

## Fraunhofer Institute for Transportation and Infrastructure Systems IVI

The Fraunhofer IVI has many years of work experience in the field of innovative propulsion systems for public transport. The focus of these projects is on fully electric, fuel cell and hybrid propulsion systems. The Fraunhofer IVI's expertise is based on numerous measuring campaigns in public transport vehicles and a detailed knowledge of vehicle technology – especially regarding innovative propulsion systems and their implementation in test vehicles (AutoTram<sup>®</sup>, EDDA-Bus as a battery bus with fast-charging capacity, plug-in-hybrid bus SaxHybrid<sup>PLUS</sup>).

The experience gained in the field of public transport vehicle technologies was incorporated into the vehicle simulation model *IVision*, a development of the Fraunhofer IVI. The product, which has been successfully employed in a large number of projects, describes entire vehicles with great precision, combining detailed component models for powertrain, energy storage systems, auxiliaries, cooling and heating, driver and passengers, as well as interaction vehicle – environment – road into one highly complex simulation model. With the help of this model, it is possible to make a range of precise prognoses such as for the energy consumption of specific vehicle and propulsion configurations under given operational conditions.

Network wide analyses are carried out using the in-house tool *IVInet* which determines suitable charging strategies, bus specifications and which optimizes the charging infrastructure.

Fraunhofer IVI's services comprise:

- technical feasibility studies on the introduction of electric or fuel cell buses
- determination of the charging infrastructure both inside and outside of bus depots
- garage equipment and necessary modifications of the bus depots
- training of management personnel
- training of drivers and bus depot staff
- financial evaluation
- calculation of the environmental impact
- support during the tender process (potential suppliers, technical part of tender documents, assistance during the negotiations).

## References – Electric buses

### Battery buses

- Concept for the introduction of electric buses in Batam and Makassar, Indonesia; 2021; commissioned by: GOPA Infra on behalf of GIZ; contact: Nicholas Kasang (Tel.: 6172/681756); recommendations for the regular operation of electric buses with the help of schedule-based energy balances; charging infrastructure, TCO calculations
- Concept for the introduction of electric buses in the bus network of Gera; 2020 – 2021; commissioned by: GVB Verkehrs- und Betriebsgesellschaft Gera mbH; contact: Sebastian Krapp (Tel.: +49/0365/7390300); recommendations for the regular operation of electric buses with the help of schedule-based energy balances; charging infrastructure, training, workshop equipment
- Support with the introduction of battery buses in Flanders (Belgium); 2020 – ongoing; commissioned by: De Lijn; contact: Mr. Dirk Lepoudre (dirk.lepoudre.ext@delijn.be); technical analyses, recommendations for bus and infrastructure procurement
- Concept for the introduction of electric buses in the bus network of JES Verkehrsgesellschaft mbH; 2020; commissioned by: JES Verkehrsgesellschaft mbH; contact: Mr. Christian Steudel (Tel.: +49/176/14994425); recommendations for the regular operation of electric buses with the help of schedule-based energy balances; charging infrastructure, training, workshop equipment

- Concept for the introduction of electric buses on selected bus lines on Lower Austria; 2019 – 2020; commissioned by: Verkehrsverbund Ost-Region (VOR) GmbH; contact: Ms. Kuehne (Tel.: +43/1/955553215); recommendations for the regular operation of electric buses with the help of schedule-based energy balances; charging infrastructure; training
- Concept for the introduction of electric buses in the entire bus network of Saarbahn GmbH (Saarbrücken, Germany); 2019 – 2020; commissioned by: Saarbahn Netz GmbH; contact: Mr. Torsten Burgardt (Tel.: +49/681/5003604; recommendations for the regular operation of electric buses with the help of schedule-based energy balances; charging infrastructure
- Concept for the introduction of approx. 1,000 electric buses in the bus network of Delhi, India; 2018 – 2019; commissioned by: DIMTS Ltd.; contact: Mr. Nishikant Gupta (Tel.: +91/11/43090134); recommendations for the regular operation of electric buses with the help of schedule-based energy balances, charging infrastructure, commercial aspects
- Concept for the introduction of electric buses in the entire bus network of OVG Sonneberg; 2018; commissioned by: OVG Sonneberg; contact: Mr. Schneider (Tel.: +49/3675/75290; recommendations for the regular operation of electric buses with the help of schedule-based energy balances; charging infrastructure, training
- Concept for the introduction of electric buses for the standard and articulated bus network of the city of Berlin; 2017 – 2020; commissioned by: BVG; contact: Dr. Daniel Hesse (Tel.: +49/030/25629500); recommendations for the regular operation of electric buses with the help of schedule-based energy balances
- Concept for the introduction of electric buses in the entire bus network of the city of Düsseldorf; 2017 – 2018; commissioned by: Rheinbahn AG; contact: Mr. Jörg Klaeden (Tel.: +49/211/5821155); recommendations for the regular operation of electric buses with the help of schedule-based energy balances
- Concept for the introduction of electric buses in the entire bus network of the city of Leipzig; 2017 – 2018; commissioned by: Leipziger Verkehrsbetriebe GmbH (LVB); contact: Mr. Andreas Böttcher (Tel.: +49/341/4922307); recommendations for the regular operation of electric buses with the help of schedule-based energy balances; charging infrastructure, training
- Concept for the introduction of electric buses in parts of the bus network of the city of Cologne; 2017; commissioned by: Kölner Verkehrs-Betriebe AG; contact: Mr. Peter Hasler (Tel.: +49/221/5474230); recommendations for the regular operation of electric buses with the help of schedule-based energy balances
- Concept for the introduction of electric buses in the entire bus network of the city of Göttingen; 2016 – 2017; commissioned by: Göttinger Verkehrsbetriebe GmbH; contact: Mr. Thomas Zimmermann (Tel.: +49/551/38444830); recommendations for the regular operation of electric buses with the help of schedule-based energy balances; charging infrastructure, training
- Support of the introduction of battery buses on five MetroBus lines in the city of Osnabrück; 2016 – 2017; commissioned by: Stadtwerke Osnabrück AG; contact: Mr. Christian Elixmann (Tel.: +49/541/20022360); schedule-based energy balances for the determination of parameters of battery buses and charging infrastructure; elaboration of the specification sheets (contract documents) for the battery buses and the charging infrastructure
- ELIPTIC – coordinated by Free Hanseatic City of Bremen; 2015 – 2017; commissioned by: European Commission; contact (Senate of the Free Hanseatic City of Bremen): Mr. Michael Glotz-Richter (Tel.: +49/421/3616703);  
Use case Leipzig: recommendations for the regular operation of electric 12 m buses with the help of schedule-based energy balances
- BEEDel – assessment of the operation of electric buses with decentralized charging infrastructure at the example of the Hamburger Hochbahn; 2015 – 2016; in cooperation with Hamburger Hochbahn AG; commissioned by: Federal Ministry of Transport and Digital Infrastructure (BMVI); contact: NOW GmbH (phone: +49 30/ 311611600); recommendations for the regular operation of electric buses with the help of schedule-based energy balances

- Concept for the introduction of electric buses on one bus line in the city of Jena; 2015 – 2016; commissioned by: Jenaer Nahverkehr GmbH; contact: Mr. Falk Hamann (phone: +49 3641/414127); recommendations for the regular operation of electric buses with the help of schedule-based energy balances, use of the electric supply infrastructure for trams
- Concept for the introduction of electric buses in the entire bus network of the city of Aachen; 2015; commissioned by: Aachen municipal administration; contact: Mr. Kai Mohnen (phone: +49 241/ 4326138); recommendations for the regular operation of electric buses with the help of schedule-based energy balances
- Assessment of the electrification of BRT route B1 in the city of Guangzhou; 2015; commissioned by: Baiyun Power Group; contact: Mr. Yi Wang (phone: +86 20/ 86608696); recommendations for the regular operation of electric buses with the help of route-based energy balances
- Concept for the introduction of electric buses in the entire bus network of the Munich district; 2014 – 2015; commissioned by: MVV GmbH; contact: Mr. Detlev Metzner (Tel.: +49 89/ 21033253); recommendations for the regular operation of electric buses with the help of route-based energy balances
- Concept for the introduction of electric buses in five medium-sized cities in Thuringia; 2014 – 2015; commissioned by: Thüringer Ministerium für Bau, Landesentwicklung und Verkehr (Thuringian Ministry of Construction, Regional Development and Traffic); contact: Mr. Jörg Kallenbach (phone: +49 361/ 3791510); recommendations for the regular operation of electric buses in the cities of Altenburg, Eisenach, Mühlhausen, Suhl and Weimar
- E-MoBus – preliminary study – assessment of the operation of electric buses in the Bavarian Forest; 2014 - 2015; in cooperation with VCDB GmbH; commissioned by: Federal Ministry of Transport and Digital Infrastructure (BMVI); contact: NOW GmbH (phone: +49 30/311611600); recommendations for the regular operation of electric buses with the help of schedule-based energy balances
- ZeEUS – coordinated by UITP; 2013 – 2017; commissioned by: European Commission; contact (UITP): Mr. Umberto Guida (phone: +32 2/ 7880124); professional accompaniment of the introduction of electric buses in the city of Bonn in collaboration with SWB-Verkehr GmbH
- Concept for the introduction of electric buses in the entire bus network of the city of Bonn; 2013 – 2014; commissioned by: SWB-Verkehr GmbH; contact: Mrs. Barbara Nick (phone: +49 228/ 7112292); recommendations for the regular operation of electric buses with the help of route-based energy balances
- Concept for the introduction of electric buses in five larger cities in Thuringia; 2013 – 2014; commissioned by: Thüringer Ministerium für Bau, Landesentwicklung und Verkehr (Thuringian Ministry of Construction, Regional Development and Traffic); contact: Mr. Jörg Kallenbach (phone: +49 361/ 3791510); recommendations for the regular operation of electric buses in the cities of Erfurt, Gera, Gotha, Jena, Nordhausen
- SEB – EDDA-Bus; 2012 – 2015; commissioned by: Federal Ministry of Education and Research; contact: project management organization VDI/VDE; Mr. Simon Verleger (phone: +49 30/ 310078381); development of core technologies of fast-charging battery buses in collaboration with industry, conversion of a serial hybrid bus to a battery bus, testing of the battery bus in the bus network of the Dresdner Verkehrsbetriebe AG
- Concept for the introduction of electric buses in Niestetal; 2012; commissioned by: Verkehrsverbund Nordhessen; contact: Mr. Olaf Rohde (phone: +49 561/ 7094928); recommendations for the regular operation of electric buses with the help of a route-based energy balance
- Concept for the introduction of electric buses in the Main-Kinzig-Kreis (distric); 2012; commissioned by: KVG Main-Kinzig mbH; contact: Mr. Volker Rahm (phone.: +49 6181/ 9192120); recommendations for the regular operation of electric buses with the help of a route-based energy balance
- Concept for the introduction of electric buses in Jena; 2012; commissioned by: Jenaer Nahverkehr GmbH; contact: Mr. Falk Hamann (phone: +49 3641/ 414127); recommendations for the regular operation of electric buses with the help of a route-based energy balance

### Hybrid Trolleybuses

- ELIPTIC – coordinated by Free Hanseatic City of Bremen; 2015 - 2017; commissioned by: European Commission; contact (Senate of the Free Hanseatic City of Bremen): Mr. Michael Glotz-Richter (Tel.: +49/421/3616703);  
Use case Eberswalde: simulation and assessment of three articulated bus routes in Eberswalde regarding hybrid trolley bus operation
- E-Bus Skorpion – hybrid trolley buses on articulated bus routes in Leipzig – projekt of the Schaufenster Elektromobilität Bayern – Sachsen (Showcase electromobility Bavaria – Saxony); 2013 – 2016; commissioned by: Federal Ministry of Transport and Digital Infrastructure (BMVI); contact: project management organization VDI/VDE (phone: +49 30/ 3100780); assessment of the articulated bus lines in the Leipzig urban area regarding their suitability for the operation of hybrid trolley buses on the basis of detailed energy balance calculations
- ElectroHybridBus Esslingen; 2013 – 2016; commissioned by: municipal transport service Esslingen am Neckar; contact: Mr. Harald Boog (phone: +49 711/ 35123223); simulation and assessment of articulated buses regarding hybrid trolley bus operation
- Vehicle simulation of an electric bus on LVB route 70; 2012; commissioned by: Verkehrs-Consult Leipzig (VCL) GmbH; contact: Mr. Wolfgang Schütze (phone: +49 341/ 9642429); simulation and assessment of articulated bus route 70 in Leipzig regarding hybrid trolley bus operation
- Use of storage systems in the trolley buses of the city of Eberswalde; 2011; commissioned by: Barnimer Busgesellschaft mbH; contact: Mr. Frank Wruck (phone: +49 3334/ 52250); Technical layout of storage units for a trolley bus with an energy storage system for improved energy recuperation and partially catenary-free operation; accompaniment of measuring campaigns

### References – Fuel Cell Buses

- Concept for the introduction of fuel cell buses for the whole bus network of Regionalbus-Gesellschaft Unstrut-Hainich- und Kyffhäuserkreis mbH; 2020 – 2021; commissioned by: Regionalbus-Gesellschaft Unstrut-Hainich- und Kyffhäuserkreis mbH; contact: Mr. Haßkerl (Tel.: +48/3601/40865201); technical feasibility of fuel cell buses, dimensioning of fueling infrastructure, training, workshop adaptation
- Concept for the introduction of fuel cell buses for the whole bus network of OVG Sonneberg; 2018; commissioned by: OVG Sonneberg; contact: Mr. Schneider (Tel.: +49/3675/75290); technical feasibility of fuel cell buses, dimensioning of fueling infrastructure, training, workshop adaptation
- Concept for the introduction of fuel cell buses for the whole bus network of Rheinbahn AG in Düsseldorf; 2017; commissioned by: Rheinbahn AG; contact: Mr. Jörg Klaeden (Tel.: +49/0211/ 5821155); technical feasibility of fuel cell buses
- Concept for the introduction of fuel cell buses for the whole bus network of LVB GmbH in Leipzig; 2017; commissioned by: LVB GmbH; contact: Mr. Andreas Böttcher (Tel.: +49/341/4922307); technical feasibility of fuel cell buses
- Concept for the introduction of fuel cell buses for the whole bus network of Göttingen; 2016 – 2017; commissioned by: Göttinger Verkehrsbetriebe GmbH; contact: Mr. Thomas Zimmermann (Tel.: +49/551/38444830); technical feasibility of fuel cell buses

## References – Hybrid Buses

- SaxHybrid<sup>PLUS</sup> – energy storage systems for hybrid buses with qualified energy management – projekt of the Schaufensters Elektromobilität Bayern – Sachsen (Showcase electromobility Bavaria – Saxony); 2013 – 2016; commissioned by: Federal Ministry of Transport and Digital Infrastructure (BMVI); contact: project management organization VDI/VDE (phone: +49 30/ 3100780); adaptive energy and performance management system for plug-in hybrid buses, test of a plug-in hybrid bus in Dresden and Leipzig
- Scientific and technological accompaniment of the long-term testing of a hybrid bus in comparison; 2014 – 2015; commissioned by: ViP Verkehrsbetrieb Potsdam GmbH; contact: Mr. Oliver Glaser (phone: +49 331/ 66141000); recording of the operating data of a hybrid bus in comparison; assessment in terms of energy efficiency; acceptance of hybrid bus technology with driving staff
- Testing program of the Federal Ministry for the Environment, Nature Conservation and Building (BMU) “Analysis of efficiency, costs and deployment for the regular operation of diesel hybrid buses”; 2014 – 2015; commissioned by: VCDB as contractor of the BMU; contact: Mr. Jürgen Lange (phone: +49 351/ 4823124); route analysis and recommendations for optimized regular operation of hybrid buses on the basis of different operating conditions; demands made of driving staff and analysis of driver influence on vehicle efficiency
- Accompanying research “Hybrid buses for more environmentally friendly public transport”; 2010 – 2012; commissioned by: VCDB GmbH as contractor of the Federal Ministry for the Environment, Nature Conservation and Building (BMU); contact: Mr. Jürgen Lange (phone: +49 351/ 4823124); assessment of hybrid technology regarding energy efficiency; recording of operating data in the transport association RegioHybrid; acceptance of hybrid bus technology; recommendations for operation in the transport association RegioHybrid
- Professional accompaniment of the introduction of different hybrid bus types in Munich; 2011; commissioned by: MVG; contact: Mr. Franz Fendt (phone: +49 89/ 21914210); assessment of hybrid technology regarding energy efficiency and costs; comparative recording of operating data of different hybrid and diesel bus types, survey on the acceptance of hybrid bus technology with drivers and passengers
- Professional accompaniment of the introduction of a Solaris articulated hybrid bus in Dresden; 2008 – 2009; commissioned by: üstra; contact: Mr. Jens Ernsting (phone: +49 511/ 16682685); assessment of hybrid technology regarding energy efficiency and costs; comparative recording of operating data of a hybrid bus and a diesel reference bus
- Professional accompaniment of the introduction of a Solaris articulated hybrid bus in Dresden; 2008 – 2009; commissioned by: DVB AG; contact: Mr. Mino Weber (phone: +49 351/ 8571454); assessment of hybrid technology regarding energy efficiency and costs; comparative recording of operating data of a hybrid bus and a diesel reference bus, optimization of the hybrid bus with regard to diesel consumption, recommendations for regular operation