Mobility as a service: The role of E-bus in Sustainable Transport Development

Charles Chuang
Chief Technology Officer

Tron Energy Technology Corporation
The way people and goods move is set to change dramatically, driven by:

1. Technology (5G/Autonomous Driving/Fuel Cell)
2. Economics (On line business and services/New business models)
3. New solutions (shared ride, on-demand services)
4. Government Policy (ITS/Environmental/Planning)
OUTLINE

1. History of land vehicles
2. Introduction to New Energy vehicles
3. Lithium ion battery characteristics
4. EV bus state of affairs
5. Urban traffic issues
6. Global warming and policies
7. Integrated Transport Solution
FIRST SELF-PROPELLED VEHICLE (STEAM ENGINE)

Nicolas-Joseph Cugnot 1770 fardier à vapeur

FIRST PORSCHE ELECTRIC CARS (BEV 1898/HEV 1901)

Ref: The Verge porsche-first-vehicle-found-after-116-years-electric
US Department of Energy Timeline
FORD MODEL T KILLED THE ELECTRIC CAR INDUSTRY

Ref: History.com, Wikipedia: the collection of Henry Ford
# Resurgence of Electric Vehicles (1996/2008)

<table>
<thead>
<tr>
<th>General Motors</th>
<th>Tesla</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EV1</strong></td>
<td><strong>Roadster</strong></td>
</tr>
<tr>
<td>Lead Acid Battery</td>
<td>Lithium Ion Battery</td>
</tr>
<tr>
<td>16.5 KWh</td>
<td>53 KWh</td>
</tr>
<tr>
<td>172 Miles</td>
<td>244 Miles</td>
</tr>
</tbody>
</table>

- **EV1**: 16.5 KWh, 172 Miles
- **Roadster**: 53 KWh, 244 Miles
- **Model S**: 40-100 KWh, 140-370 Miles

![Images of EV1, Roadster, and Model S](image-url)
NEW ENERGY VEHICLE TYPES

HEV
- Motor
- Engine
- Battery
- Gasoline Tank

PHEV
- Motor
- Engine
- Battery
- Gasoline Tank

E-REV
- Motor
- Engine
- Battery
- Gasoline Tank
- Generator
- Inverter

EV
- Motor
- Battery

Ref: Citi Research
BLOCK DIAGRAM OF EV AND RANGE EXTENDED EV

Ref: Citi Research
ICE Fuel Type

- Gasoline
- Diesel
- Compressed Natural Gas (CNG) or Liquefied Petroleum Gas (LPG)
- Methanol

Ref: Citi Research
FUEL CELL VS. BATTERY

- Fuel cell characteristics
  - High temperature operation
  - Need time to warm up to operation
  - Drive cycle load Variation taxing to system

- Battery should be the main energy source, with fuel cell, gasoline, or diesel supplying power to range-extender generator

Ref: ARTC
RANGE EXTENDER IN OPERATION

Ref: https://www.sciencedirect.com/topics/engineering/extended-range-electric-vehicle
LITHIUM-ION BATTERY INTRODUCTION

- Lithium ion battery energy density is significantly better than lead acid
- 1/3 of the Vehicle cost comes from battery pack
- Battery life impact total cost of ownership

Ref: EPEC Engineered Technologies
POORLY UNDERSTOOD LI-ION BATTERY

- Many misconceptions on Lithium ion battery
  - Cell phone usage
  - Small form factor replacement battery (AA/AAA)
  - Lead acid battery usage
- Ignorance on the thermal event chemistry and preventive measures
- Many product failures and safety events
  - Across the globe
  - No government has taken the lead to address this problem
CHARGING – COMMON MISTAKES

- Lead acid batteries are inherently leaky
- Lead acid chargers must be leaky as well to compensate

- Lithium-ion batteries are not leaky
- Lead acid chargers causing Lithium-ion battery to fill to the brim
  - Accelerated aging
  - Safety hazard

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CHARGING – COMMON MISTAKES

- Voltage across batteries are inherently not equal
- One cell will reach limit before others
- Continue charging will cause cell rupture and short circuit
- Domino effect causes other cells to fail
- Total short circuit with serious fire hazard
HIGH DEGRADATION AT HIGH TEMPERATURE

<table>
<thead>
<tr>
<th>City</th>
<th>Time for Li-ion battery capacity to fade to 85%</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minneapolis</td>
<td>14 Years</td>
<td>10 °C</td>
</tr>
<tr>
<td>Houston</td>
<td>7.5 Years</td>
<td>20 °C</td>
</tr>
<tr>
<td>Phoenix</td>
<td>4 Years</td>
<td>30 °C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cooling</th>
<th>Time for LFP battery pack capacity to fade to 80%</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid Cooling</td>
<td>8 Years</td>
<td>30 °C</td>
</tr>
<tr>
<td>Air-Cooling</td>
<td>4 Years</td>
<td>40 °C</td>
</tr>
<tr>
<td>Non-Cooling</td>
<td>2 Years</td>
<td>50 °C</td>
</tr>
</tbody>
</table>

Ref: Addressing the impact of temperature extremes on Li-ion batteries for vehicle applications, NREL (National Renewable Energy Laboratory) Report [https://www.nrel.gov/](https://www.nrel.gov/)
OVER TEMPERATURE = THERMAL EVENT

- Battery self heating, if not in check, will lead to thermal event
- Slow reaction at first, pace pick up quickly as temperature elevates

Ref: ARC of LiCoO2, 100% SOC 2.1 Ah cell  Thermal Management Modeling for Thermal Runaway Avoidance in Lithium-ion Batteries, Exponent Inc.
CHARGING SENSITIVITY

- Overcharging very harmful, even dangerous
  - Without BMS, overcharge is inevitable
  - Lead acid charger is likely to overcharge
- Low temperature charging very harmful, eventually short circuit
- Overly fast charge will cause cell temperature rise, can even lead to thermal event

Ref: http://www.mpoweruk.com/lithium_failures.htm
CYCLE LIFE VS. DEPTH OF DISCHARGE/CHARGE

• Battery is alive. Shallow charge/discharge cycles is much better than deep charge followed by deep discharge
• Departure from cell phone charging

Ref: Q. Badey, et al. University Paris Sud, Ageing forecast of lithium-ion batteries for electric and hybrid vehicles
DISCHARGE SENSITIVITY

- Overly fast discharge will cause cell temperature rise, shorten life, can even lead to thermal event
- Highest discharge rate is SOC dependent
- Kept in over-discharge condition too long and the battery cannot be charged again.

Ref: Christoph R. Birkl “Degradation diagnostics for lithium ion cells”
MOISTURE/WATER SENSITIVITY

- Moisture creates shorting path to cells
- Water incursion into battery pack may lead to short circuit
- Air cooling cannot prevent moistures from penetrating battery pack

Ref: Condensation – RedVerz “6 Best Ways to Reduce Condensation in a Tent”
LITHIUM ION BATTERY SENSITIVITIES AND REMEDIES

- **Temperature sensitivity**
  - Life degradation at high temperature
  - Unstable at high temperature
  - Sluggish at low temperature

- **Charge sensitivity**
  - Cannot tolerate over charge
  - High charge rate degrades life
  - Cannot charge below 0 degrees

- **Discharge sensitivity**
  - High discharge rate degrades life
  - Cannot tolerate over discharge

- **Moisture/Water sensitivity**

- **Cell temperature controlled via liquid cooling**

- **Smart charger with intelligent charging algorithm**

- **Active battery management system**

- **Sealed battery pack design to keep out moisture**
# ELECTRIC VS. DIESEL BUS COMPARISON

<table>
<thead>
<tr>
<th>Item</th>
<th>Diesel</th>
<th>Tron-e</th>
<th>R Brand</th>
<th>S Brand</th>
<th>B Brand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise</td>
<td>High</td>
<td>Very Low</td>
<td>Ave</td>
<td>Ave</td>
<td>Low</td>
</tr>
<tr>
<td>Incline Brake</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Cooling</td>
<td>Liquid (Patented)</td>
<td>Air</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seats</td>
<td>24~26</td>
<td>29</td>
<td>25</td>
<td>24</td>
<td>27</td>
</tr>
<tr>
<td>KWh per KM</td>
<td>0.9~1.0</td>
<td>1.3</td>
<td>1.2</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>ADAS</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Web based monitor</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>Highest</td>
<td>Lowest</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>
EV BUS OPERATION TODAY

Affordable  
Quiet  
Reliable  
Spacious  
Web Based
EV BUS OPERATION TODAY
EV BUS OPERATION TODAY
## TRON-E EV BUS AVAILABILITY DATA

<table>
<thead>
<tr>
<th>Year/Model/Qty</th>
<th>2018/10</th>
<th>2018/11</th>
<th>2018/12</th>
<th>2019/1</th>
<th>2019/2</th>
<th>2019/3</th>
</tr>
</thead>
<tbody>
<tr>
<td>12M EV</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Availability</td>
<td>99.32%</td>
<td>99.36%</td>
<td>99.30%</td>
<td>99.22%</td>
<td>99.58%</td>
<td>99.55%</td>
</tr>
<tr>
<td>12M/ 8.8M EV</td>
<td>-</td>
<td>60</td>
<td>60</td>
<td>69</td>
<td>69</td>
<td>69</td>
</tr>
<tr>
<td>Availability</td>
<td>-</td>
<td>99.39%</td>
<td>99.46%</td>
<td>99.76%</td>
<td>99.48%</td>
<td>99.85%</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>70</td>
<td>70</td>
<td>79</td>
<td>79</td>
<td>79</td>
</tr>
</tbody>
</table>
 USAGE OF DECOMMISSIONED BUS BATTERY PACK

• EV battery pack is decommissioned at 70%-80% capacity
• Good pack design allows decommissioned packs to be used in energy storage applications

Ref: UMC Battery Environmental Issues
ENERGY STORAGE SYSTEM EXAMPLE
ENERGY STORAGE SYSTEM EXAMPLE
- Oil and coal based power plants’ generation is higher than demand at night
- Excess power is completely wasted
- Charging EV with the wasted energy is environmentally friendly

<table>
<thead>
<tr>
<th>Power Generator</th>
<th>Ramp Rate</th>
<th>Down Time</th>
<th>Up Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[MW/min]</td>
<td>[min or Hr]</td>
<td>[min or Hr]</td>
</tr>
<tr>
<td>Solar</td>
<td>200</td>
<td>0,5 [min]</td>
<td>0,5 [min]</td>
</tr>
<tr>
<td>Pump Hydro</td>
<td>200</td>
<td>0,5 - 1 [min]</td>
<td>0,5 - 1 [min]</td>
</tr>
<tr>
<td>Hydro Reservoir</td>
<td>150</td>
<td>1-5- 1 [min]</td>
<td>1-5[min]</td>
</tr>
<tr>
<td>Wind</td>
<td>30-60</td>
<td>1-2[min]</td>
<td>1-2 [min]</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>20-50</td>
<td>2-20 [min]</td>
<td>2-20 [min]</td>
</tr>
<tr>
<td>Nuclear</td>
<td>20</td>
<td>1 [hr]</td>
<td>2 [hr]</td>
</tr>
<tr>
<td>Natural gas / Steam</td>
<td>10-20</td>
<td>1 [hr]</td>
<td>2 [hr]</td>
</tr>
<tr>
<td>Oil / Steam</td>
<td>1-7</td>
<td>2-10[hr]</td>
<td>4-12[hr]</td>
</tr>
<tr>
<td>Coal / Steam</td>
<td>2-4</td>
<td>4-48 [hr]</td>
<td>8-24 [hr]</td>
</tr>
</tbody>
</table>

Ref: Alejandro Hoese National University of San Juan
FIRST PUBLIC BUS SERVICE (1820)

There is no profit in public bus operations

- Public bus is oriented for mass transit
- Bus fare is set too low for profit
- Government subsidy is required
- Government mandates unprofitable routes and unprofitable operating schedule
- Bus become a lower social class means of transport
TRAFFIC JAM

You Waste 158 Hours A Year Stuck In Traffic—These 4 Solutions Could End That In M'sia

Ref: Vulcan Post 0221 2018malaysia-traffic-jams-solutions
The Star online its-a-slow-slow-drive-back-to-the-city-cny-travel-rush-back-sees-heavy-traffic-on-major-highways
PARKING LOT STATISTICS

- Only 5% of time the car is in use
- 20%-30% city space allocated to parking
- People still complaining not enough parking spaces

<table>
<thead>
<tr>
<th>City</th>
<th>New York</th>
<th>Philadelphia</th>
<th>Seattle</th>
<th>Des Moines</th>
<th>Jackson, WY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Parking Spaces</td>
<td>1.85 million</td>
<td>2.2 million</td>
<td>1.6 million</td>
<td>1.6 million</td>
<td>100,119</td>
</tr>
<tr>
<td>Parking density per acre</td>
<td>10.1</td>
<td>25.3</td>
<td>29.7</td>
<td>28.4</td>
<td>53.8</td>
</tr>
<tr>
<td>Parking spaces per household</td>
<td>0.6</td>
<td>3.7</td>
<td>5.2</td>
<td>19.4</td>
<td>27</td>
</tr>
<tr>
<td>Total replacement cost of parking</td>
<td>$20.1 billion</td>
<td>$17.5 billion</td>
<td>$35.8 billion</td>
<td>$6.4 billion</td>
<td>$711 million</td>
</tr>
<tr>
<td>Parking cost per household</td>
<td>$6,570</td>
<td>$29,974</td>
<td>$117,677</td>
<td>$77,165</td>
<td>$192,138</td>
</tr>
</tbody>
</table>

Ref: Smart Cities Conference 2019
OTSnews.co.uk problem-parking-big-cities
TRAFFIC FATALITY DATA (WHO)

• 1.35 Million people died of traffic accidents, 54% are pedestrians and bike riders.
• 3.5 Million died of air pollution

Ref: WHO Global Status Report on Road Safety 2018
The Paris Agreement’s central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below **2 degrees Celsius** above pre-industrial levels and to pursue efforts to limit the temperature increase even further to **1.5 degrees Celsius**.

Ref: Rosamund Pearce for Carbon Brief
GLOBAL WARMING FORECAST

Ref: Green Peace We’ve got 10 years to ditch fossil fuel cars – or it’s game over for the climate
# GLOBAL BAN ON PETRO VEHICLES

## Countries with aspirations to ban fossil-fuel vehicles

<table>
<thead>
<tr>
<th>Country</th>
<th>Ban announced</th>
<th>Ban commences</th>
<th>Scope</th>
<th>Selectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>2017</td>
<td>2040[9]</td>
<td>Gasoline or diesel</td>
<td>New vehicles sales</td>
</tr>
<tr>
<td>Costa Rica</td>
<td>2018</td>
<td>2021[10]</td>
<td>Gasoline or diesel</td>
<td>All vehicles</td>
</tr>
<tr>
<td>France</td>
<td>2017</td>
<td>2040[12]</td>
<td>Gasoline or diesel</td>
<td>New vehicle sales</td>
</tr>
<tr>
<td>India</td>
<td>2017</td>
<td>2030[13]</td>
<td>Gasoline or diesel</td>
<td>New vehicle sales</td>
</tr>
<tr>
<td>Ireland</td>
<td>2018</td>
<td>2030[14]</td>
<td>Gasoline or diesel</td>
<td>New vehicle sales</td>
</tr>
<tr>
<td>Israel</td>
<td>2018</td>
<td>2030[15]</td>
<td>Gasoline or diesel</td>
<td>New vehicle sales</td>
</tr>
<tr>
<td>Netherlands</td>
<td>2017</td>
<td>2030[16]</td>
<td>Gasoline or diesel</td>
<td>New vehicle sales</td>
</tr>
<tr>
<td>Norway</td>
<td>2017</td>
<td>2025[17]</td>
<td>Gasoline or diesel</td>
<td>New vehicle sales</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>2017</td>
<td>2040 – England, Wales, Northern Ireland[18] 2032 – Scotland</td>
<td>Gasoline or diesel</td>
<td>New vehicle sales</td>
</tr>
<tr>
<td>Sweden</td>
<td>2018</td>
<td>2030[19]</td>
<td>Gasoline or diesel</td>
<td>New vehicle sales</td>
</tr>
</tbody>
</table>

EV MARKET BY DRIVETRAIN TYPE

EV Sales

- 2018 2 Million
- 2025 10 Million
- 2030 28 Million
- 2040 56 Million

Ref: BloombergNEF
EV CROSS OVER INTERNAL COMBUSTION ENGINE

- EV passenger cars expect to surpass ICE by 2037
- EV bus shall crossover even sooner

Ref: BloombergNEF
GENERAL PURPOSE LANE CAPACITY

- Cars:
  - 1,600 people/hour
- Bus:
  - 4,000-8,000 people/hour
- Dedicated right of way for bus:
  - 10,000-25,000 people/hour

Ref: Transitcetner.org 4 Things For Transit Agencies to Remember in a World of Driverless Car Hype
### RIDE SHARING REDUCES PARKING SPACES

#### Exhibit IX: Estimated space that can be saved by adopting rideshare assuming rideshare substitutes for private cars

<table>
<thead>
<tr>
<th>City</th>
<th>Hectares Saved</th>
<th>Landmark Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singapore</td>
<td>872</td>
<td>Sentosa</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>1,264</td>
<td>Victoria Park</td>
</tr>
<tr>
<td>Taipei</td>
<td>1,619</td>
<td>Botanic Gardens</td>
</tr>
<tr>
<td>Kuala Lumpur</td>
<td>9,583</td>
<td>Lake Gardens</td>
</tr>
<tr>
<td>Bangkok</td>
<td>15,556</td>
<td>Lumpini Park</td>
</tr>
<tr>
<td>Jakarta</td>
<td>10,647</td>
<td>Soekarno-Hatta Airport</td>
</tr>
<tr>
<td>Hanoi</td>
<td>339</td>
<td>Old Quarter</td>
</tr>
<tr>
<td>Ho Chi Minh City</td>
<td>366</td>
<td>Zoo¹</td>
</tr>
<tr>
<td>Manila</td>
<td>3,362</td>
<td>EDSA</td>
</tr>
<tr>
<td>Surabaya</td>
<td>545</td>
<td>Tanjung Priok</td>
</tr>
</tbody>
</table>

**Hectares saved with rideshare**

**Landmark equivalent**

1. HCMC Zoo and Garden complex

**Note:** Size of local landmarks vary greatly between cities. Area represents estimated total flat area of all parking lots (existing and needed) to serve a city’s car population. Area estimated by deriving ratio of cars (private + rideshare) to estimated parking lots in Singapore (~2.2) and then extrapolating this ratio to car populations in other markets. Assumes standard parking lot (15m2), Area saved under hypothetical scenario in which rideshare becomes displaces private vehicles in terms of modal split and 50% of rideshare is pooling.

**Source:** ASEAN Maritime Working Group, Data.Gov.Sg, FIFA, MapDevelopers/Google Maps, HDB, HK Census and Statistics Dept., LTA, Manila Times, Perdana Botanical Garden, URA, Thaithnien News, The Straits Times, Taipei Botanical Garden, expert interviews, BCG analysis

Ref: Boston Consulting Group “Unlocking Cities”
SCOPE OF CURRENT TRANSPORT MANAGEMENT FOCUS
PARCEL DELIVERY OUT OF CONTROL

- Store Delivery
- Personal Package
- Take-out Delivery
- Office Document
- House Moving
- On-line Shopping

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SERVICES ENABLED/ENBOLDENED BY 5G

- Bicycle Rental/Sales
- School
- Store
- Coffee House
- Catering
- Insurance
- Post Office

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Transport is not an end in itself, but rather a means allowing people to access what they need: jobs, markets, social interaction, education, and a full range of other services and amenities contributing to healthy and fulfilled lives. The report moves away from a focus on providing mobility based on individual motorized transport and improved traffic speed, to the idea of access through transport, prioritizing people and their quality of life, with strong attention to safety and social equity. The 2030 Agenda for Sustainable Development charts this kind of course. Through sustainable transport, we can make significant progress on the Sustainable Development Goals and the Paris Climate Agreement, improving the lives of billions of people around the world.
TRON-E DISRUPTIVE SOLUTION

- Store Delivery
- Personal Package
- Take-out Delivery
- Office Document
- Jobs
- Social Interaction
- Market
- Food
- School
- House Moving
- On-line Shopping
- Delivery
- Take-out
- Delivery
INTEGRATED TRANSPORT SOLUTION

- Buses must be designed specifically to support Integrated transport solutions
  - People transport
  - Parcel transport
  - Service to home
- Increase bus usage beyond passengers only
- Allow creative applications make possible by 5G and autonomous technology

Make bus operation profitable again!
PUBLIC TRANSPORTATION GOING AUTONOMOUS

Ref: The Conversation driverless-buses-can-help-end-the-suburbs-public-transport-woes-117258
The Mainichi https://mainichi.jp/english/articles/20190627
https://mainichi.jp/english/articles/20190627

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WILL AV SOLVES BUS SUBSIDY ISSUE?

Autonomous public bus helps:
- Defray driver salary
- Enables 24/7 operation

Autonomous bus does not solve:
- Poor ridership at night
- Low spatial coverage

Autonomous shuttle/taxi
AUTONOMOUS – HOW FAR AWAY?

- Autonomous car is:
  - Expensive
  - Trials in many places

- Autonomous bus and cargo van is:
  - Expensive
  - Trials in many places
  - Will happen sooner than you expect

- Government attitude on AV
  - Limited geo fences