



**Innovative Technologies for Light Rail
and Tram:
A European reference resource**

**Briefing Paper 6
Hydrail -
Hydrogen Hybrid and
Hydrogen Fuel Cell Systems
September 2015**



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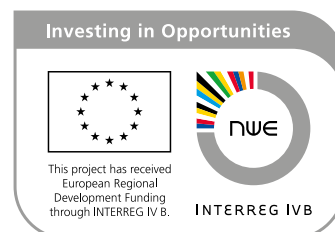
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Sustainable transport for North-West Europe's periphery

Sintropher is a five-year €23m transnational cooperation project with the aim of enhancing local and regional transport provision to, from and within five peripheral regions in North-West Europe.

INTERREG IVB



INTERREG IVB North-West Europe is a financial instrument of the European Union's Cohesion Policy. It funds projects which support transnational cooperation.



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Report produced by University College London

Lead Partner of Sintropher project



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Background

This briefing paper is one of a series that together comprise a European reference resource for innovative technologies rail-based systems, with particular reference to light rail and tram-based schemes in cities and regions. The approaches are also relevant, in many cases, to heavy rail and even other forms of public transport for example bus.

The resource is one of the Investments undertaken for the Sintropher project funded under the INTERREG IVB North West Europe Programme for transnational co-operation. The overall aim of Sintropher project is to develop sustainable, cost-effective solutions to improve connectivity to, from and within poorly connected regions in North-West Europe - to use innovative transport links to connect peripheral regions of NWE with the core European transport network of high-speed trains, via effective interchange hubs.

There has been a particular focus on tram-train systems which allow local trams to run on to national rail networks, pioneered in Germany, firstly in Karlsruhe and developed in Kassel, which allow urban tram systems to extend over national rail tracks to serve extensive city regions. The project has also looked at other innovative forms of tram systems such as single-track tramways, as well as high-quality transport interchanges that link such systems to major national or transnational rail or air hubs.

The project began in late 2009, with fourteen partner agencies in five EU Member States, and lead partner University College London (UCL): Valenciennes (France); the Fylde Coast (UK); West Flanders (Belgium); North Hesse (Germany); and Arnhem-Nijmegen (Netherlands). Participants included public transport operators, local authorities, regional transport agencies, and universities.

They have worked together on a series of feasibility evaluations, pilot investments and demonstration projects, as well as comparative analyses of EU best practice. The total budget is more than €23m, with funding part-financed by the EU's INTERREG IVB Programme.

A €1.5m project extension in 2014, covers follow-on work to capitalise on results from the initial project, and added a fifth objective: to test technologies for low cost transport links in different territorial contexts, plus integrated territorial corridor plans that help these links unlock wider economic and regeneration benefits; and better recognise these in business cases. This included two new partners (total now 16) and two extra demonstration regions (total now 7) in West Flanders Brugge-Zeebrugge (Belgium) and Saar-Moselle (a cross-border region France-Germany).

Innovative technologies for light rail and tram – developing opportunities

Previous results from Sintropher show that low-cost systems, such as tram-train, tram-rail, and single-track tram systems, have clear potential but there is no single “best” solution and these opportunities must be assessed and adapted to city/regional circumstances. (Sintropher Report *Connecting European regions using Innovative Transport. Investing in light rail and tram systems: technological and organisational dimensions*. See references at end.)

Additionally over the 5 years of Sintropher, there have been dramatic developments in relevant transport technologies. The most important are (a) very long-life batteries that allow electric trams and trains to operate over substantial distances “off the wire”; (b) charging devices that boost battery life by recharging at stops en route – e.g. the supercapacitor technology demonstrated at the 2010 Shanghai Expo, or the induction system employed by Bombardier in their Remove trams and buses; (c) discontinuous

electrification that allows electric trains and trams to “coast” under bridges and through short tunnels where it would be impossible or prohibitively expensive to install overhead catenary.

Also, a recent Report by UK Network Rail “*Network RUS: Alternative Solutions*” (July 2013) - an input to its Route Utilisation Strategy for long-term planning of the national rail network - has reviewed these developments. This work followed a remit to think imaginatively about cost effective solutions for accommodating growth in UK passenger demand, and operating services more efficiently. The solutions which are considered in the UK context are generally over and above the conventional solutions such as types of rolling stock and 25kV AC overhead line electrification. It looked at tram-train, tram systems, battery-powered vehicles, hybrid light rail, personal rapid transit, bus rapid transit and guided bus, and electrification solutions for lightly-used routes. Its main focus is existing rail lines in the UK network, but it can also be used to consider options for new transport corridors in urban areas.

The Report’s overall comment is “Whilst some of the solutions are close to an appropriate stage of development (or adaption) for introduction onto the UK rail network, others will require more attention, for example on battery technology. It is important to be aware that, by definition, a process of innovation is a process of change and that some technologies that are not listed as appropriate at present may become appropriate after further development work. It is possible that over the next 30 years there may be some significant technological developments that could reshape the market for public transport and how it is powered.”

So within the project’s partner regions, there has been further feasibility work to test these kinds of innovative low-cost solutions in different city/regional contexts, including new developments in technical solutions.

The European reference resource informs project partners’ work, and is also intended to be of relevance to much wider audiences especially. Particular target audiences are governmental authorities and transport agencies at city, regional, national and EU levels; and transport professionals and practitioners who may be involved in the initiation and implementation of new transport links

The reference resource is a snapshot in time (September 2015) and obviously the field of technologies is developing on an ongoing basis - it is hoped to update the briefing papers periodically as necessary.

Hydrail Trams

Hydrail is a newly coined term referring to the use of on-board hydrogen as a fuel source for generating power on all forms of rail vehicles. As with traction batteries hydrogen has become popularised through its use in cars and buses. Recent developments in safe storage techniques, the pairing of fuel cells to traction batteries in ‘hybridisation’, and a significant amount of government investment into hydrogen technologies – particularly in the United States and the United Kingdom – have led to many large rail and light rail engineering firms to develop and test hydrail rolling stock. Seen as the “greenest” fuel, hydrogen vehicles have been mired in controversy but promise to help reduce the transportation industry’s reliance on fossil fuels.



Above: Hydrail hydrogen fuel cell tram unveiled by CSR in China.

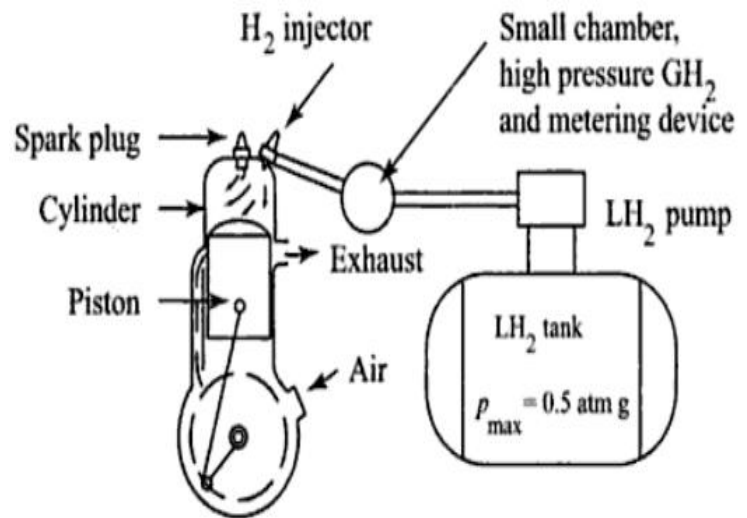
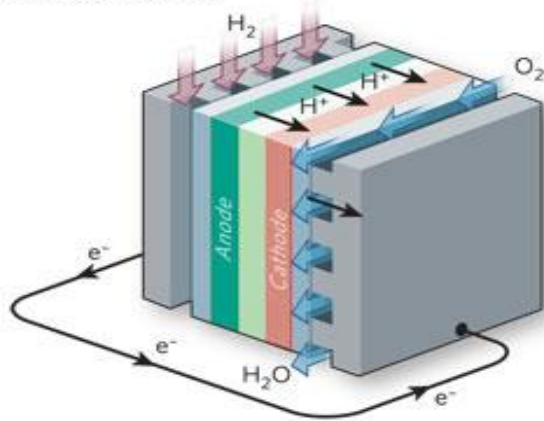
Technology

Hydrogen can be used to fuel either a hydrogen combustion engine or a hydrogen fuel cell. The hydrogen combustion engine works similarly to a fossil fuel combustion engine where liquid hydrogen is fed into a combustion chamber and ignited, driving a piston. This method of hydrogen combustion is seen as an inferior way to generate energy relative to fuel cells, which use hydrogen ions to form an electrochemical gradient that generates power through bonding to oxygen.

In hydrail both types of engines have been developed in test models. Hydrogen combustion engines are touted as a low-cost upgrade to conventional engines, and in some cases conventional engines can be retrofitted to use hydrogen as a fuel source. Hydrogen fuel cells are generally implemented alongside traction battery systems to help improve energy capture, efficiency, and for helping augment the energy output of fuel cells, which tends to be lower than that of combustion engines.

HOW THE FUEL CELL WORKS

The fuel cell combines hydrogen from the tank and oxygen from the air to form water vapour and electric power.



Above: APS track/tram interaction and visualisation of the moving electrified rail.

Attractiveness

- Only point-emissions produced from operation are water and oxygen gas.
- Self-electrified units can operate for long distances without refuelling or catenary support.
- Older rolling stock can be modified or retrofitted with fuel cells or to use hydrogen gas for combustion, helping augment and reduce consumption of traditional fuels.
- Can reduce operator reliance on fossil fuels.

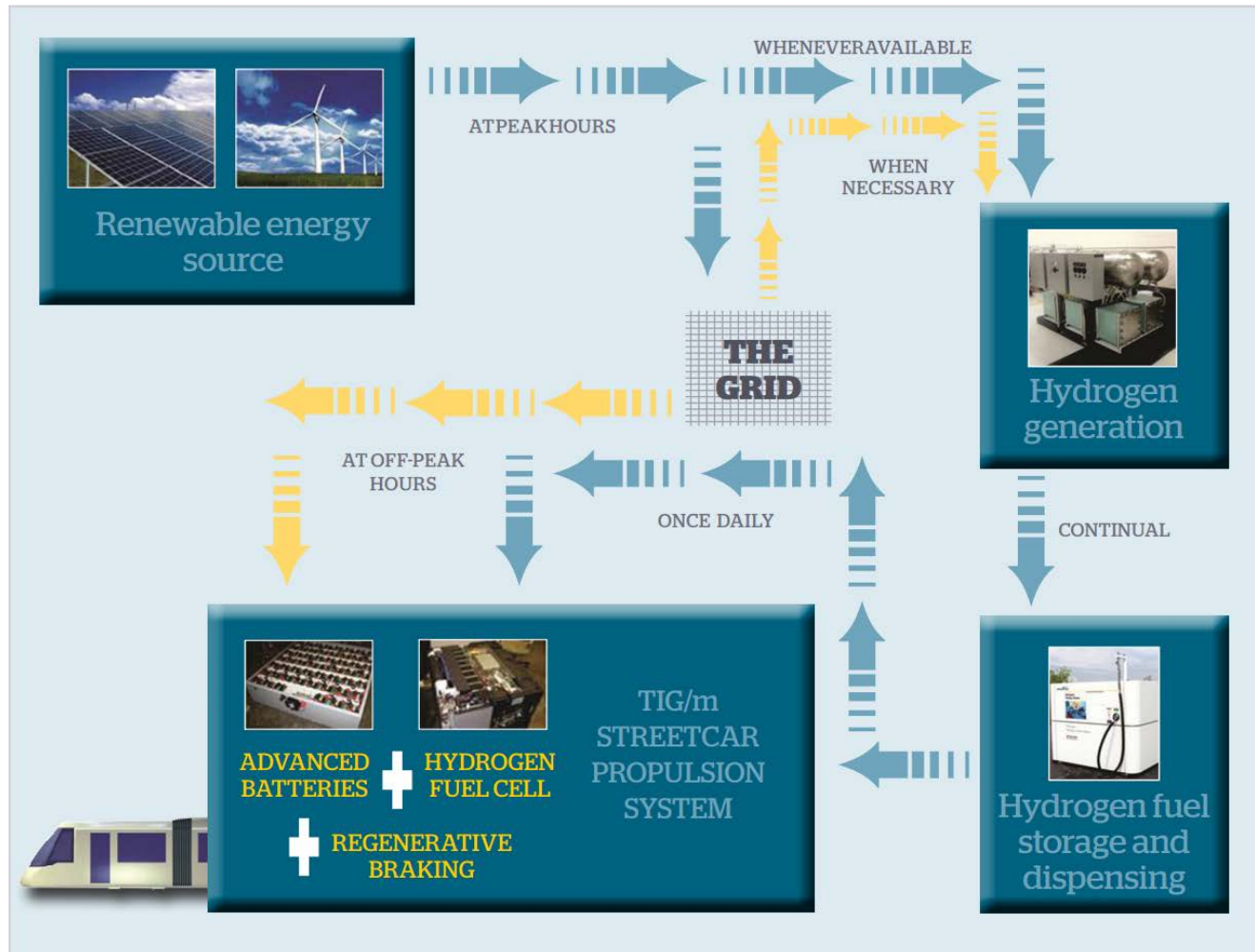
Risks

- Can emit more carbon than traditional fossil fuels when hydrogen fuel is generated from non-renewable energy sources.
- Fuels cells have relatively low energy outputs, require the combination of many units increasing weight significantly.
- Storage and transfer of compressed hydrogen fuel often difficult and requires additional engineering.
- Cost of technologies significantly higher than other catenary-free alternatives.

Track Record

There have been a number of tests and trials of hydrogen-propulsion rail and light rail systems internationally. Hydrail vehicles have operated briefly in Japan, the United States, Canada, the United Kingdom, and China. Presently there is only one hydrogen-propulsion light-rail system in operation globally on the island nation of Aruba, however, networks in Dubai and China are set to commence operation in 2015 or 2016.

Hydrail-Hydrogen Hybrid Case Study: Oranjestad Tram



System Specifications:

Line: Single rail 2.7km line connecting Welcome Plaza with Plaza Comercio, standard gauge.

Rolling Stock: TIG/m (1) Single-Deck Heritage-style Streetcar, (2) Double-Deck Heritage-style Streetcar
Cap. 45, 75

Hydrogen-hybrid streetcars use high-capacity lithium-iron phosphate battery system. The batteries are charged overnight by an onboard system. During daily operation, battery power is augmented by regenerative braking and a hydrogen fuel cell that produces 11kW of power for 8 hours.

Status: Operational since 2012

Cost: USD\$3M

Ridership: Unknown, primarily tourist.



Why was the technology chosen in Oranjestad?

Proof of concept test agreement: Oranjestad coordinated with TIG/m Modern Street Railways to design and engineer the world's "first inner-city streetcar system operated by using green technology". Their

inspiration for the system came from Los Angeles' battery-powered streetcar operation at The Grove.

Commitment to become “100% green economy by 2020”: The island nation of Aruba's partnership with the Carbon War Room (CWR) initiative pioneered by Sir Richard Branson committed the country to introduce “green technology” in all sectors.

Urban Aesthetics: The mayor of Oranjestad along with residents found that catenary-based systems were “ugly” and disagreed with the architectural form of the island. Additionally, traditional trams were deemed too “urban” which partially inspired the use of the open-air heritage trams.

Benefits

- Hydrogen fuel mix will be generated using 100% “green” renewable energy by 2020 and generated on-site (via electrolysis).
- Fuel generation system procured and built for less than cost of 1km of overhead line.
- Hybrid trams significantly more energy efficient than traditional diesel trams.
- Catenary-free system preserves heritage of city.

Drawbacks

- Relatively low ridership among locals due to tourist-centric route.
- Trams operations depends on reliability of fuel-generation system which has been shown to be susceptible to breakdowns.

Assessment

While the Hydrogen Hybrid technology has been heralded as a positive step forward for self-powered trams the implementation of the system was criticised for not informing tourists of operation schedules leading to delays from cars parked along tracks. Overall the reception from the public post-inauguration has been positive. Operation and maintenance costs have remained low, and as the island moves to 100% renewable energy generation the hydrogen produced on-site will truly become “green energy”.

Future Prospects and Transnational Relevance

A major trade-off between on-board hydrogen fuel storage and passenger capacity will need to be managed for the technology to become viable on a larger scale. The Oranjestad streetcars seat relatively few passengers, and while TIG/m states they have another “modern supertram” hydrogen hybrid model under development, it has yet to prove itself in operation.

Additionally, in many jurisdictions the generation of hydrogen fuel is not a “green” process with significant electrical energy devoted to the hydrolysis process. For hydrogen to develop as a regular fuel greater efficiencies in production and economies of scale will need to be introduced to reduce negative environmental externalities.

TIG/m has been contracted to engineer another hydrogen hybrid tram line in downtown Dubai which will open early 2015. Other projects have been conceptualised and many publications are suggesting that hydrogen will continue to gain traction in the rail industry as a power generation source, replacing diesel as the dominant fuel once the CNG boom ends. Hydrogen cars are also under development in many countries, suggesting that a hydrogen-fuel network could eventually be established in many developed countries that could reduce implementation and fuel generation costs for hydrail technologies.

Transnational relevance

The technologies and approaches and city/region case examples on the reference resource are context-specific and reflect:

- the geographical context: for example the extent of the urban or regional rail (and/or tram) network and degree of electrification or non-electrification; density of traffic; extent of urban and rural areas; and physical urban conditions such as street width, environmental conditions, historic areas.
- the technical context: the national regime of technical standards for rail or tram infrastructure, rolling-stock vehicles, rail electrification power supply.
- the regulatory context: the national regime for matters especially safety standards, CO2 emissions, environmental impact.

Some of the technical and regulatory matters are EU-wide. A Sintropher Report on the technological and organisational aspects of innovative tram-based systems looks at the desirability of greater harmonisation across Member States where different standards exist (see references).

These potential low-cost solutions now need to be tested in different regional cases in EU Member States. There are some distinct physical differences:

- rail systems in most Member States were built at lower cost than in the UK, with fewer over-bridges and more at-grade road/rail crossings, which may reduce the benefits of some technological alternatives (e.g. discontinuous electrification).
- many areas have historic towns where conservation considerations make overhead catenary undesirable, increasing the advantage of battery-based solutions.
- in many European countries, in contrast to the UK, many urban tram systems have been maintained, or even constructed in the last 20 years, making tram-train solutions more relevant.

Even though the various approaches and case examples are context-specific, their transnational relevance is strong:

- the approaches offer a stimulus and possibilities for wider thinking by cities and regions in other European countries
- some or all of the various approaches might be potentially adaptable within the particular organisational and governance regime of another country, and technical and regulatory regime. For example the Governments' UK tram-train trial in Sheffield, Network Rail's UK trial with battery power for trains on a non-electrified heavy rail line in East Anglia, and (in Sintropher) Province Gelderland's feasibility studies for battery power to enable electric trains to operate on non-electrified routes in their regional network..

The reference resource should be seen from this perspective, as a means to promote knowledge transfer and learning across different NWE countries and regions.

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Further information

This paper was produced by UCL Bartlett School of Planning (Sintropher team members Charles King, Giacomo Vecia, Imogen Thompson) using desk research and expert comment. The paper reflects the views of the authors and should not be taken to be the formal view of UCL or Sintropher project

The European reference resource can be accessed on the following:

Sintropher project website

<http://www.sintropher.eu/publications>

POLIS website

<http://www.polisnetwork.eu/sintropher> or <http://www.polisnetwork.eu/res/resources>

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Co-funded by the INTERREG IVB programme for North-West Europe



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