km fuel .**



Monthly Temperature and Humidity



Consumption Madrid Summer/Winter

Lessons Learned: Topographic Effects

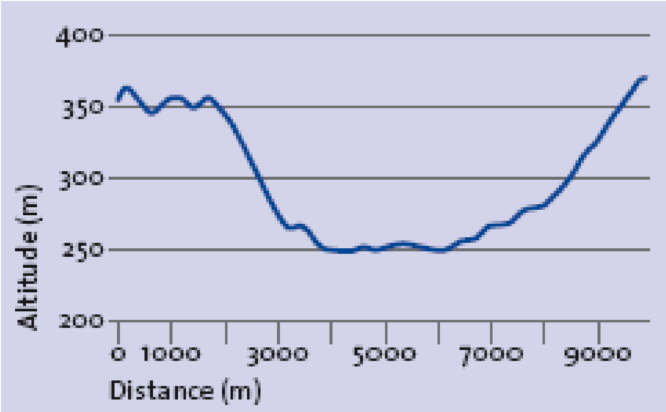
- CUTE/ HyFLEET:CUTE -

- Very different topographical conditions for buses.
  Flat: Hamburg, London and Amsterdam
  Hilly: Stuttgart gradient up to 8.5%

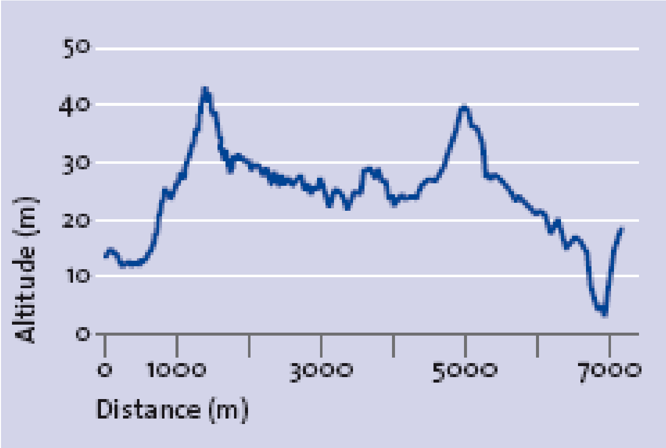
- No obvious long-term effect of topography on the wear of buses or fuel cells

- A challenging topography → increase in the fuel-consumption similar to diesel.

  Disadvantage: Due to minimum current limitation of the Fuel Cell Citaro buses set on the fuel cells (safety reasons) buses still consume relatively much fuel downhill

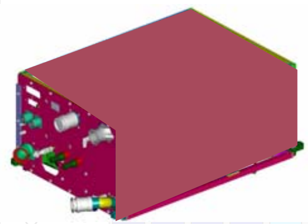


Route 44 Stuttgart

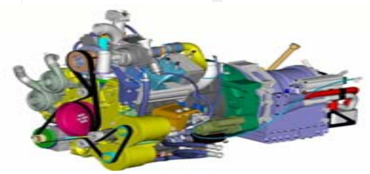


Route 66 Stockholm

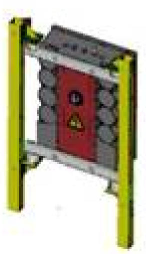
Lessons learned
-Technical Experiences with the Fuel Cell Citaro -



The Ballard Stack Module: Special Heavy Duty FC
- First "low mass production"
- Lifetime much better than expected
- High performance and high availability
- Still expensive, good weight/performance ratio
- CVM board to be improved



The Electric Drive Train:
- High reliability
- "Diesel-similar behaviour"
- Efficiency to be improved
- Comfort aspects should be improved



High Voltage Components:
- Still one of the major risks in Electric Vehicles (with regard to reliability)
- "Automotive suitable"
- Expensive

Technical Optimization Potential: Next Generation Fuel Cell Bus Prototype

- To improve fuel economy the buses have potential for improvement in fuel cell system, the driveline, as well as in adaptation of bus auxiliary systems to electric power source
- Minimum current limitation to overcome (15% fuel savings)
- Electric driveline without transmission is more efficient and quieter
- With electric auxiliaries idling losses due to mechanical driven auxiliaries can be avoided and overall efficiency increased
- Hybridization would save up to 20% of energy
- Electric drivelines with fuel cells have the chance to build up optimized passenger compartment and axle-weight distribution
- Lower weight of components would give better driving performance, higher passenger capacity and reduced fuel consumption

Fuel Cell Bus Maintenance Workshop

- At most sites existing workshops were adapted to hydrogen requirements. Barcelona and London built new workshops
- Hydrogen sensors installed on ceiling. Safety alarms activated when hydrogen concentration detected (pre-alarm at 0.6% hydrogen/air, main alarm at double)
- In case of a hydrogen alarm: Fans in roof start operation and natural ventilator hatches open
- Non explosion-proof installations switch off, ex-proof lighting turn on
- All staff to leave premises, according to alarm-chain fire brigade alarmed automatically

Workshop Madrid

Release Pipe Reykjavik

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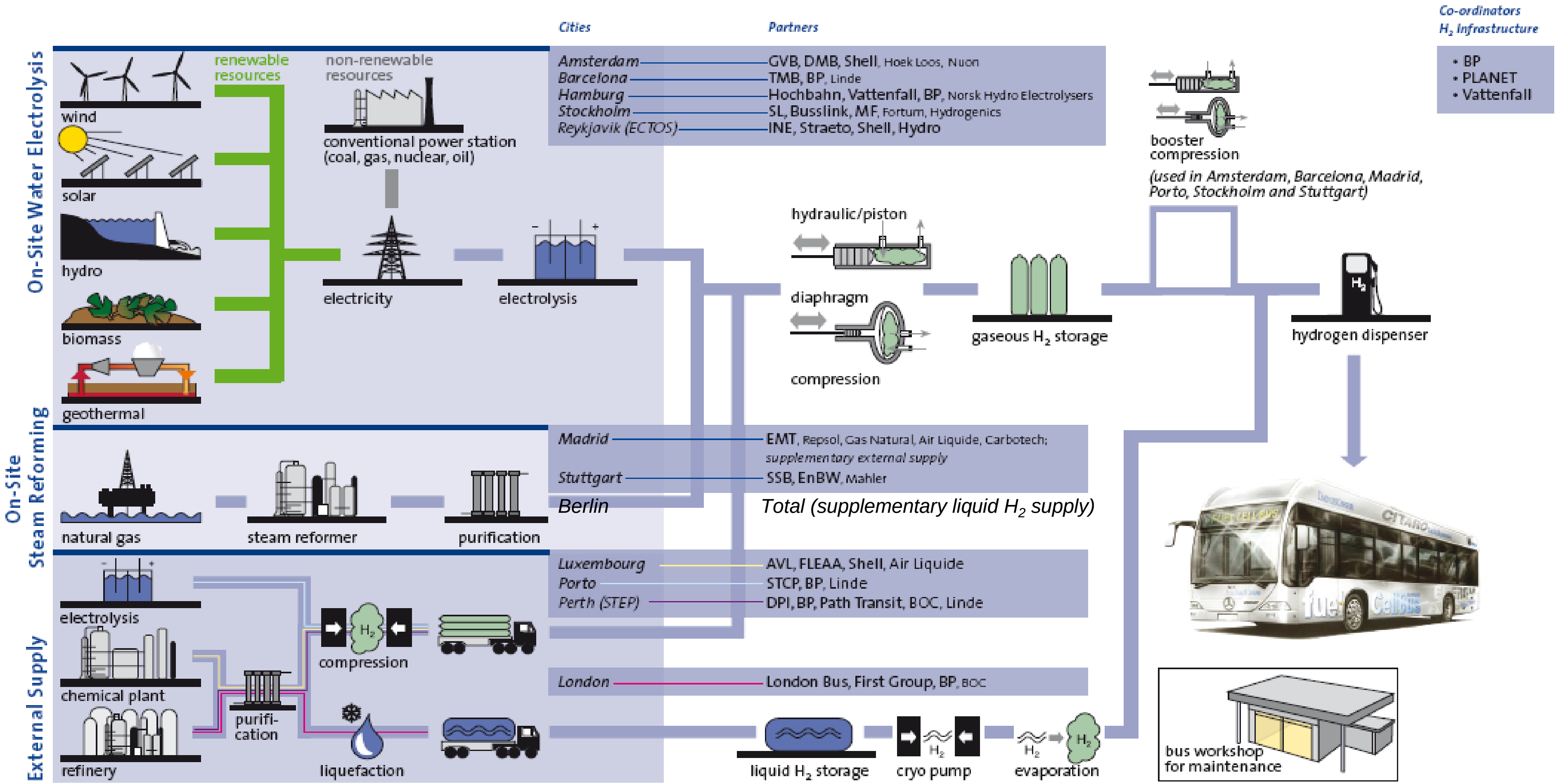
Hydrogen Supply Pathways
- CUTE / HyFLEET:CUTE -



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Lessons Learned: Infrastructure
- CUTE / HyFLEET:CUTE -

- Failure modes are very different in the infrastructure facilities (even with almost identical equipment).
- Optimization of reliability still in progress – “Every day new experiences”.
- Back-up solutions in the design of the station have to be considered in case on-site production fails.
- Due to maintenance intervals being to big or procedures not adequate, failures occurred.
- “Automated data acquisition”.
- Information exchange between infrastructure suppliers has to be improved.
- Pricing for hydrogen increased (significantly for HyFLEET:CUTE).

Electrolyzer - Hamburg

Steam Reformer - Madrid

➔ Too early for unmanned hydrogen refuelling stations, maintenance procedures have to be defined and followed up.

Further Learnings
- CUTE / HyFLEET:CUTE -

- Easier gathering of data if integrated in on board data collection-system from the project start
- The need to develop entire support structures for the whole system, especially infrastructure, has been demonstrated.

9 Hamburg Buses Ready for Action

Conclusion
- CUTE / HyFLEET:CUTE -

- Moved the state of the art in hydrogen and fuel cell technologies for transport a significant step forward
  - The fuel cell buses reliable under European climate, topography & traffic conditions
  - High availability of the buses compared to expectations
  - Highest operating hour of buses: > 5000 hrs
  - Durability of stacks:Cell Row Lifetime up to 4000 h
- Provided unparalleled visibility for hydrogen and help to establish its credibility as an alternative to petrol
- Put the European transport industry and the cities involved amongst the global leaders in production and operation of such buses
- Raised new questions and challenges that will foster the development of emission-free technology

Roadmap for the city bus of the future
- Bus operator perspective -

Goal of a Zero Emission Bus (PM, NO_x, Noise, CO_2) is reachable with the fuel cell technology. ➔ **BUT: Improvements must be reached!**

12 cities (Europe, Asia, Australia) – 36 Busses

Europe

Beijing

Perth

Need for Improvements

- Lifetime must come close to 15.000h
- Fuel consumption must be reduced
- Service and maintenance
- Reduction of unit costs
- Braking energy recuperation
  ➔ Use of electric storages
- Bus-specific auxiliaries
- Use of bus specific traction motors

Thank you for your attention!

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