

Propulsion technology trends across major bus operators in Europe, North America and South-East Asia



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Aims of this research

- Share thinking on the **future direction of bus propulsion** and the trend towards zero local emissions
- Understand (cost) implications for future **fleet decisions**
- Understand practical considerations that need to be addressed early on in **planning for electrification**
- Take the opportunities and mitigate the risks of the rapidly-developing market in **zero local emissions vehicles**



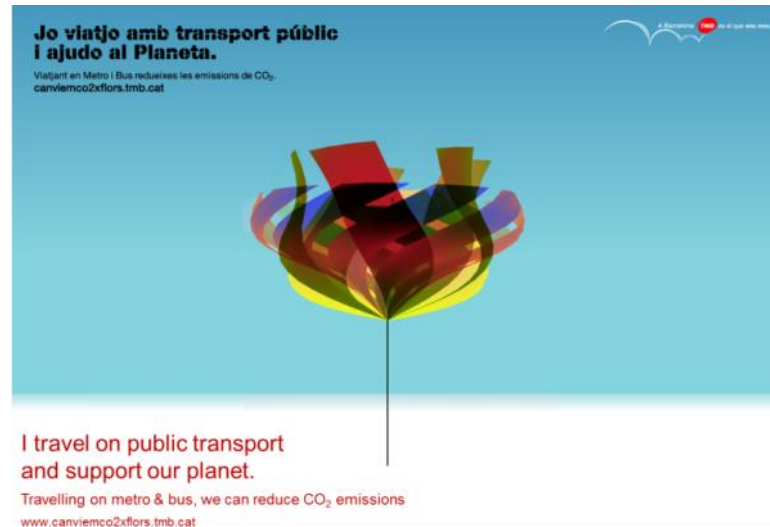
The International Bus Benchmarking Group



- Presentation shows high level, anonymised results from a study executed for and with the thirteen member cities of the IBBG



1. Environmental Visions and Measurement



Bus operations have both positive and negative environmental impacts

Indirect environmental impact

- 😊 Reduce car use
- 😊 Reduce congestion
- 😊 Enable urban density



Direct environmental impact

- 😞 Fuel use
- 😞 Air pollution
- 😞 Use of road space



Different operators/cities prioritise different environmental issues



Energy efficiency:
6 operators

Energy-related

**Climate change, CO₂,
and Greenhouse Gases
(GHG):** 5 operators

Pollution-related



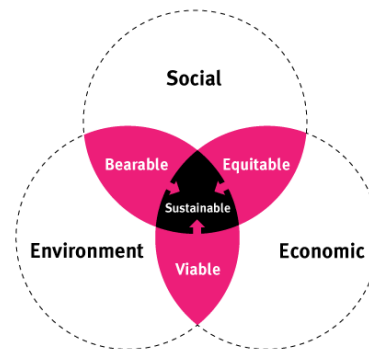
**Renewable/alternative
energy:** 3 operators

Air quality and health:
5 operators

Sustainability:
3 operators



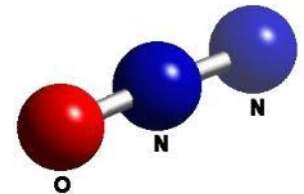
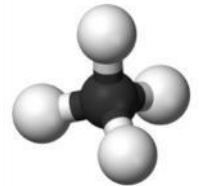
Go 'green':
1 operator



**No environmental vision
reported:** 3 operators

CO₂ is the most commonly measured facet of environmental performance

- Eight of thirteen IBBG organisations have targets for **CO₂**
 - But ten report it, illustrating that it is politically useful to do so
- 50% of thirteen IBBG organisations measure **CO₂ equivalent**.
- Only three IBBG organisations have calculated **avoided carbon**
- Seven members have targets for **NO_x** and **PM₁₀**
 - PM_{2.5} is more dangerous than PM₁₀ but targeted by only five members



Considerations for different emissions

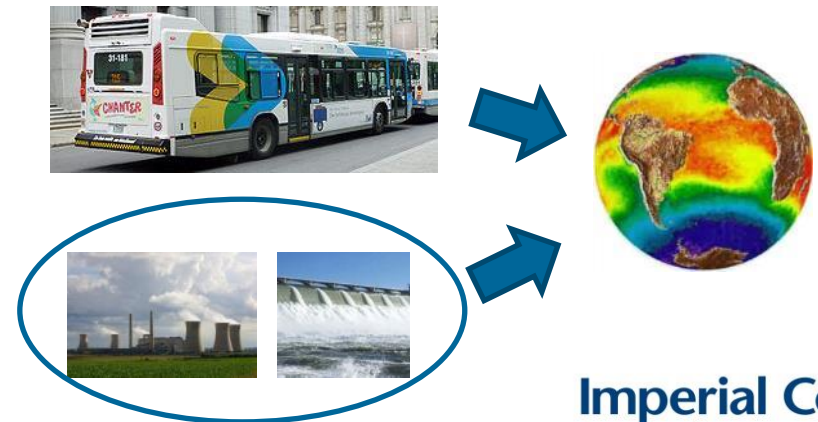
Local Pollutants (NO_x, PM)

- Local health/smog impacts
- Affect the specific area in which they are emitted
- Therefore emissions at the tailpipe are most important
- **Diesel produces most**

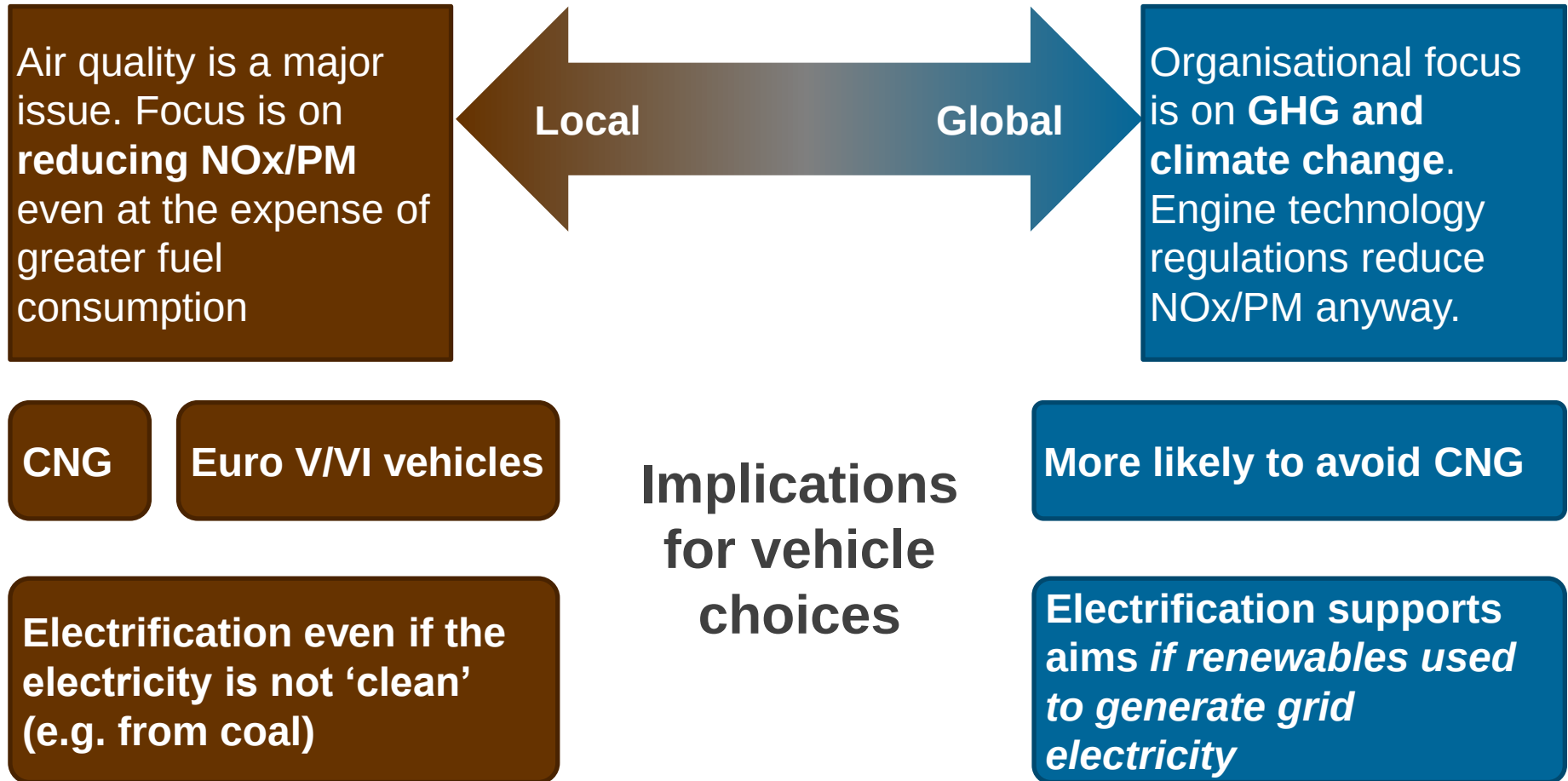


Greenhouse Gases (CO₂, CH₄, N₂O)

- Effects are global
- Cause the same climate change impact wherever they are emitted
- Therefore reporting should take into account emissions at the tailpipe and elsewhere
- **CNG produces slightly more greenhouse gases**



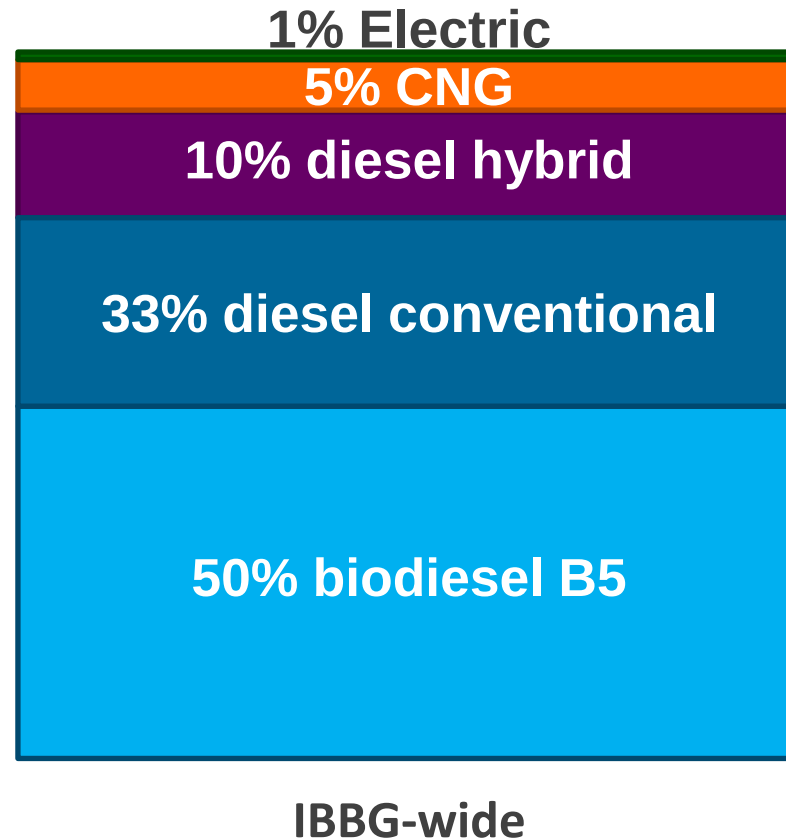
Many organisations prioritise EITHER local pollutants OR greenhouse gases. This seems to depend on local air quality



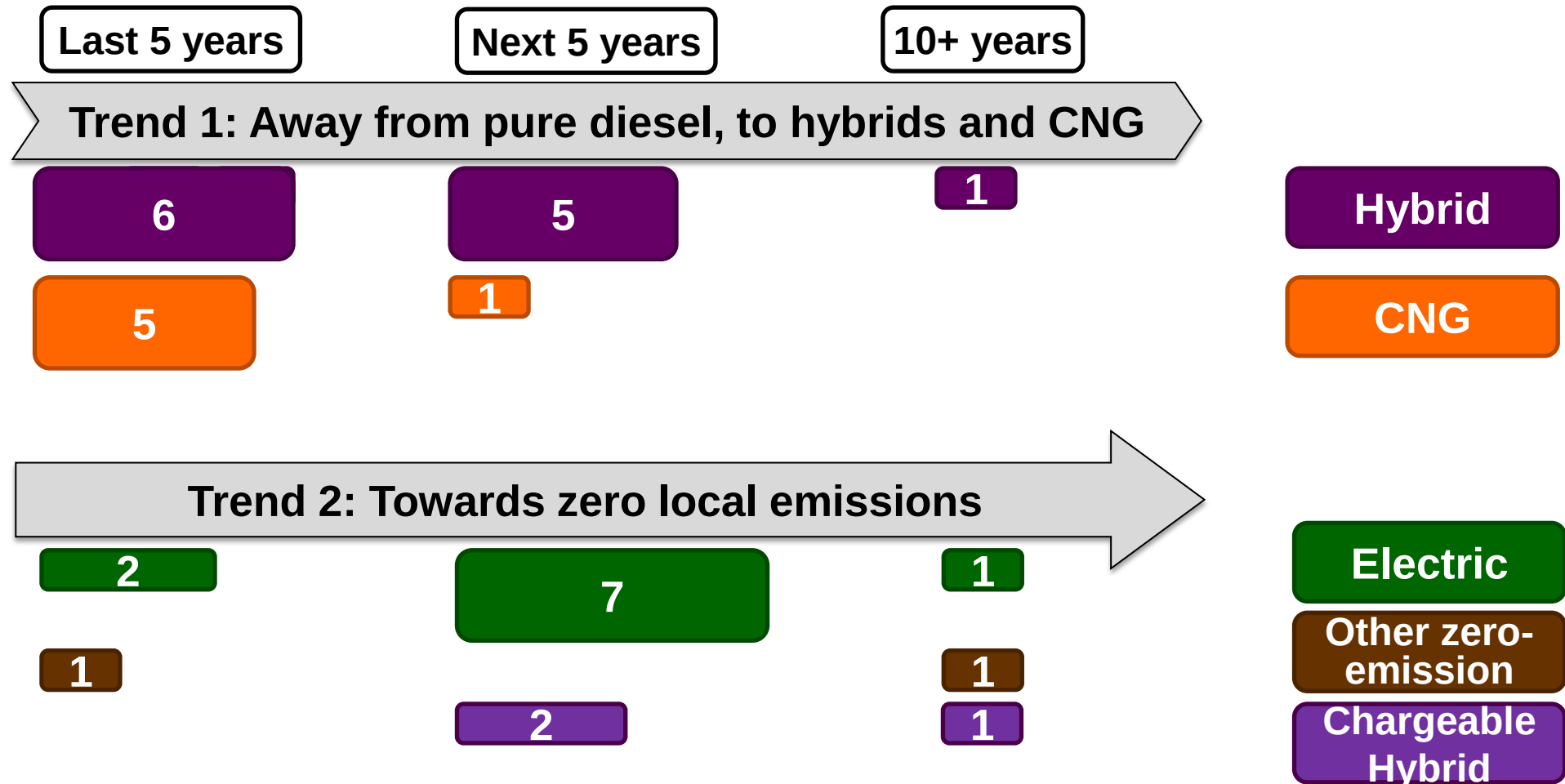
2. Propulsion Choices



In 2013, conventional diesel buses dominate but B5 biodiesel is widely used



There are two main strategic trends in propulsion: towards zero local emissions; and away from diesel



Biodiesel can reduce CO₂ emissions with minimal additional cost

Biodiesel can reduce whole life CO₂ emissions by 15-25% if it is based on waste products (e.g. animal tallow) and not plants grown specially

One operator helped to create a local supply chain

The main drawback of biodiesel is the need for more filter changes. This can slightly increase maintenance costs, by +2-5%.

One operator also reported higher NO_x emissions.

Higher blends (>B20) are more problematic: they can increase maintenance costs, invalidate vehicle warranty, and have a higher risk of freezing in cold weather

Hybrid use has doubled in 5 years, but whole life costs remain uncertain

- 10% of IBBG vehicles are hybrids
 - In **2009**, only one member had a significant fleet of hybrids
 - Since **2009**, 6 organisations have moved towards hybrids
 - By **2019**, 5 more organisations expect to be buying hybrids

Average estimated fuel savings: 24%
Average for standard 9/12m buses: 12%
Average for articulated and double deck buses: 43%

Average purchase price is 35% more than standard diesel, but has reduced from 55% more in 2009

Savings are better for larger buses because hybridisation enables downsizing the engine

CNG reduces local pollutants; outcomes for whole life costs vary

- 5% of IBBG vehicles are CNG
 - Between 2009-2014, 5 organisations have moved towards CNG

	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8
Whole life cost	-10%	-	=	=	ND	ND	+	+10-15%
Emissions	-90% (v. Euro 3)	= (v. Euro 4+)	-NOX +CO ₂ e	ND	=	+CO ₂ e	-PM =CO ₂	ND

- The difference in business cases is probably down to local CNG infrastructure, cost and availability factors
 - Double decker CNGs not readily available
- CNG requires outdoor facilities or a LOT of ventilation due to flammable gas refuelling

Zero local emissions are the future, but **hydrogen** fuel cells are not currently realistic

“There is only one way, and that is towards zero emissions. How long will it take? I don’t know.”

—Van Hool (pers. comm.)

Up to 2020, the majority of buses *in operation* will still be diesel.

By 2030, the majority of buses on the road will be zero local emissions



Hydrogen buses cost between 200% and 600% of diesels

Hydrogen fuel cells have similar weight issues to batteries

Hydrogen fuel cells are an alternative to a battery – the drivetrain is electric

Fuel cells overcome logistical issues of battery electric buses – charging, battery life etc.

If hydrogen fuel cell buses were cheaper, would they be preferable to battery electric?

Electric Battery Buses vs. Conventional Diesel

No local emissions, lower lifetime environmental impact

	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8
Whole life cost	-26%	=	=			+	+58%	+100%
Purchase cost	+33%	+50%	+100%	+150%	+200%		+100%	
Fuel consumption	-70%		-70%		-90% cost -70% energy			
CO2 emissions			-70%				-81%	

Key: + + significant increase, + minor increase, - minor decrease, - - significant decrease
?: uncertain, (blank): information unavailable, =: no change

Specific equipment include charging facilities (possibly a major expense) and tools for servicing high-voltage equipment

Performance is good except for problems driving up steep hills

Trolleybuses have lower fuel costs and last a long time, but the infrastructure required is expensive

Lower whole life
environmental impact

40-50% lower energy
use and cost than
diesel

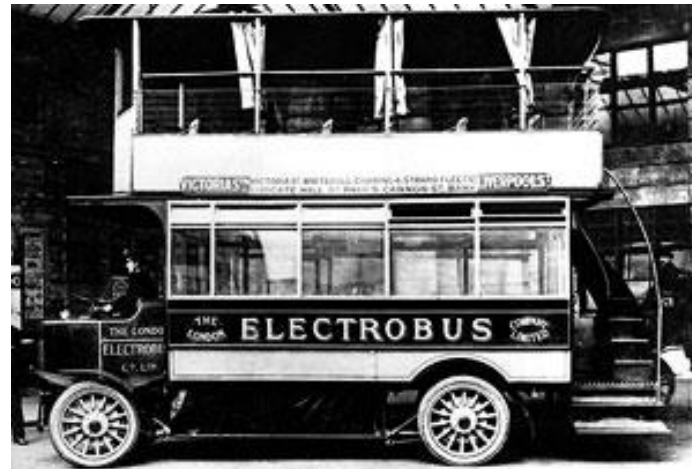
60-90% lower
emissions, depending
on electricity

Longer vehicle life

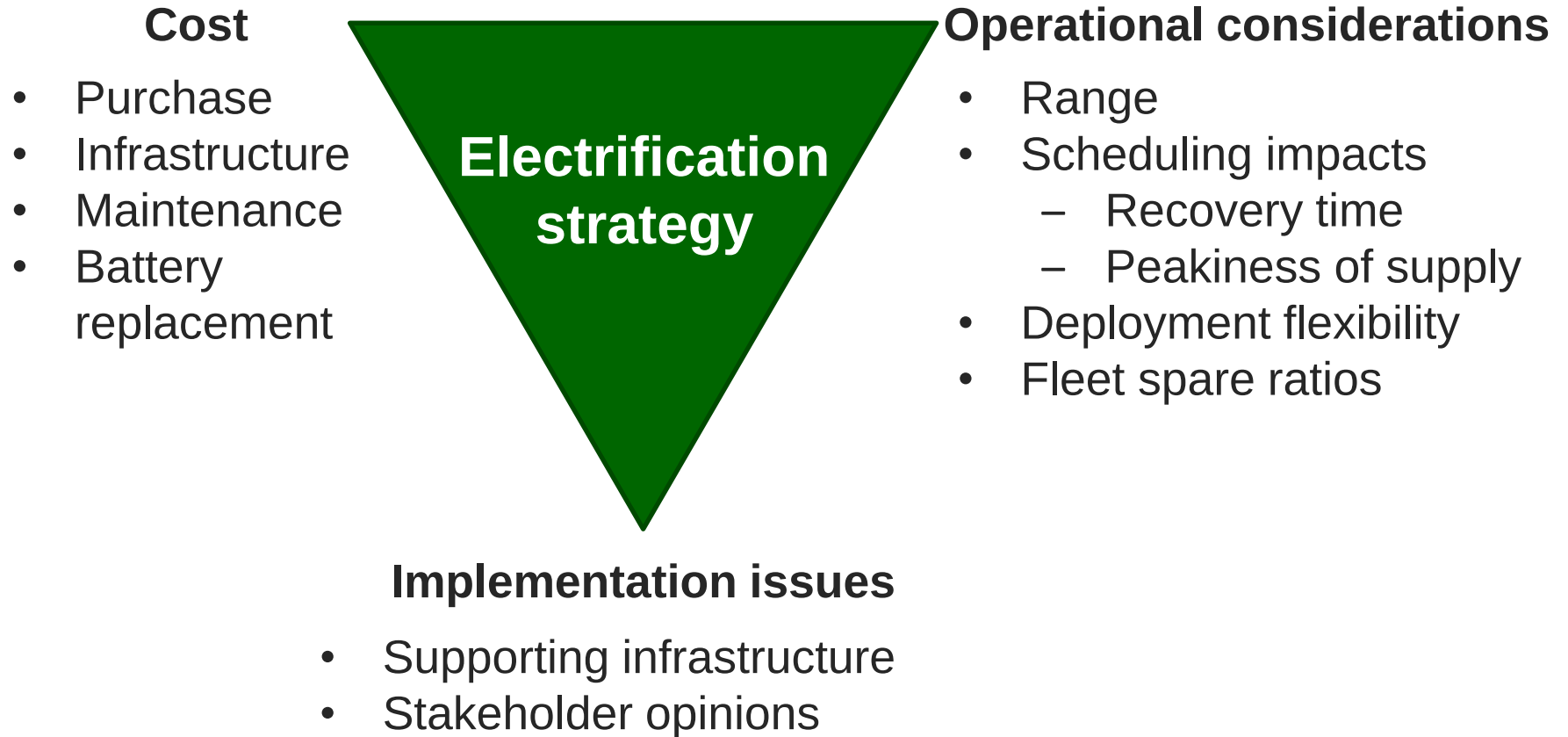
Trolleys with significant off-wire capacity (battery-trolley hybrids) may be an important emerging technology in cities with trolley wires.

This solution solves problems of range and charging equipment by using existing infrastructure.

3. Practicalities of Autonomous Electric Buses



Consider operations and implementation as well as cost when choosing electrification strategy



Depot charging is simpler, but on-road charging enables lighter buses and greater range

Depot base station

- ✓ Simpler
- ✓ Lower cost equipment
- ✗ Lower range (100-250km)
- ✗ Bigger, heavier batteries
- ✗ Makes whole bus heavy – reduces passenger capacity

Charge time

3-8hr slow charge,
1-3hr med charge

On-road

- ✓ Quick
- ✓ Not going back to the depot
- ✓ Greater autonomy >500km
- ✗ High charging station cost
- ✗ Higher dwell or recovery times, depending on charge location
- ✗ Charging devices occupy public space (and are unattractive)

Charge time

5-21 min/hour of
service (12m bus)

On-road charging technologies

Pantograph

- Pantograph raises from roof of bus or charger lowers down to collector on bus roof
- Low precision needed
- Charging stations are expensive

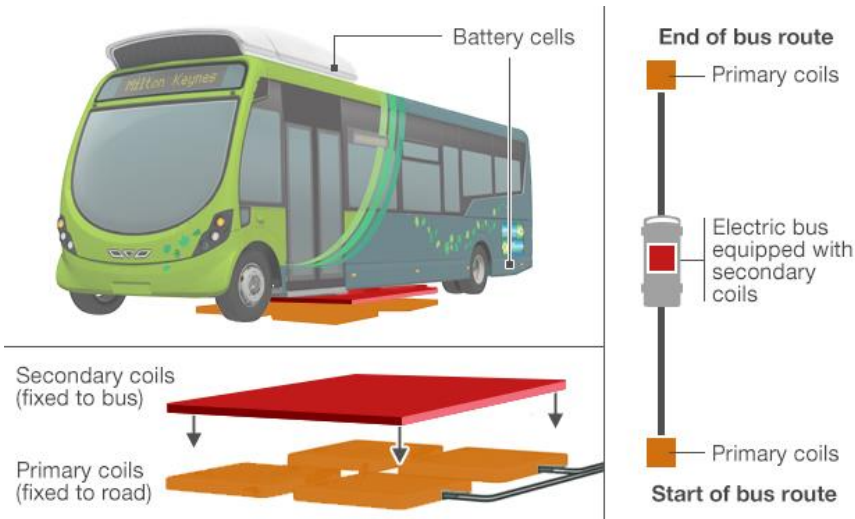


Image: BBC

Ground induction

- Precision docking needed, which can add time to stops
- Parked cars or ice can block it
- Some models overheat if no 'time off' between buses



Image: Busbar system demo in Sweden

A call to action on interoperability for on-route charging

- Non-standardised, non-interoperable on-route charging equipment is a major risk
- Charging equipment is currently proprietary and matched to a bus type...
- ...if operators buy one type of bus and on-route charging kit, they cannot charge another manufacturer's bus on that route without duplicating the equipment.
- There is currently a window of opportunity for standardisation and interoperability while the technology is developing



4. Conclusions

Conclusions – Environmental Visions

- Organisations' environmental priorities differ
 - Generally, either 'NOx/PM' or 'greenhouse' gases are given greater priority
- Measuring and communicating environmental performance is **politically important**
- **Avoided carbon** is significant and a selling point for bus / transit
 - Benefits due to denser land use can be huge, 2-4 times the modal shift impacts, but are often not accounted for



Conclusions – From diesel dominance to electric future

- **Five years ago**, 91% of IBBG buses were conventional diesels and 2% were hybrid
- **Now**, 10% are hybrid and 1% are zero local emissions
- **In 5 years**, 7 more organisations expect to be buying or testing electric battery buses
- **In 10 years**, most IBBG members expect to be buying zero local emission vehicles
- **In 15 years**, a manufacturer expects >50% of vehicles on the road to be zero local emission

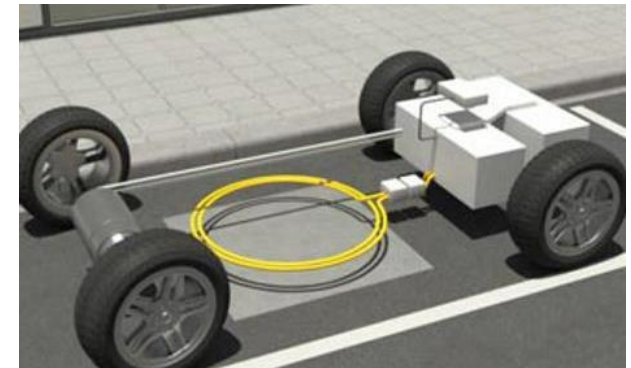


Summary of Propulsion Findings

Propulsion Trend	Advantages	Disadvantages	Recommendation
Biodiesel 	Same purchase price Carbon savings if re-used biodiesel used	2-5% higher maintenance costs Plant based biodiesel may not be low carbon	Use if sustainable biodiesel available at reasonable price
Diesel hybrid 	40% lower fuel costs for artics /double deckers Prices coming down	Fuel savings less than expected for 9/12m vehicles	Check whole life cost Use for large vehicles
CNG 	Lower local pollutants Cheaper in some places Subsidies for vehicles	High cost if no local infrastructure Slightly higher GHGs	Use if cheaper locally Consider if smog a problem
Electric battery 	Zero local emissions Good for public image	Operational constraints Infrastructure costs	Keep options open Develop operating strategy
Hydrogen fuel cell 	Zero local emissions Runs all day	Expensive No commercial market	Participate in funded development projects

Conclusions – Aside from cost, electric buses present significant new logistical and operational challenges

- Battery types, life, charging, and conditioning are complex – a knowledgeable **battery expert** can be invaluable
- Battery technology continues to develop, and **further innovations** are expected
- **Different technologies** may be required for different routes or types of routes
- There is a need and an opportunity for interoperability for electric vehicle on-road charging



Thank You