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Electric vehicles in rural demand-responsive systems: requirements and challenges for an efficient service provision

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Executive Summary

This paper presents two electric-vehicle volunteer-based rural demand-responsive services; a Buerger(ruf)Auto ("Citizen-operated-car") and a Buergerbus ("Citizen-operated-bus"), outlining vehicle related aspects to be addressed in order to achieve a comparable operational efficiency as a service using internal combustion vehicles. Challenges are identified, namely technological limitations and the required physical characteristics of the vehicles. In addition, challenges include the need for vehicle components for gathering data directly from the car's electric motor to analyse the car's performance under different operational conditions. The paper mentions the issues explicitly and specifies what would be required from electrical vehicles to become an asset in the provision of rural demand-responsive systems.

Keywords: energy, BEV (battery electric vehicle), bus, public transport, case-study, mobility concepts

1 Introduction

By 2050, Germany anticipates strong demographic changes. Rural areas are expected to be particularly affected. The delivery of mobility services in these areas will represent a big challenge. The complexity will be increased by the unfeasibility of the provision of high-frequency public transport; mainly due to low population densities, dispersed urban structures and changes in age structure. Notwithstanding, to fill in mobility gaps, volunteer-based flexible transit solutions have been successfully implemented in Germany since early 1980s. These concepts have evolved to address a diverse array of needs and situations and to incorporate new solutions and technologies. Such is the case of electrical vehicles, which found an application in these systems through state-run initiatives seeking to promote sustainable mobility. However, up to now, electrical vehicles do not fully meet the specific needs of these systems, mainly due to technical limitations, which are enhanced by offensive driving styles, topography, and weather. Additionally, sizes for electrical vehicle for public transport are limited, especially in relation to comparatively heavy batteries, which for volunteer-based solutions poses a problem (i.e. vehicles need to weigh less than 3.5 tons for normal driving licenses which in Germany corresponds to a class B) and other technical components (e.g. interfaces to gather battery readings).

This paper presents the use of electric vehicles in volunteer based demand responsive transport (DRT) systems in rural areas. The paper concentrates on two case studies researched at the University of Stuttgart and the Institute of Transportation Research of Stuttgart (VWI), Germany [1, 2]. The document starts by describing DRT systems and identifies reasons for their implementation in Germany. In specific, the section describes the types of DRT systems used in the rural area context and delineates their governing aspects (i.e. the volunteer based operation). Subsequently, the reason behind the use of electric vehicles (EVs) in this context is briefly discussed.

In the second part, specific challenges and requirements regarding the use of EVs in this context are outlined. Lastly, a brief conclusion mentions aspects to be considered for a successful implementation of EVs in DRT systems, but above all, in a way that the public and the system's operators welcomes them as a viable form of sustainable transport.

1.1 Demand responsive systems in rural areas

In [3] several transportation options for rural areas are described. The options include traditional public transport services, taxis, car rentals, special need transport or even carsharing. However, most of the systems mentioned are unable to fulfil efficiently the mobility needs required in rural areas since they are either too expensive to maintain by local transport authorities, in terms of providing higher frequencies, or are unfit to provide mobility to a wide range of users and most reduced mobility groups such as seniors and children since they require either a driver's license or a higher frequency public transportation that allows them to move on demand. In Germany, temporal and spatial flexible forms of public transport or DRTs, which cater to fluctuating and low demands in small communities, have been already used for 40 years. Today, according to German journalist expert in DRTs there are 332 of these systems running mostly through volunteering work [4]. At some point in time, some of the services either disappeared or changed to for profit operations [5]. The volunteer based systems have been identified as community transport or DRTs and are described as a mixed of public, private and citizen resources to achieve an economically viable solution to social and environmental needs to maintain and promote mobility and quality of life in small communities. According to [5] other schemes of community services exist. Some experience with systems mixing paid staff and volunteers have existed in Germany, however, the experiences have not been positive. Other schemes seek to reimburse drivers for expenses they might incur. As some examples in Germany suggest, volunteering DRTs could represent the first step towards a normal bus service with paid staff if later it is determined that the demand for running it is available. According to [5] five services have been converted to a non-volunteer service. Nonetheless, most services remain successfully running under a volunteer scheme.

DRTs come in different forms and sizes, covering from traditional single occupancy vehicles to the most common fixed route bus system. The systems operate on demand, either fully flexibly or through demand oriented schedules and times [6]. Most DRTs are mainly used in areas where mobility demand is low, such as rural areas or for special needs (e.g. non-emergency medical transport). In a German context for rural areas, the system can be categorized depending on its flexibility in time and space (Fig. 1). The more flexible systems are ideal for small settlements while the least flexible options are better suited for larger communities [1, 2].

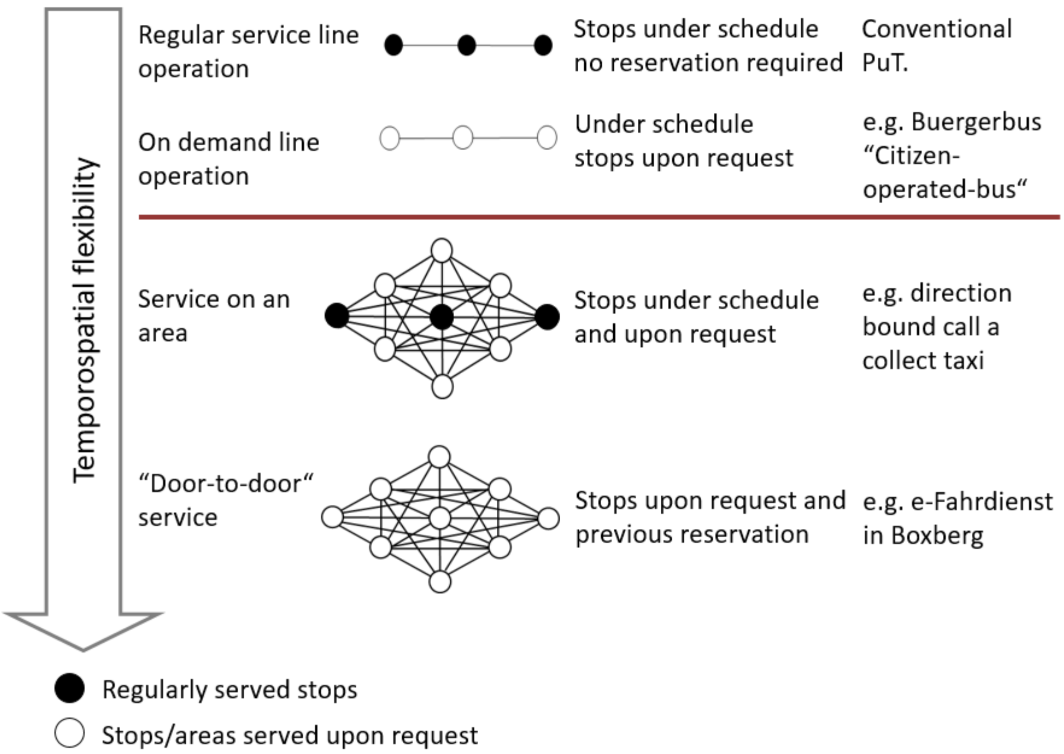

Figure 1: Demand responsive transit: temporospatial flexibility on a route or "door-to-door" service - own diagram adapted from [6]

DRTs are important in rural areas, namely due to the low densities observed caused by dispersed settlements and low population [1]. The importance of these systems increases due to the demographic structural changes experienced in Germany, namely, more elderly people. DRTs however, are not designed or intend to replace regular public transportation systems [7], they intend to offer an opportunity to close service gaps, which otherwise would be financially impossible to cover due to the limited governmental resources or lack of coordination between authorities and funding agencies. According to [8], three aspects are required for the implementation of a demand transport system and hence the type of vehicle to be chosen:

- The type of mobility required depending on the service area; varying from region to region
- The potential demand, which should be between 3.000 and 5.000 people [9]
- The specific group to be serviced, such as senior, youngsters, housewives and their kids, etc. and the type of trips such as shopping, doctor's appointments, extracurricular activities, etc.

1.2 Volunteer-based DRTs in Germany

Several types of services have been developed for rural areas in Germany as mentioned in section 1.1, most of the 332 services that exist in Germany are volunteer based associations, but according to an interview with a German DRT expert at least 90% of those are fixed route and scheduled services [4]. Most of the systems in Germany are the so called "Buergerbus" ("citizen operated bus"). However, other forms such as the "Buerger(ruf)Auto" (i.e. full temporospatial Dial-a-ride or "Citizen-operated-car") have been developed to fulfil more flexible and low demand services [1, 7].

However, there is a perception that the use of volunteers for the operation of the DRT systems in rural areas might represent a way for authorities to release their obligations regarding the provision of mobility services to the population. Nevertheless, this might be a simplistic conclusion since an association of people under volunteering basis requires close cooperation with local authorities for the system to operate successfully. In fact, the creation of an association makes use of local resources and knowledge, creating a great part of the basis of sustainable mobility since social, economic, and institutional aspects are closely considered and brought together.

Moreover, when a local association seeks to improve the mobility conditions of a low demand and dispersed area, it in many ways is more successful since according to [5] when authorities attempt to tackle the mobility issues in dispersed and low demand communities their approach leads to inefficiencies and high costs. One aspect in favour of volunteer associations is without a doubt the cost reduction. An association of volunteers complementing the regular public transport service lowers costs by 60-70% in comparison to the regular transportation system. The ,lower costs derive from savings in wages and social security fees [5]. However, not only monetary savings are important in rural areas, volunteering also generates social cohesion and sense of place, enhancing the image and name of the place. These two aspects are heightened by the fact that most volunteers are seniors in retirement that have their daily needs met and who care deeply about their place of residence. In terms of the service provided, local volunteer drivers have a more intimate relation to their customers and can respond to specific local needs [Schiefelbusch 2016]. This is extremely important since an important characteristic of these systems is the strong consideration of the perspective of passengers and not just those of administrations and companies as regular public transport systems do [10].

Volunteer based systems provide the social, economic and institutional aspects of sustainable mobility, however, most of the DRT systems in Germany make use of conventional internal combustion vehicles. However, a new approach with EV has been explored in the last five years through initiatives of the federal government, as well as several states who have started to promote sustainable mobility by the use of electric vehicles [11]. In specific, some projects have been conceived in conjunction with rural volunteer based services [2]. The University of Stuttgart through IEV/VWI and WIUS have taken part on two of those projects. The knowledge so far acquired is a valuable resource for the development of vehicles that fit the needs of rural DRT systems. The studies have also identified big opportunities for the use of EVs for these systems, but above all, have identified specific challenges to overcome if EVs are to be considered for their use in rural DRT services. The latter is certainly important if the use of EVs is to be encouraged and promoted; adding to the 20-25 EV systems that according to [4] exist in the country. Important is to recognize that these initiatives serve as the introduction of EVs to the DRT and public transport markets. Furthermore, they serve as a display of the technology to the public, which is reflected on the surveys performed in the studies mentioned in section 1.3. In many ways, these studies are the display window of EVs to a big market consisting of millions of people in rural areas who still do not believe the technology represents a solution to their mobility needs.

Although this paper focuses on Buergerbuses and Buerger(ruf)Autos, it is worth mentioning that there are other forms of DRT services operated by volunteers and none volunteer based organizations increasing the potential of EV market. For example, the "Sozialer Buergerfahrdienst" which is a full temporospatial "Citizen-operated-car" but with access to a limited group of people, e.g. members of a registered association and the "PKW-Buergerfahrdienst" which is like the previously mentioned system, but the volunteers make use of their own vehicles despite the existence of a coordinating organization e.g. a municipality owning the car [4]. NVBW in Baden-Württemberg identifies other examples such as the system in which several associations share vehicles.

According to experienced consultants, in Germany there are many more non-volunteer DRT services than volunteer ones. These exist especially as complement of fixed route public transportations systems in times and places where demand is very low. The share of passenger kilometres of these systems is also very low. The use of EVs would only be efficient if the technology is accessible in comparison to the internal combustion options available and the energy to run the system is also readily available and affordable.

1.3 DRTs studied

Despite the large palette of DRT options, this paper concentrates in two systems which are the result of studies carried out by IEV/VWI and WIUS at the University of Stuttgart. However, these two systems have been part of the efforts of the state to introduce EVs in the most characteristic DRTs in rural areas. The two systems under study and their characteristics are shown in Table 1. Their requirements in terms of the vehicles needed, as well as the challenges encountered in the use of EVs are detailed in the following sections.

Table 1: DRT systems under study – own table adapted from [10]

	Buergerbus	Buerger(ruf)Auto
Spatial flexibility	Bus lines with fixed stops	Fully flexible "door-to-door" service
Temporal flexibility	None (time table)	Fully flexible within service area
Type of vehicles	Minibuses with up to eight passengers	Automobiles with easy accessibility and large trunks

The data used for the development of the projects was gathered throughout the two projects described in chapters 1.3.1 and 1.3.2 and was obtained using a GPS (global positioning system) logger in combination with driving protocols filled out by the volunteer drivers. Driving distances and slopes were tracked automatically; driving speed was calculated whereas additional information such as outdoor temperature and battery capacity were documented manually. The obtained data allowed for the calculation of the driving range under different circumstances (e.g. for different temperature ranges and driving styles. In addition, questionnaires applied to drivers and passengers complemented the findings regarding the overall level of satisfaction with electric vehicles and identified aspects of the vehicles that need improvements.

1.3.1 Buergerbus

An electric Buergerbus has been evaluated in the municipality of Salach (830 ha) and the city of Ebersbach (2.630 ha), both located near Stuttgart [2]. Both areas vary in terms of population, service hours, and demand. The systems are operated on a fixed time table with fixed bus stops located close to each other to cover the area as thoroughly as possible. The population varies from ca. 8.000 (Salach) to ca. 15.000 (Ebersbach). The driving distance varies form 66 km (Salach) to 146 km (Ebersbach) per day. Hence, the requirements for an electric minibus vary. A converted diesel Mercedes-Benz Sprinter electrified by German E-Cars GmbH has been evaluated (Fig. 2). This bus has been produced in a small batch series. It has a 38.8 kWh battery, achieves a range of 120 km according to the New European Driving Cycle (NEDC) and can be charged with a loading station with a charging capacity of 11 kW/h maximum.

Figure 2: Scenery of the electric Buergerbus in Ebersbach (photo by Maerker)

1.3.2 Buerger(ruf)Auto

The electric Buerger(ruf)Auto in Boxberg, Germany (100 km north of Stuttgart) is a fully spatiotemporal service offering "door-to-door" trips in a town spreading over a large area (10.000 ha) with a population of 6.500 people [12]. The system is operated by volunteers daily during weekdays. The driving distance in average is about 72 km/day. The main users of the service are senior women. The trips are mainly grocery shopping and health related. Many of the users have walking assistance devices such as walkers; hence a large room in the car is needed [1]. The solution at the time was the 2013 Renault Kangoo ZE (Zero Emission) (Fig. 3). This car has a 22-kWh battery, achieves a range of 170 km according to the NEDC and can be charged with maximum 3.7 kW/h.

Figure 3: Fully temporospatial Buerger(ruf)Auto through a Renault Kangoo ZE (photo by Seufert

In Boxberg, during the course of the study, drivers and costumers were questioned about the EV service twice [1]. Regarding the customers the results were very positive. In each stage of the survey, 23 customers responded of whom at least 74% were at the age of 65 or older and a minimum of 78% of the responders were female. Regarding the first stage, short after the launch of the service in April 2014, 81% of the customers were satisfied or very satisfied whereas 100% of the costumers were satisfied or very satisfied with the service regarding the second stage of the survey (October 2015).

With respect to the drivers 15 had been asked within the first survey in January 2015, 20 drivers responded in the second survey in November 2015. At least 93% of the drivers were male and a minimum of 65% of the drivers were 65 years old or older. Drivers had the most problems with the EV, thinking the distance driven was not enough, but identified electromobility as a way to improve the environment and as a sensitive technology. However, they think the cost is still too high [1].

Within the second survey, drivers had for example been asked about the relevance and the importance of the climate control (heater and air conditioner as one item of the study) of the vehicle. Whereas 39% regarded the climate control as very important, 32% of the responders were unsatisfied or very unsatisfied with it; being by far the item of the study with most discontent in comparison to the acceleration, brakes, driving noise, and vibrations [13].

In general, the general perception of the technology still needs to be improved to be able to compete with internal combustion vehicles, for example people are used to internal combustion engines and expect the same performance for a reasonable price [13].

2 Electric vehicles in rural DRTs – requirements and challenges

The intention of this section is to explain the issues encountered in the vehicles used in the case studies to provide assistance to EV's manufacturers in determining the specific needs for the future development of vehicles used in DRTs, especially in rural areas.

2.1 Buergerbus – requirements

Electrical minibuses must comply with the transportation law in the country of implementation. In Germany, it is the "Personenbeförderungsgesetz "(Eng. Public Transport Act) which sets the regulations for the development of the system, e.g. maximum weight of the vehicle to be driven with a class B license and maximum number of passengers. Further requirements, based on best practices, include single seats for convenient entry and exit through an aisle in the middle, a high roof for upright standing, several support straps, etc. Additionally, to fulfil state-level funding requirements, criteria such as accessibility or barrier free access needs to be met in all vehicles. Therefore, crucial for a convenient transportation specifically for elderly people, is the availability of lower floors. In addition, the minibuses need to have sufficient electric power to serve the transportation service throughout the whole day. Notwithstanding, today, there is no existing vehicle that provides these requirements (at least not for volunteer based Buergerbus systems obliged to operate vehicles with a limited weight) [14]. To be able to implement an electrical Buergerbus system, the solution in this project was the conversion of an existing diesel vehicle. However, this solution is far from optimal since there are compromises to be made. For example, the total weight (due to the battery) allowed and the amount of people than can be transported (two seats were taken out in the conversion due to the weight restriction) or the accessibility aspect, which could not be met due to the high floors required for the placement of the battery. Specific challenges are mentioned in chapter 2.3.

2.2 Buerger(ruf)Auto - requirements

For a Buerger(ruf)Auto service a large enough vehicle is needed to carry shopping and walking assistant devices. However, the car needs to be low enough whereas the seats should be rather high for easy access since most users are older people. In addition, the weight should be low as well in order to avoid excessive use of the battery, especially if the service is provided around hilly areas [1]. In addition, to be able to evaluate the performance of the service, digital devices are needed, which tell the exact usage of energy in relation to other conditions, such as driving styles and climate conditions [1]. A demand responsive system requires as much availability as possible for the costumers, especially for the times where no public transport is available. For this, fast charging during occurring short breaks between operating times is essential. In addition, in dispersed areas, people travel long distances and roadworks on main roads within a community can cause huge detours. It is essential that the vehicle used is able to travel longer distances before needing to charge the battery [1].

2.3 Challenges and improvements needed for both systems in general

Although the vehicles used in the studies fulfil their task regarding the provision of a DRT service for a small town under a flexible system, they do display several aspects that require improvement if efficiency and public acceptance are to be sought.

1. Driving range:
   The driving range is low. The cars run out of battery relatively fast. Although DRT services allow predictable routes, especially for larger communities our findings showed that in one city the electric Buergerbus service could not be provided every day. As a fall back option, an internal combustion engine Buergerbus had to be used on days with high passenger demand. For the Buerger(ruf)Auto some service requests had to be refused. Additionally, the vehicle used requires a midday charging pause of two hours, taking important time away from the operation. It is evident that more powerful and efficient batteries are needed to increase the driving range, which seems to be already the case for the new Renault Kangoo according to the manufacturer's website [15]. Concerning the Buergerbus, appropriate minibuses are not yet available for mass production or small batches. So far, it seems that there are no further improvements or future developments of the technology currently in use in the project studied.

2. Charging capacity:
   The charging capacity is also important to put the vehicle back on the road as soon as possible. The versions bought could not be charged with high capacity charging stations. For example, the ability to use a more powerful charging facility for the Renault Kangoo ZE would be extremely helpful. Currently at midday pause for charging only about 50% of the capacity is charged. A more powerful charging capacity, which also does not damage the battery, could allow the car to be significantly recharged at the charging pause and in between trips or at idle times (e.g. when driver waits for a customer at a super market – 30 to 40 min wait). The Buergerbus can be charged with 11 kW/h, which leastwise allowed recharging the battery during a break at noon close to one third of its capacity, but the ability to go beyond a third of the capacity would certainly increase the easiness that the system operates (e.g. would allow the operators to provide the service accounting for eventualities and in a more relax manner).
3. Overall weight:
   The weight is important to negotiate all types of topography, especially in the winter, when the battery runs out faster e.g. due to the use of the heater. This is especially true for the Buergerbus system (minibuses) which besides the higher energy consumption of heavier vehicles, it needs to be maintained below 3.5 tons. A European act allowing to drive a minibus for cargo transportation with a maximum weight of 4.25 tons does not apply to the transportation of people [2].
4. Vehicle size:
   The size of the vehicle and choices of vehicles is important. The transportation of people with different requirements needs to be incorporated in the design of vehicles. Accessibility of seniors or little kids driven to their sport activities is essential. This is also especially so for the Buergerbus where accessibility needs to be insured to secure funding, but also to provide the quality of service people with mobility impairment require. Some reasons why low floors are not yet standard in this type of electric vehicles include
   a) OEMs (Original Equipment Manufacturers) and car manufacturers do not see a market for this kind of vehicles except for the transportation of goods,
   b) batteries are yet too big and too heavy and therefor placed in the floor area of those vehicles, making it difficult to implement a lower floor, and
   c) additional alternations raise the overall vehicle weight.
5. Energy consumption:
   There is no way to accurately determine the use of battery. For example, the dial in the Renault Kangoo ZE is analogue. An interface connected directly to the battery would help determine the battery use and to optimize the service, especially if there is a software that could do the optimization by using the data obtained. This is aggravated by the fact that DRT services have a driver pool with more than 20 drivers. This makes it difficult for any intelligence implemented to precisely determine the remaining battery energy.
6. Driving styles:
   First, due to the driver pool, driving styles vary very much depending on the behaviour of each driver regarding e.g. foresighted or defensive driving. Second, due to the expectancy for performance, drivers maintain their driving habits, using greater battery than otherwise; a system that advises them about their driving style in consideration to their local environment would be helpful. Such a system could be developed with the help of the data obtained from the battery as the vehicle is in operation under different circumstances.
7. Financing opportunities:
   A leasing option for the battery or the vehicle that is advantageous to the operator would be helpful. In fact, the operators are creating an added value for the electric vehicle industry and in many ways, are the promoters of the concept. Closer cooperation with associations running the system through research institutions, OEMs and car manufacturers would be beneficial.

3 Conclusion

As the paper presents, the use of electrical vehicles in DRT systems is well underway. E.g. the shown use case of the Buerger(ruf)Auto in Boxberg has been founded during the research project and is still operating successfully after the termination of the project. Buergerbuses are operating in Germany since the 1980s and the number is growing ever since. But there are aspects that still need to be worked out to make the electric vehicles more attractive for these types of applications and for the mobility of people in general in rural areas. The already taken steps should be however encouraging to the automobile sector who, in the mind of the research community, should feel enticed to invest themselves more fully into the development of more suitable vehicles for DRT systems. A larger engagement from their part will certainly improve the impression of society to a point which the technology would be better accepted as a viable solution not only for DRT applications but for others as well. Promising is that electric vans and minibuses play a big role for the movement of goods, especially for parcel deliverers. The demand for parcel delivery is rising due to the ongoing increase of e-commerce, internet orders and new ways of the delivery of goods. The area of people transportation and DRT services will benefit from this evolution. On a larger scale, the size of the cars used for DRT systems is pretty the same as nowadays first autonomous city buses (“robo shuttles”). DRT services as described within this paper set a basis for future transportation scenarios with flexible services spontaneously aligning demand and supply in megacities.

Notwithstanding, it is important to realise that more comprehensive and holistic studies need to take place to set the path for the acceptance of the system. The studies should be done with the aim of optimizing the use of EVs in dispersed and low demand rural areas. For this, the methodologies to perform the studies need to improve. They need to be based on the management and use of larger amounts of data that can be obtain during the operation of the existing or new services, but with newer vehicles. However, the data needs to be measured as accurately as possible through interfaces measuring directly from the vehicle engine, GPS positioning systems and installed accelerometers that can determine driving styles. The data obtained should be analysed through algorithms that are able to learn the best solutions in terms of energy savings, strategies for the efficient assignment of trips and charging times. These studies are in the best interest of the EV industry if the intention is that the technology is well accepted in the future by a demanding market used to the reliability and in certain ways comfortable (not efficient) internal combustion technology

However, based on some of the given reason alone, it is encouraging to see that the automobile industry takes clear steps towards understanding the needs of the market in a direct manner through symposia such as the 'Electric Vehicle Symposium and Exhibition - EVS30.

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