ZEB On-Route Infrastructure Implementation Guidebook

Revision History

Revised On	Version	Description	Approved By
January 31, 2022	1	Guidebook drafted by ZEB committee members (Jan 31, 2022)	
April 11, 2022	2	Feedback from TTC (April 10, 2022)	
June 17, 2022	3	Feedback from Metrolinx (May 24, 2022)	

Introduction

Many transit agencies in North America have embarked on a journey to deploy zero emission buses (ZEB) to reduce greenhouse gas emissions, deploying an attractive alternative that is a cleaner and quieter form of transportation. This document serves as a tool to educate transit agencies on the adoption and deployment of on-route charging infrastructure to support the needs of a battery electric bus (BEB)[1] fleet and service providing context and knowledge on best practices gathered from transit industry peers and available industry resources.

Each deployment will be guided by the agency's specific needs and priorities; therefore, the document does not provide prescriptive answers for each decision point but rather context and knowledge to understand the complexity of this type of deployment. Although the information provided can be generally applicable to all transit agencies, regardless of size, location or experience with deployments, this document has been developed with considerations for agencies in the early stages of deployment, specifically in the Province of Ontario – with any applicable regulations that may have been cited.

Scope

This document is focused on on-route charging infrastructure for battery electric buses (BEB's), where buses receive a top-up charge mid-way through daily service to continue operating the vehicle. There is particular focus on standardized and shared infrastructure use among multiple agencies and across jurisdictions. This document is focused on infrastructure and assumes that the reader is aware of BEBs and vehicle models in the market.

This document does not include hydrogen fueling as part of scope primarily because hydrogen fueling requires infrastructure that is not typically conductive to installation at shared infrastructure locations. The added benefit of fuel cell bus technology is the ability to store more energy on board the bus, providing longer service ranges (similar to diesel buses)

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[1] A battery electric bus is an electric bus that is propelled by an electric motor, obtaining the required energy from on-board batteries. Battery electric vehicles significantly reduce the amount of energy conversion on board the vehicle and use very efficient electrical power conversion components to power the driveshaft and auxiliary systems, such as lighting and air conditioning. This is the simplest, most efficient, and cleanest method of powering a vehicle.

Credits

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Disclaimer

Information provided is based on agency experience or industry research and should be used for educational and reference purposes only. Agencies looking to adopt any form of ZEB should obtain the services of qualified professionals to review their operations and determine an optimal conversion strategy for their specific operational requirements.

Battery Electric Bus Technology

Generally, there are two types of battery electric buses (BEB's) available in the industry: (1) opportunity/fast charge buses and (2) long or extended range buses. Opportunity/fast charge buses have smaller battery capacities but have a battery design suitable for frequent, high rate of charging. Such buses may only have 2-3 hours of range, but can be charged from high-power chargers for short periods of time throughout the day. Long or extended range buses typically have larger battery capacities, but cannot accept such high charge rates. A typical long-range BEB may have an operating range of 12+ hours in urban transit service but may require over 3 hours to complete recharging. However, developments in battery technology and chemistries can potentially accommodate high powered charging in long or extended range buses in the coming years.

On-route charging infrastructure is generally always required for opportunity-charged buses, but can have applications for long-range buses operating long blocks of service or particularly severe duty cycles. If the on-route charging capabilities are implemented effectively, the buses will recharge every time they return to the charger and can run indefinitely without needing to stop for an extended charging session. For this reason, fast-charge BEBs can often be a 1:1 replacement for conventionally fueled buses.

Charging infrastructure options for on-route applications are described in the next section.

Example Fast Charge 40’ BEB Characteristics

- Battery capacity: 50–250 kWh
- Reliable range in transit service: Indefinite range with periodic charging of sufficient duration
- Capital costs: About $1M-$1.2M for base bus
- Charging approach: 150–450+ kW overhead or wireless chargers, typically charged on-route

Battery Electric Bus Charging Infrastructure (On-Route Application)

This section provides an overview of charging infrastructure typically installed for on-route charging applications. It consists of overhead conductive charging and wireless inductive charging– providing a summary of each technology, including a description of existing standards. The use of on-route electric charging infrastructure is typically referred to as opportunity charging, which extends the range/distance and use of the vehicles while in-service. This application is typically used for heavy-duty electric vehicles, particularly buses, with charging power delivery between 150kW-600kW to deliver a quicker charge to the vehicle.

Charging Infrastructure Summary

Infrastructure Type	Typical Installation	Advantages	Disadvantages

Overhead Conductive Charging	• Typically installed on-route or at transit centers where layovers occur, allowing for opportunity charging; may also be installed at the bus depot or yard. • Typically serve multiple BEBs operating on routes or from transit centers. • Typically used with buses with smaller battery packs and less range. – Charge type: DC. Charge power: 150–600 kW. • Recharge times: 5–20 minutes.	• Buses typically use smaller, lighter battery packs • Can support 24-hour bus operation if implemented correctly • Total infrastructure costs may be less expensive if fewer chargers are needed for a larger fleet • Automated charger connection with the bus • One charger serves multiple buses • Buses are able to remain in service while charging on route • May increase resilience during power outages if chargers are on a different utility feed or service area	• Higher cost of charging infrastructure • Requires charging infrastructure, equipment, and civil work • Peak demand charges can significantly affect operational costs • Land use and/or rights must be obtained at deployment sites • Requires signification overhead clearance. • Overhead systems may interfere with road clearances or require dedicated/restricted pull-off • Fixed infrastructure constrains route changes for BEBs in the future or can be costly to relocate • Requires proper bus-charger alignment for optimal charging • Not all OEMs offer overhead conductive charging • Less redundancy due to fewer chargers, which could result in service outages

			• Property rights may be required, limiting possible charger locations on-route • May interfere with road clearances, or require a dedicated pull-off • Less flexibility in route assignments or to use buses for special service and emergency purposes since buses must stay near a charger
Wireless inductive charging	• Typically installed on route or at transit center where layovers occur but could also be used at bus depot • Typically serve multiple BEBs operating on routes or from transit centers • Typically used with buses with medium-to-large battery packs and medium range • Charge power: 50 kW (up to 250 kW planned)	• Can remain in service while charging on route • Decreased infrastructure footprint • Charging interface does not interfere with road clearances or require dedicated/restricted pull-off • No manual connection or moving parts • No right-of-way restrictions • Aesthetically more pleasing	• Slightly less efficient than conductive methods (90% versus 95%) • Requires high-precision parking typically within 200 mm of the charging pad. • Requires installation in the road bed. • Requires charging infrastructure, equipment, and civil work • Land use and/or rights must be obtained at deployment sites • Fixed infrastructure constrains route changes for BEBs in future or can be costly to relocate

			• SAE standard is still under development

Charging Standards

The standards for heavy duty vehicle charging are primarily defined by the SAE J3105 and SAE J2954/2 standards. These standards are applicable to overhead conductive charging and wireless inductive charging respectively.

SAE J3105

This is a recommended practice for overhead conductive charging through the use of automated connection devices (ACD) that connects chargers with battery electric buses and heavy-duty vehicles. It defines a conductive power transfer method, including the curbside electrical contact interface, the vehicle connection interface, the electrical characteristics of the DC supply and the communication system. It also covers the general physical, electrical, functional, testing, and performance requirements for automated conductive DC power transfer systems intended for heavy duty vehicles, focusing primarily on transit buses. J3105 defines a common automated conductive charging system architecture so that any vehicle selecting one of the supplemental specific ACD implementations can use any charger that complies with that specific implementation, regardless of manufacturer

Further to this, J3015 defines supplementary implementations methods as further described below:

1. SAE J3105/1: Infrastructure-Mounted Pantograph uses a pantograph installed at the charging location which lowers to meet a pair of rails mounted on top of the bus.
2. SAE J3105/2: Vehicle-Mounted Pantograph Connection uses a pantograph mounted on the vehicle which raises to meet fixed rails at the charge location.
3. SAE J3105/3: Enclosed Pin and Socket Connection is a large probe-type plug which enters a socket mounted high on the bus. This is not a comment scheme for buses and was developed with other vehicle types in mind.

In general, SAE J3105/1 pantograph-down systems are more common in North America and J3105/2 style systems are more common in Europe. In North America, agencies have adopted to de-couple the charging equipment from buses and have the charging equipment operated on independent infrastructure, which increases the reliability of the vehicle and reduces the overall vehicle weight. Additionally, in North America it is possible to order buses that are compliant with J3105/1 rails and J1772 sockets to allow fast charging on route and slower charging in depots or repair centres, including the connection of portable charging packs.

Examples of manufacturers product offers for electric bus automated connection devices:
https://www.schunk-group.com/transit-systems/en/products/charging-devices-electric-vehicles
https://www.stemmann.com/en/products/charging_systems

SAE J2954/2

The SAE standard defines a guideline that works along similar principles as inductive charging. It establishes an industry-wide specification guideline that defines acceptable criteria for the interoperability, electromagnetic compatibility, minimum performance, safety, and testing for wireless power transfer for high power wireless charging of BEV and PHEV vehicles.

This standard is currently under development.

Key Factors to Consider for Charging Infrastructure Adoption

When selecting charging infrastructure and an approach for implementation, agencies must consider many factors such as service requirements, route characteristics, technology, layover or transit center locations, space considerations and power availability. The analysis should be tempered through an equity analysis to ensure that quieter, non-polluting BEB's are not assigned predominately to more affluent neighbourhoods or to lower density neighbourhoods. Careful planning is required by transit agencies in the deployment of on-route charging infrastructure for BEBs, with special consideration for standardized and use of shared infrastructure across jurisdictions among multiple agencies. Key factors that should be considered in the decision-making process have been described below:

Operations

- Route demands (e.g., average speed, stop spacings, topography, passenger loading, etc) and blocking demands (e.g., deadheads, duration and frequency, operator breaks, collective bargaining requirements) will affect service time and range requirements of the vehicle, thereby overall demand for charging and critical locations of infrastructure
- For transit services, the service planning and scheduling groups should consider bus charging time into their planning activities. This also includes:

    - Dwell time: Consider areas with existing dwell time or plan for sufficient time (including time for the charger to dock and undock from the bus) to charge the vehicle on-route, until it can receive its next charge
    - Consider schedule adherence and the effects of interlining if charging infrastructure is installed at common stop
    - Charger availability: Charger downtime due to planned maintenance or unplanned repairs
- Type of service
    - Intraregional – infrastructure sharing should be explored with neighbouring regions, which is especially possible in denser markets such as communities in the Greater Toronto Area (GTA)
    - Intercity - infrastructure sharing should be explored with regions receiving servicing, such as northern transit agencies in Ontario with overlapping systems such as Ontario Northland and GO Transit

Real estate

- Existing transit centers/terminals, or end-of-line layover sites are ideal locations for charging infrastructure. In general, the charging is most flexible at locations were vehicles lay-over as this provide the opportunity for lower-power charging.
- Service that converges with multiple routes, other transit services (e.g GO Transit) and other local municipal services (e.g fire, paramedic), can provide additional opportunities for charging infrastructure locations. The core technology in a charger is the same for a BEB charger and a vehicle charger, thus a charger equipped with both a pantograph and a cable dispenser could be time-shared between different vehicle types.
- Consider if charging will be needed or advantageous for complimentary uses such as fast-charging for park-and-ride lots, taxi stands, etc.

Collaboration and Partnerships

- A coordinated approach among agencies would be ideal when considering standardized and shared charging infrastructure in regions where service would intersect. This would reduce the cost of infrastructure, including the cost of design, build and maintenance, while sharing the risks among multiple agencies.
- Early collaboration with local utility companies will be critical in adopting on-route charging infrastructure and minimizing energy costs

- Local utility companies must be engaged early, providing an overview of power supply requirements and schedule of when charging may occur. Utility companies may have capacity constraints at some locations that must be considered before the adoption of charging infrastructure
    - Deploying BEBs will greatly increase electric usage and may become the largest electric users in the utility's service area
    - Utility and distribution agencies in the GTA have begun to express interest in the ownership of charging assets and exploring alternative delivery models to support agencies through fleet electrification
    - Some utility companies (through approvals from the appropriate regulatory agencies) have implemented rate structures and pilot programs that promote the deployment of BEB's
    - Utility companies will aid in designing and building grid resiliency, including a priority list for service restoration to the charging infrastructure based on operational needs of each agency
- Explore opportunities (competitive or direct) with Original Equipment Manufacturers (OEM's) and other vendors that offer turnkey services for the supply, design and build of the charging infrastructure. Some of the same vendors may also offer operations and maintenance services for the charging infrastructure.
    - Alternative delivery models may also be considered (e.g. Charging as a Service[2]).

Costs

The expected capital and operating costs associated with charging infrastructure are described below:

Capital Costs

- Power supply (i.e utility connection)
- Non-utility connection (e.g transformer, conductors, distribution panels, etc)
- Site/facility upgrades (civil, structural, electrical design and works)
- Equipment and electrical infrastructure
- Warranty
- Professional fees

Operating Costs

[2] Subscription-based model whereby an entity provides turnkey EV charging solutions with minimal upfront capital costs, paying an subscription fee over a fixed term

- Electricity: Electricity rates will have a significant impact on operational costs. In Ontario, the utility rate schedule and pricing plans determine how electricity is charged to the agency. In general, the three components of an electricity bill in Ontario are global adjustment, demand charges and hourly energy costs.
    i. Demand charges are minimized by ensuring the chargers are used as frequently as possible.
    ii. Global Adjustment (GA) can be managed with a combination of GA peak prediction services and either deferring charging, rate-limiting or the use of battery-energy storage to
- Maintenance: Planned and unplanned maintenance; parts inventory and management
    i. Maintenance for opportunity/on-route charging systems are driven by charging cycles and typically have high usage, with higher frequency for planned maintenance. They are also exposed to the elements (ex. weather, salt and moisture), especially connectors and sensitive equipment, leading to increased maintenance costs.
- Operations: The impact to operator hours (increase) is dependent on service planning and scheduling activities. There may be limited impact to operator hours to accommodate charging based on available dwell time available in service.
    i. Union agreements and scheduling of staff must also be reviewed, so determine cost-efficient operations of the workforce. For example, the evaluation of longer breaks (without additional pay) to be considered in collective agreements, allowing for enroute charging without an increase in operator costs.
- Software: On-going licensing costs for software to actively manage the buses, charging equipment and infrastructure, providing operational support and data analytics services for energy management, diagnostics and cyber security.

Other

- The design and configuration of the charging infrastructure vary by each OEM's product offerings and the operational requirements of each agency
- On-route infrastructure may be scalable as additional buses may not require additional infrastructure. Where additional blocks of service use existing charging infrastructure, the O&M costs will generally decrease.
- Overall costs are expected to decline in the future as the market matures – including the technology and supply chain. However, with evolving technology, available support for maintenance and the supply chain of parts must be monitored
- Agencies are not restricted to only using on-route infrastructure and can configure their fleet to utilize on-route charging and depot charging solutions.
- The number and types of funding programs being offered associated with the ZEB industry are constantly changing

Best Practices

Modeling and simulation

1. Complete an initial service review, simulating the operations of electric buses
    - Review of current service plan and scheduled blocks
    - What are the shorter blocks that can be electrified?
    - Which blocks are you uncertain about, identifying sites that may require on-route charging systems
    - Consider dwell time on street and increased operators hours as part of the analysis

2. Model “nominal” and “strenuous” vehicle efficiencies
    - Planning the worst case may not be feasible or practical for load profiles and energy costs
        - The agency still requires a plan to make the worst-case service day
    - Treating time and distance separately allows you to account for changes more easily in planned service
    - Factors that influence vehicle range and therefore infrastructure locations include route conditions, passenger loading, temperature, driving style and battery state and health,

3. Incorporate BEB Charging
    - Account for equipment power efficiency and charge time but also for time for charger to dock and disengage from the bus
    - Identify if seasonal adjustments must be made to the deployment plan to accommodate longer charge times or shorter blocks

4. Apply Results
    - Use to determine any needed changes to operational schedules and charging schedule requirements; changes include charging layovers, route adjustments, preconditioning before pullout
    - Determine relative differences between seasonal behavior and expected performance
    - A thorough analysis of current and future ZEB plans should be conducted to consider scalable solutions

5. Validate and Update Model
    - Use real-world data to update model assumptions and parameters

Technology selection and specifications

- Selecting suitable ZEB technology and deployment strategy based on bus performance evaluation using modeling and deployment data analysis
- Developing clear technical specifications and performance requirements to ensure your buses and infrastructure meet the agencies operational needs
    - Pay particular attention to the modularity and scalability of the equipment for future needs
- The on-route charger specifications should also consider any charge management capabilities, demand management capabilities, or energy storage systems your agency desires for energy cost or service stability
- Ensuring procurement documents include thorough and effective considerations for inspection, acceptance testing with the ZEB's, and warranties
- The technology for both BEB's and charging infrastructure continue to evolve, but careful consideration must be made with equipment specifications to ensure alignment and applicability with existing standards and operational requirements

Resiliency and maximize uptime (charger availability)

- Consider integrating energy storage into the project and look at all possible uses of the ESS including
    i. GA avoidance
    ii. Demand charge reduction
    iii. Utility upgrade cost reduction/deferment
    iv. Deferment of standby generator costs including the significant O&M costs
    v. Integration of renewables
- Where necessary, consider back-up generation (ex. Standby natural gas generator)
- Discuss grid-based resiliency with the utility companies
- Plan for continuity of service with respect to supply chain and maintenance (planned/unplanned)
- Emergency planning including planning for emergency operating modes if applicable

Software

- Integrated charger management systems play a critical role in the effective connection and control of the electric charging infrastructure
    i. Ensure charging equipment are Open Charge Point Protocol (OCPP) complaint
    ii. Consider software that is open, interoperable and hardware-agnostic
- These systems allow for various functionality that includes energy management, active monitoring and diagnostics, vehicle schedule integration, smart building and grid integration and many more
- Consider the agencies cyber security needs with infrastructure assets located in publicly accessible spaces and over a distributed network.
- Consider communications needs. Cellular service is common and can be cost-effective, however it will not be as reliable as a wired network and your data will be switched over the public internet unless additional and services are obtained at higher cost. Rather than providing every charger at a location with a cellular connection, consider a local wired connections at each location with a single cellular modem or, preferably, a pair of modems on different carriers.

Cost Optimization

- Assess multiagency use of the equipment, developing cost sharing models with other public or private entities
    i. Encourage economies of scale through joint procurement
- Maximize the utilization of on-route infrastructure with buses (8:1) to minimize overall costs
- Understand consumption patterns and utility rate structures
    i. Costs can vary based on type of charging utilized, time of use pricing, and size of deployment (BEB)
    ii. Increased usage of the bus will reduce the overall cost per km – demand costs are a significant contributor to operational costs and the charges can be spread out over total operating distance
    iii. Understanding the factors that will impact electricity costs – time of electricity usage/number of buses charging simultaneously
    iv. Plan charging sessions to minimize costs
- Assess revenue generation methods, considering opportunities to sell energy back to the grid using on-site energy assets
- Note fixtured infrastructure constraints that can be costly to relocate based on route changes in the future

Design and Construction Roadmap

Described below is high level overview covering considerations for design and construction of on-route infrastructure.

Step 1:

Obtain approval to fund a feasibility study / Preliminary Design Review to define how many buses need to be charged, when, where, and for how long (i.e. dwell time considerations). This will establish the following:

- Bus battery capacity, charge rate, connection type
- Charger ratings
- Power demand requirements
- Battery storage systems / redundancy
- Type and quantity of chargers
- Amount of real estate / number of bus bays to allow for bus charging
- Complete an energy consumption and bus range modelling and simulation exercise with an electric bus operating under current service parameters
    - Determine charging requirements per block based on multiple charging scenarios
- Determine if you plan to electrify a route to drive ridership or awareness or prefer to electrify on a block-by-block basis to meet agency goals such as CHG reductions, operating costs, etc.
- Identify potential synergies with other EV users - i.e., other TAs, first responders, non-revenue vehicles, etc.
- Identify any state-of-good repair or expansion projects that may provide opportunities for cost-reduction (e.g. installing conduits when replacing roadbeds, leaving space in new facilities for charging equipment, etc.)

Step 1B:

Prepare a lifecycle cost analysis to review if on-route charging is the best solution for your agencies and which, if any, other ZEB strategies will be required. On-route charging is often not the lowest cost route to a zero-emissions fleet, but may be part of a lowest-cost solution. It may be prudent to show any external savings in this analysis and to wisely consider increasing fuel cost and carbon taxes.

Step 2:

Conduct a real estate inventory to assess optimal real estate in the TA portfolio that can be leveraged for battery electric bus charging investment. Part of this inventory evaluates public right of way, ownership, encumbrances, and other barriers that might impede on deployment of charging infrastructure. Assess the terminal / station design and the impacts that layovers for charging BEBs will have on the site. There may also be land use and/or rights must be obtained at deployment sites.

It is important to identify locations but plan for charging to meet the service needs of the agency and community. The key is finding locations that make sense operationally based on the feasibility study from Step 1.

Step 3: Develop equipment specifications

Developing the specific equipment specifications may not be required. As charging systems are built to established standards, at minimum you should specify:

- Vehicle parameters
    - Connection type (e.g. J3105/1 infrastructure-mounted pantograph)
    - Charging voltage (consider future requirements)
    - Minimum and maximum power ratings
- What monitoring and/or remote control you may want. There is a wide range of capabilities available, but at a minimum consider remote status monitoring, charge transaction record keeping and remote reset capability. More advanced systems may include demand management, global adjustment prediction and avoidance, renewable generation integration, etc.
- Space available for charging equipment
- Overhead clearance requirements
- Noise limits, aesthetic considerations
- Climate, seismic and flood plane data for your location which can be found in the Environment Canada Climate Normals or ASHRAE documentation, Ontario Building Code, and from your local conservation authority.
- Uptime requirements, availability, mean-time-to-repair especially if the procurement model includes O&M.
- Operator interface requirements such as status lights, emergency stops, etc.

Step 4: Obtain costs for the following:

- Chargers and vehicle connections (e.g. infrastructure-down pantograph, wireless, etc.)
- Battery Storage Systems
- Upgrades to transformers/sub-stations, if applicable
- Utility upgrade costs
- Upgrades to distribution equipment, if applicable
- Real estate, if applicable
- Consulting services to support the design/build
- Sustaining capital, electricity costs, equipment O&M.
- Reduced diesel costs
- Vehicle maintenance cost variance from your existing vehicle to the new BEB.

This will provide a Rough Order of Magnitude (R.O.M.) price for the project. It is important to review the costs on a lifecycle basis. The initial infrastructure can have high capital costs, but a well-planned project can have long-term operating savings.

Step 5:

Select procurement approach – single RFP, Joint Procurement, Design-Bid-Build, DBOM, DBFOM. The approach selected will impact on how to mitigate risk, and also proceed for budget approval and RFP process. Investigate funding opportunities available from government and other agencies. For project procurement approaches that involve financing, ensure that the costs of borrowing are well understood.

Step 6:

Obtain approval to fund the charging infrastructure investment, the procurement approach selected, and the Consultant that will act as Project Manager and Subject Matter Expert.

Business Risk Assessment

- Industry scan and research, engage peer agencies to learn about their experiences, lessons learned and equipment OEMs to continually learn about product offerings and new features
- Based on modelling results and future service needs, assess short and long-term fueling infrastructures needs and available capital
- Engage your electric utility company early on to discuss timelines and cost to meet your energy requirements
- When considering shared infrastructure with other agencies, an uncoordinated approach may lead to some agencies potentially defining charging requirements and configuration
- Based on delivery model pursued, a responsibility matrix identifying ownership and management of infrastructure
    - Many transit agencies may not have the internal capacity and resources to own and manage charging infrastructure
- Pay close attention to published standards for charging infrastructure and BEBs
- Plan with modularity and scalability in mind.
- During the design and operations phase, pay particular attention to safety, fire protection and emergency planning
- Cyber security risks should be well understood and a robust and ongoing cyber-security program should be developed. Cyber-security required constant vigilance, it is not sufficient to rely on a hardware solution. In addition, plans should be developed both for operations in the event of a cyber-attack and for recovery.
- Through the evolution of technology, the BEB market is maturing, creating risks that investments in capital today can become obsolete in the future
- Transit agencies deploying BEB should research and consider technologies that may positively impact their deployment or long-term BEB goals
- Leverage charging management solutions for the active management of the infrastructure and integration with existing assets and systems

Emerging Technologies

- Dynamic Wireless EV Charging Systems

References

- Guidebook for Deploying Zero Emission Transit Buses (TRB)
- Best Practices and Key Considerations for Transit Electrification and Charging-Infrastructure Deployment to Delivery Predictable, Reliable and Cost-Effective Fleet Systems (CUTRIC)
- SAE International