

# Environmentally friendly public transport (buses) Best practice projects in Europe

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# Background

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# Background

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- Many municipal and urban transport authorities are in need to replace ageing bus units within their fleets or purchase new buses to enhance their offer / services.
- This is generally required in order to
  - ✓ meet current standards,
  - ✓ increase efficiency,
  - ✓ passenger comfort and
  - ✓ reduce transport related emissions.
- The selection of bus technology for the units replacing obsolete buses can have a major cost, operational or environmental implications and needs to be adequately informed and assessed.





# Bus technologies - general

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# Bus technologies

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- There is a significant choice in terms of fuel and engine technology for urban bus operations. The most relevant alternatives are listed below:
  - ✓ Diesel and biodiesel;
  - ✓ Natural Gas (CNG or LNG);
  - ✓ Electric;
  - ✓ Hydrogen; and
  - ✓ Hybrid (diesel + electric or trolleybus + battery).
- While there are numerous possible variations within each category, the above list covers the most relevant options with regards to fuel, engine and propulsion technology for urban buses in Europe.



# Diesel

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Parameter	Description
Technical description	Diesel is the predominant technology for urban buses in Europe, due to its long-history of successful implementation.
Charging	
Autonomy	350 km
Pros	<p>Increased efficiency and decreases in emissions to comply with Euro VI standards make diesel an interesting and low-risk alternative for many cities looking at replacing their ageing bus fleets.</p> <p>There is no need of new/additional infrastructure, and reliability (consolidated technology); LOWER CAPEX and OPEX.</p>
Cons	Fossil fuel and a major contributor to GHG and other harmful emissions (e.g. PM); therefore, it is anticipated that its share of the market will decrease significantly, particularly in the mid to long term.





# Bio-Diesel

Parameter	Description
Technical description	Biodiesel (Fatty Acid Methyl Ester – FAME) is produced from natural vegetable oils and can be used in diesel buses with some minor adaptation. The use of biodiesel blends for urban transport has been tested in numerous European cities, with varying degrees of success. While the common approach has been mixing pure biodiesel or FAME B100 with diesel to produce different blends (B20, B40, etc.), there have also been a number of instances where B100 has been used.
Charging	
Autonomy	Up to 350 km
Pros	The main benefit of biofuel blends, given their organic origin, is the significant potential for reductions in transport related WTW GHG emissions.
Cons	Biodiesel is less energy efficient than conventional diesel, mostly as a result of larger water content and this can impact bus range, particularly in the event that pure biodiesel blends are used. This can be exacerbated by relatively high biodiesel costs, which could lead to the requirement for municipal or state financing of fuel supply. Some moderate impacts on vehicle maintenance costs (e.g. engine filter replacement) have also been reported when utilizing second generation biodiesel or B100.



# Compressed Natural gas (CNG)

Parameter	Description
Technical description	Natural gas consists mostly of methane and is as a rule drawn from gas wells or in conjunction with crude oil production.
Charging	
Autonomy	350 km
Pros	Natural gas buses generally produce lower CO <sub>2</sub> and NOx emissions than diesel ones, whereas CO emissions tend to be higher. Methane can also be produced from forestry, agricultural and / or urban waste (biomethane), which can help reduce WTW emissions further.
Cons	<p>It has been found that depending on the gas source and extraction method, WTW GHG emissions can in some cases be slightly higher for natural gas than for diesel buses. Both LNG and CNG require the presence of pipeline and gas infrastructure. Furthermore, it will be essential to undertake a study of the local conditions including consultation, engagement with the fuel provider in order to determine solutions that will be technically satisfactory and financially sustainable for the whole life cycle of the new fleet.</p> <p>Natural gas engines / buses are generally less efficient than diesel ones. Due to its storage in gas form, the amount of stored energy per litre is lower in CNG than in diesel, which in order to maintain acceptable ranges often requires buses to be fitted with additional fuel storage (circa 600kg), which may affect capital and operational costs.</p>



# Liquefied Natural gas (LNG)

Parameter	Description
Technical description	Natural gas consists mostly of methane and is as a rule drawn from gas wells or in conjunction with crude oil production. Liquefied Natural Gas or LNG is natural gas stored as a super-cooled (cryogenic) liquid at a temperature of between -120 and -170°C. LNG, therefore, requires liquefying, which is generally undertaken at large facilities off-site and distributed wherever required by the transport networks.
Charging	
Autonomy	350 km
Pros	Natural gas buses generally produce lower CO <sub>2</sub> and NOx emissions than diesel ones, whereas CO emissions tend to be higher. The main advantage of LNG vs. CNG is that it offers an energy density comparable to diesel fuels, decreasing fuel storage requirements. Methane can also be produced from forestry, agricultural and / or urban waste (biomethane). This can help further reduce WTW emissions.
Cons	It has been found that depending on the gas source and extraction method, WTW GHG emissions can in some cases be slightly higher for natural gas than for diesel buses. LNG has additional costs associated with the liquefaction and transport processes. Both LNG and CNG require the presence of pipeline and gas infrastructure. Furthermore, it will be essential to undertake a study of the local conditions including consultation, engagement with the fuel provider in order to determine solutions that will be technically satisfactory and financially sustainable for the whole life cycle of the new fleet.



# Electric Buses (slow charging)

Parameter	Description
Technical description	Electric buses are powered by a rechargeable battery and do not require an internal combustion engine. Electric bus with 400 kWh battery
Charging	3 to 6 hours
Autonomy	120-150 km (without charging)
Pros	Up to 75% cut in energy consumption and associated emissions, depending on how electricity is produced (grid emission factor). Relatively well established for some niche services (e.g. small buses in central areas sensitive to noise and emissions).
Cons	Electric vehicles are at a relatively early stage of market development and their availability is likely to be limited in the short term, which should be considered when undertaking substantial fleet renovation or replacement of large units. There may also be significant associated infrastructure costs in the transition to an electric fleet, including charging infrastructure. An important element in the maintenance and associated life cycle cost of the fleet is the replacement of the batteries, the implications of which need to be considered when assessing this technology. Given the limited ranges currently offered by electric buses, the operational impact from the required battery charging procedure (charging requires several hours per unit) and implications on charging infrastructure and required fleet size should also be attentively considered.





# Electric Buses (fast charging)

Parameter	Description
Technical description	Electric buses are powered by a rechargeable battery and do not require an internal combustion engine. Electric bus with 150 kWh battery
Charging	15 -20 min
Autonomy	Up to 250 km
Pros	Up to 75% cut in energy consumption and associated emissions.
Cons	<p>Electric vehicles are at a relatively early stage of market development and their availability is likely to be limited in the short term, which should be considered when undertaking substantial fleet renovation or replacement of large units. There may also be significant associated infrastructure costs in the transition to an electric fleet, including charging infrastructure.</p> <p>An important element in the maintenance and associated life cycle cost of the fleet is the replacement of the batteries, the implications of which need to be considered when assessing this technology. Given the limited ranges currently offered by electric buses, the operational impact from the required battery charging procedure (charging requires several hours per unit) and implications on charging infrastructure and required fleet size should also be attentively considered.</p>



# Hydrogen

Parameter	Description
Technical description	Hydrogen is a highly flammable gas that can be produced from natural gas and other hydrocarbon sources or by the electrolysis of water.
Charging	
Autonomy	250 – 300km
Pros	In the mid to long term, major hydrogen production through water electrolysis powered by renewable energies or other low carbon sources could result in large GHG emission savings.
Cons	<p>Hydrogen fuel cell buses wider commercial implementation in the urban transport sector will greatly depend on further development of large-scale, low-carbon hydrogen production. At present, only hydrogen produced from natural gas through methane steam reforming appears to be commercially viable.</p> <p>Hydrogen buses currently have significant associated infrastructure and maintenance costs and also face significant restrictions due to safety risks.</p> <p>Hydrogen powered vehicles are at a relatively early stage of market development and their availability is likely to be limited in the short term, which should be considered when undertaking substantial fleet replacements.</p> <p>Given the limited ranges currently offered by hydrogen buses, the operational impact from the required refuelling procedure and implications on infrastructure and fleet should also be considered.</p>



# Hybrid (diesel – electric)

Parameter	Description
Technical description	The introduction of hybrid electric vehicles enables to combine the benefits of different energy sources and engine technologies to optimize and tailor operation to different local conditions or requirements. As an example, a diesel hybrid vehicle could be operated in electric mode in central or populated areas that are highly sensitive to noise or emissions. Diesel Hybrid electrical vehicles combine an internal combustion (ICE) and an electric engine. It is generally accepted that a series hybrid is more suitable for low-speed urban-type operation, where recuperating brake energy technology can also be used to additionally charge the generator.
Charging	
Autonomy	350 km
Pros	Hybrid vehicles may generate significant fuel savings that could justify the higher capital investment. An important benefit from diesel hybrid buses is the significant potential for reduction in overall emissions (between 10 and 30% has been reported), particularly when the energy source is a low-carbon one. The actual level of reduction in energy consumption highly depends on the actual cycle of usage. It also provides a lower-risk approach to implementing electric engine technology in the bus fleet, enabling a relatively seamless transition from diesel.
Cons	Hybrid vehicles are significantly more expensive to purchase than diesel or natural gas buses. Battery replacement costs. Until now no mass production/operation was put in place, so uncertainties in reliability and actual decrease in consumption remain.



# Hybrid (trolleybus – electric)

Parameter	Description
Technical description	The introduction of hybrid trolleybus - electric vehicles enables to combine the benefits of different energy sources and engine technologies to optimize and tailor operation to different local conditions or requirements. As an example, a trolleybus - electric hybrid vehicle could be operated in battery mode in central area that is highly sensitive to the overhead electric lines.
Charging	
Autonomy	350 km
Pros	<p>Longer life duration (15-20 years)</p> <p>Hybrid vehicles may generate significant fuel savings that could justify the higher capital investment.</p> <p>An important benefit from diesel hybrid buses is the significant potential for reduction in overall emissions (between 10 and 30% has been reported), particularly when the energy source is a low-carbon one. It also provides a lower-risk approach to implementing electric engine technology in the bus fleet, enabling a relatively seamless transition from diesel.</p>
Cons	<p>Hybrid vehicles are significantly more expensive to purchase than diesel or natural gas buses.</p> <p>Battery replacement costs.</p>





# Bus technologies: costs

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# Comparison of approximate costs (I)

## Indicative costs, standard bus (12-m)

Technology	CAPEX	APPROX OPEX (LIFE CYCLE O & M incl. Replacement)*
Diesel	Bus 0.30 M EUR	$(2.5 - 3) \times \text{CAPEX}^{**}$
Bio-diesel	Bus 0.30 M EUR	$(2.5 - 3) \times \text{CAPEX}^{**}$
CNG	Bus 0.35 M EUR CNG fuelling station (circa EUR 10k per bus)	Dependent on CNG cost, studies indicate approx. 0.05 M EUR saving per bus vs diesel: $(2.0 - 2.5) \times \text{CAPEX}^{**}$ Maintenance of CNG station
LNG	Bus 0.35 M EUR LNG station	Dependent on LNG cost OPEX LNG Station
Electric	Bus 0.30 M EUR Battery 2,000 EUR / kWh Bus (150kwh) 0.6 M EUR Charging station 0.3 M EUR (fast charging 300Kw) Power Transformer (0.04 M EUR)	$1 \times (\text{Bus} + \text{Battery CAPEX})^{**}$ Infrastructure OPEX

\* Operational costs vary significantly depending on different factors such as effective traffic, infrastructure or staff / rolling stock management. Technology will just be one factor of many.

\*\* Approximate life cycle , discounted operating costs



# Comparison of approximate costs (II)

Technology	CAPEX	APPROX OPEX (LIFE CYCLE O & M incl. Replacement)*
Hydrogen	Bus 0.40 – 0.70 M EUR Hydrogen Refuelling Station: Electrolyzer (0.5 – 1 M EUR) Compressors Gas storage (1,300 – 1,700 EUR /kg) Dispenser (0.12 – 0.22 M EUR) Project: 0.3 – 1 M EUR Civils: 0.15 – 5 M EUR	Estimated approx. 3 times bus CAPEX.** Heavily dependent on Hydrogen production method and transport (price).
Hybrid diesel – electric	Bus (incl. battery) 0.45 – 0.5 M EUR	2 x (Bus + Battery CAPEX)**
Hybrid trolleybus-electric	Infrastructure: 0.5 M EUR /km Bus 0.30 M EUR	OPEX Infrastructure

\* Operational costs vary significantly depending on different factors such as effective traffic, infrastructure or staff / rolling stock management. Technology will just be one factor of many.

\*\* Approximate life cycle , discounted operating costs



# OPEX and Operations

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The following aspects should be considered during the planning and assessment of the project:

- Detailed consideration of fleet fuel / energy requirements. Also fuel / energy price evolution and opportunities to guarantee its stability with providers;
- Opportunities for associated infrastructure (LNG / CNG, HRS, charging stations) to be partly or fully financed by energy providers. OPEX associated with new infrastructure (not only buses) needs to be attentively considered;
- Introduction of new technologies may initially lead to a significant increase in maintenance / maintenance staff costs. This can lead to operational risks that should be mitigated through adequate project planning and timely staff training;
- Incorporate major items such as likely replacement costs or capital repairs into the assessment, on the basis of reasonable and evidence-based lifespan estimates;
- Ensure timely, affordable and reliable provision of replacement parts throughout the lifespan of your fleet;
- Consider the benefits of preventive fleet maintenance;
- Consider additional operational costs associated with comfort / PRM / other fleet upgrades (low floor, air conditioned, electronics, AFC system);
- Use of pilot projects as a means to decrease risks related to less mature technologies; and
- Technology related security requirements and associated impact on life cycle costs.





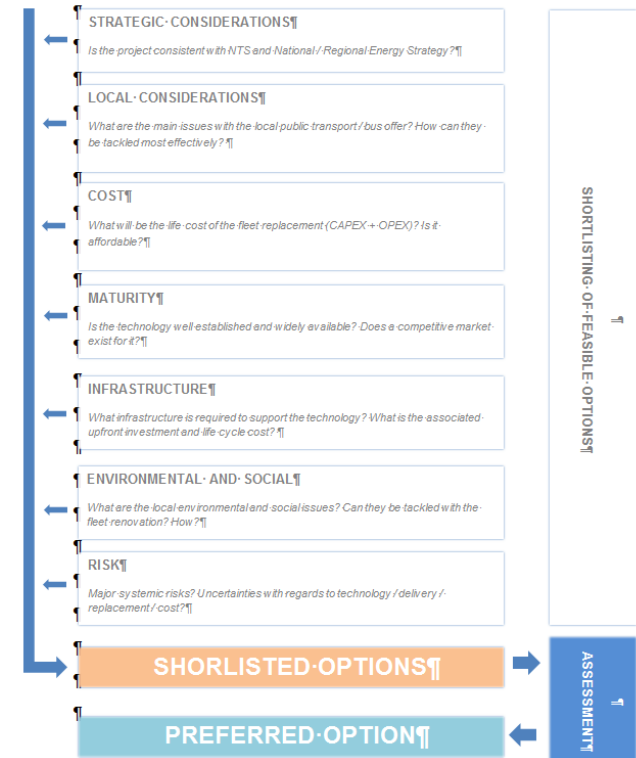
# Option appraisal



# Initial appraisal and shortlisting

The decision to replace the bus fleet and technology should always be supported by a feasibility study in accordance with European and national guidance. The process is illustrated below:

- Strategic considerations (EU, National, Regional, Industry);
- Local considerations: compatible with strategy, satisfy future demand, public opinion, market structure / segmentation;
- Life cycle costs: avoid financial sustainability risks;
- Technology development, maturity;
- Infrastructure requirements;
- Environmental / social issues: understanding outstanding local PT issues and tackling them;
- Risk (cost, financial, operational, maintenance / replacement, energy / environmental).



# Criteria for selection of the best option (1)

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## Strategic Considerations (EU, National, Regional)

- Have a wider plan considering infrastructure, traffic management, operations, regulatory measures in addition to technology. The largest benefit component will likely be related to mode shift by private car users;
- The European Union energy policy aims at diversifying energy sources while reducing CO<sub>2</sub> and other harmful emissions. The ability to mitigate the likely environmental impacts of urban transport by utilizing more effective or environmentally friendly technologies should be a primary consideration when selecting suitable technologies.
- The National Transport Strategy, associated objectives and measures and all of the regional and local strategies deriving from it may set clear recommendations in terms of the approach to adopt or the objectives to be attained with regards to the urban transport offer and the urban bus fleet in particular.
- The selection of bus technology is intimately linked to fuel / energy source and generally aimed at increasing effectiveness of the transport system. National or regional level considerations in terms of energy security or transition to more sustainable energy mix are likely to be of relevance.



# Criteria for selection of the best option (2)

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## Local Considerations

- The bus fleet needs to help accommodate and satisfy the local demand for transport => the bus offer needs to be attractive and of sufficient quality.
- Potential impacts on the current offer as a result of transition to a new technology (e.g. disruptions to the service, less capacity per unit or more expensive vehicles leading to fleet shortages) need to be considered.
- Decisions on bus fleet replacement should be compatible with the anticipated evolution of passenger demand and associated recommendations in the local transport strategy.
- Public consultation is strongly recommended, in order to gauge local perception with regards to the quality of the bus offer and related environmental issues (e.g. noise, air quality).





# Criteria for selection of the best option (3)

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## Life Cycle Costs and Financial Sustainability

- Bus CAPEX and OPEX can vary quite significantly as a result of the adoption of a different bus technology.
- In many cases, budget constraints and / or the need to tackle urgent issues (e.g. severe capacity constraint on a bus corridor) will also be a major factor in the decision making process.
- A comparison of life cycle expenditure of different alternatives under consideration will help identify risks to the financial sustainability of the project or the local transport sector as a whole and may, therefore, set a limit to the scale and / or available choices for the planned replacement.



# Criteria for selection of the best option (4)

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## Technology Development

- The degree of maturity of different technologies should have a significant weight in the decision making process. Implementation of innovative technologies with no successful tested precedents may have significant associated risks and is not recommended when major or urgent fleet renovation is required.
- Phased implementation, including initially limited-in-size pilot projects, may be in many cases a suitable approach to introduce new, innovative bus technologies.
- Small transport authorities with relatively modest institutional, financial and technical means and capabilities should as a rule favour well-tested and low-risk technologies for their fleet replacement.
- Situations where there is a severe limitation in the number of manufacturers for a given technology should be considered carefully in relation to potential risks to future operation or further fleet replacement.



# Criteria for selection of the best option (5)

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## Infrastructure Requirements

- Upfront provision of infrastructure (e.g. service stations, utility networks, depot and safety improvements) may be a prerequisite for the introduction of certain bus technologies.
- The associated capital and operational expenditure of each option will have to be estimated and incorporated into the economic assessment of the project.
- Likewise, specific skills may have to be acquired by local maintenance and operations staff, incl. provision of funding, support or training by the energy provider and the bus manufacturer, should be considered.
- The impact on project timescales from required major infrastructure upgrades associated with the introduction of the new technology must also be considered. The construction of a full new depot may be required in some cases where an extension or significant replacement of the fleet with a new bus technology takes place. Given the likely cost and time implications, the impact of transition to new bus technologies on bus depot infrastructure should be thoroughly investigated.



# Criteria for selection of the best option (6)

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## Environmental and Social Issues

- At the **strategic level**, it is essential to understand the potential for realization of certain objectives (e.g. reduction of GHG emissions) on the basis of a fleet replacement. In the event that most energy is or will be predominantly sourced from fossil fuels, this will negate some of the potential benefits from technologies that do not rely on internal combustion engines (ICE). A *Wells-to-Wheels* (WTW) analysis comparing the available options will be required to demonstrate the ultimate benefits of the proposed alternative vs. the status quo.
- At a **local level**, thorough understanding of social and environmental issues will enable identification of opportunities to tackle these most effectively through technology replacement, since some technologies will be better suited than others to address specific problems (e.g. noise, harmful emissions). As an example, low-noise and zero-emission electric vehicles that may be often outperformed by more standard alternatives could turn out to be suitable for town centre areas that are highly sensitive to vehicular noise and emissions.



# Criteria for selection of the best option (7)

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## Risks

- The previous analysis of strategic, local, operational, technical and environmental factors will enable identifying possible risks to the successful delivery and operation of the alternatives under consideration. The likely severity of the potential risks should also be established:
  - ✓ Cost: uncertain or excessive capital, operational, maintenance or replacement expenditure for both rolling stock and other associated infrastructure, affecting the financial sustainability or the scale of the project;
  - ✓ Financial: risks of decreased revenue, currency risks;
  - ✓ System and operational risks: decreased resilience of the system as a result of different technologies being in place, disruption to operations, decreased capacity or level of service, safety risks;
  - ✓ Maintenance / replacement risks: for both rolling stock and infrastructure; and
  - ✓ Energy and environmental risks: worsened energy security, increased GHG emissions (WTW).





# Detailed assessment

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- Below are some outline considerations on standard detailed project appraisal tools:
  - ✓ Engineering and operational assessment and considerations;
  - ✓ Multi-criteria analysis (MCA) could be undertaken in accordance with the above or other suitable criteria, with the main purpose of determining a preferred option from a shortlist of feasible options;
  - ✓ Cost effectiveness analysis may be useful to compare – for example – the cost per emission reduction unit for the shortlisted options;
  - ✓ Cost Benefit Analysis (CBA): while these projects are often considered to be mere rolling stock replacement with no significant journey time or safety benefits, there can be significant economic and financial implications from decisions to adopt a new technology. For projects where there may be significant rolling stock or infrastructure CAPEX / OPEX implications and / or quite different energy and emissions performance, a CBA of shortlisted or preferred options may be desirable.



# Case studies

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# Case study (1) – Technology risks

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## Douai (France)

- Hybrid buses (LPG – electric)
- Planned 2008, implemented 2010
- 12 buses hybrid buses (producer VDL /APTS)
- The LPG-electric motorisation never worked: had to be replaced by a classical diesel motorisation.
- The diesel motorisation was planned to be replaced by hydrogen motors, never implemented.
- 12 km guided bus infrastructure never worked
- Initial CAPEX : 134 M EUR



2014, cancelled and replaced by 16 classical CITARO GC2 buses (Euro 6) without guided bus infrastructure. CAPEX: 8 M EUR.





# Case study (2) – Comprehensive efficiency improvements

## Donostia – St Sebastian (Spain);

- Bus fleet replacement (efficiency and reduced emissions);
- Implementation of BRT lines (faster, higher capacity);
- Dedicated bus lanes and junction priority;
- EKO system (more efficient driving);
- Anti bunching system;
- MIP friendly fleet;
- Province-wide fare integration;
- Estimated 10.5 M EUR benefits annually.



Source: Donostia Bus ([www.dbus.es](http://www.dbus.es))

The highway network should be considered as a significant urban asset for the development and improvement of the public transport and active mode offer. Urban highways should not be planned to maximize private car flow.

# Case study (3) – Phased implementation

## Utrecht (Netherlands)

- Concession awarded to sustainability oriented transport provider;
- Ultimate objective: zero emissions. Low-risk, sequential implementation;
- Initial introduction of 3 electric buses, including a trial on induction charging;
- Initial charging and technical issues led to low initial reliability (10%). This was dealt with and a reliability of 90% achieved;
- Project to be scaled up from 3 to 11 or more buses within the city and Province.



[Source: Gemeente Utrecht \(Lot van Hooijdonk\)](#)



# Case study (4) – Political and infrastructure risks

## Vancouver (Canada)

- 20 Fuel Cell Units at \$90m purchased prior to the 2010 Olympics;
- No local hydrogen production and transport issues. Hydrogen to be transported from Quebec by diesel powered trucks (2350 miles);
- OPEX per km twice as much as for conventional diesel buses;
- Olympics associated, original H2 infrastructure plan (hydrogen highway) dropped after OG;
- Diesel buses to replace the 20 units.

## Vancouver Ends Hydrogen Bus Program Amid High Costs

March 10th, 2015 by Steve Hanley



Source: <http://gas2.org>

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# Case study (5) – Seeking Synergies

## Cologne (Germany)

- Co-financed by the programme “NRW Hydrogen HyWay” and the European Regional Development Fund (ERDF);
- Use of local Hydrogen by-product (chemical plant);
- Initial small pilot deployment: 8 units;
- An existing paint shop was adapted to be able to host fuel cell buses. This allowed to lower the costs of the workshop;
- Refueling station has no building (only a protective wall and a fence surrounding it), sufficient production capability, availability (95%) and refueling time (10mins per bus).



Source: <http://www.rvk.de>



# Germany: Main messages

- **Very high interest** of municipalities/operators for alternative and in particular electric bus technologies
- **Very cautious and progressive approach**, long-term reliability and overall cost-efficiency have highest priority
- E-buses fundamentally still considered as **too expensive** (life-cycle)
- **Small pilot projects** running, mainly in large cities with well functioning bus systems (**no full “real-life” project** yet, as evidence of feasibility still lacking)
- **Technical heterogeneity**, no dominant established technology exists (energy storage/conversion, charging, powertrain, etc.), strive for standardization (uncertain outcome)
- **Ambiguous political environment:**
  - Strong **commitment and financial support** to e-mobility but focused on e-cars
  - Significant **research funding** (DE+EU) is available - also for e-bus projects
  - Ongoing discussion on **taxation schemes** of electricity for PT purposes
  - E-bus debate to be seen within the general intense **debate on long-term funding** of Public Transport (central government vs. local authorities)

## Germany: Main messages – Hard facts

- **21 cities** testing E-buses (largest project: 10 E-buses in Cologne)
- **Price** of 18m E-bus currently (2016) approx. **twice** the price of a diesel one (700T EUR vs 350T EUR)
- Estimated **emission benefits** of **1** E-bus = estimated emission benefits of **100** E-cars
- E-bus systems considered to be up to 40-60 EUR/100vehicle-km **more expensive** than diesel (over life-cycle)
- Main **cost drivers**: vehicle, infrastructure, replacement batteries, modification of depots, specialized personnel (commercial data from testing cities not publicly available)
- **Diesel** buses considered to be at the moment (2016) still “significantly” more **reliable** than e-buses (operational data from testing cities not publicly available)

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# Thank you!

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