Battery Electric Vehicles (BEV)
• brief history
• characteristics

Examples of current projects:
• car of the future/VW Lupo 3L conversion
• Formula Student Electric

Concluding remarks
The electric car has a long history

Around 1900 most cars sold were electric...

Baker Electric Vehicles
The Aristocrats of Motordom

The Baker “Queen Victoria”

Baker Electrics are safest to drive—easiest to control—simplest in construction, and have greater speed and mileage than any other electrics.
The electric car has a long history

First car to exceed 100 km/h… (1899)
The electric car has a long history

In the 1960’s and 1970’s renewed interest

- oil crisis/emission: various prototypes, limited city car production
Developments at the TU/e

Battery electric VW Golf I (1980-1983)

- top speed: 90-110 km/h, range up to 100 km
- vehicle mass: 1400 kg
- lead-acid battery: 15 kWh, 144 V, 450 kg (32% of vehicle mass)
- motor: 32/16 kW (peak/nominal), 160 Nm
- 2+2 seats
Developments at the TU/e

- PhD thesis Van Dongen (1983)
  well-to-wheel efficiency: similar for electric vehicle and ICE…
Developments at the TU/e

- PhD thesis Van Dongen (1983)
  relative battery mass should be high to achieve range!

![Diagram showing relationship between range and relative battery mass](image-url)
Example

vehicle: 1400 kg, batteries (lead-acid): 590 kg (18.7 kWh), 42% of vehicle mass
vehicle: 1319 kg, batteries (NiMH): 481 kg (26.4 kWh), 36% vehicle mass
80% rule of thumb…

- charging/discharging of the battery: 80% efficiency
- DC electricity to wheels: 80% efficiency
- 80% of the nominal battery capacity is used

Drivetrain efficiency:

- ICE tank to wheel: petrol ±18%, diesel ±22%
- BEV plug to wheel: ±64%
What will be the mass/size of the “fuel tank”?

Starting point: energy at the wheels

<table>
<thead>
<tr>
<th>energy carrier</th>
<th>10 kWh at the wheels</th>
<th>energy carrier characteristics</th>
<th>drive train efficiency</th>
<th>required energy</th>
<th>energy carrier mass/kg</th>
<th>energy carrier volume/L</th>
<th>relative to petrol mass</th>
<th>relative to petrol volume</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>utilisation factor</td>
<td></td>
<td>-</td>
<td>kWh</td>
<td>kg</td>
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<td>petrol</td>
<td></td>
<td>12.10 9.12 1.0</td>
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<td>55.6</td>
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<td>6.1</td>
<td>1.00</td>
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<tr>
<td>diesel</td>
<td></td>
<td>11.80 9.97 1.0</td>
<td></td>
<td>0.22</td>
<td>45.5</td>
<td>3.9</td>
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<tr>
<td>battery (lead-acid)</td>
<td>0.030</td>
<td>0.06 0.8</td>
<td>0.80</td>
<td>12.5</td>
<td>520.8</td>
<td>260.4</td>
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<tr>
<td>battery (NiMH)</td>
<td>0.060</td>
<td>0.15 0.8</td>
<td>0.80</td>
<td>12.5</td>
<td>260.4</td>
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<tr>
<td>battery (LiFePO4)</td>
<td>0.100</td>
<td>0.15 0.8</td>
<td>0.80</td>
<td>12.5</td>
<td>156.3</td>
<td>104.2</td>
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<td>17</td>
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<tr>
<td>battery (LiPo/LiCo)</td>
<td>0.135</td>
<td>0.25 0.8</td>
<td>0.80</td>
<td>12.5</td>
<td>115.7</td>
<td>62.5</td>
<td>25</td>
<td>10</td>
</tr>
</tbody>
</table>

using recent battery technology:

- energy storage in batteries is at least **25x** as heavy as petrol
- the accompanying volume is at least **10x** as big
Example

• Tesla Roadster (2008- …)
  vehicle: 1235 kg, batteries (Li-ion): 450 kg (53 kWh), 36% of vehicle mass
  “donor vehicle” Lotus Elise (petrol): 860 kg
the “kWh feeling” for petrolheads

including the efficiency of the drive train:

- with 6.1 L petrol the same is achieved as 12.5 kWh energy in the battery
  roughly: $0.5 \times E_{\text{battery}} [\text{kWh}] = V_{\text{petrol,eq.}} [\text{L}]$

- typically 80% of the nominal battery capacity is used:
  $0.4 \times C_{\text{batt,nom}} [\text{kWh}] = V_{\text{petrol,eq.}} [\text{L}]$

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<tr>
<td></td>
<td>drive train</td>
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</tr>
<tr>
<td>_utilisation</td>
<td>factor</td>
<td>efficiency</td>
<td>energy</td>
</tr>
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<td>0.8</td>
</tr>
<tr>
<td>battery (LiFePO4)</td>
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<td>0.15</td>
<td>0.8</td>
</tr>
<tr>
<td>battery (LiPo/LiCo)</td>
<td>0.135</td>
<td>0.25</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Examples

$0.4 \times C_{batt,\text{nom}} \, [\text{kWh}] = V_{\text{petrol,eq.}} \, [\text{L}]$

Equivalent “fuel tank”:

- 16 kWh = 6.4 L petrol
  
  Mitsubishi i-Miev

- 24 kWh = 9.6 L petrol
  
  Nissan Leaf

- 53 kWh = 21 L petrol
  
  Tesla Roadster
Charging the battery

approximation: $0.5 \times E_{\text{battery}} \text{[kWh]} = V_{\text{petrol,eq.}} \text{[L]}$

overall charging efficiency efficiency about 80%

$0.4 \times P_{\text{charger}} \text{[kW]} = Q_{\text{petrol,eq.}} \text{[L/h]}$

- normal fuel pump: 40 L/minute

- normal socket (Europe: 3.6 kW):
  approx. 1.5 L petrol/hour (1600x slower)

- DC fast charging (50 kW, CHAdeMO):
  approx. 20 L petrol/hour (120x slower)
Advantages of electric cars

heavy vehicle, slow charging, limited range…
…what makes an electric car still interesting?

- the electric car is the most efficient way to get renewable energy to the wheels
- it is ultimate “flexi-fuel” vehicle: it can run on natural gas, coal, hydropower, biomass, nuclear, wind, solar energy
- no emissions locally
- good acceleration properties
- relative simplicity, less maintenance
- more silent in city traffic
- may assist in stabilizing the electricity grid in the future
Project “the Car of the Future” (c,mm,n)

- initiative of the Netherlands Society for Nature and Environment (Stichting Natuur & Milieu)
- environmentally friendly individual transport
- 3 TU project, TU/e: powertrain and chassis
C,MM,N specifications

A usable electric car...

requirements:
• small four seater
• top speed $> 120$ km/h
• acceleration 0 - 100 km/h $< 15$ sec.
• range 200 km
• charging within 8 hours on a normal socket
• mass of the vehicle: $< 1000$ kg

The car of the future will drive!
building a new vehicle from scratch will require a lot of time/costs
start with conversion of an existing vehicle, “learning by doing”
as the project is executed new ideas will develop…
Donor vehicle selection...

<table>
<thead>
<tr>
<th></th>
<th>C,MM,N 2.0</th>
<th>Lupo 3L</th>
</tr>
</thead>
<tbody>
<tr>
<td>dimensions</td>
<td>3750x1650x1450</td>
<td>3529x1621x1455 mm</td>
</tr>
<tr>
<td>wheelbase</td>
<td>2400</td>
<td>2321 mm</td>
</tr>
<tr>
<td>frontal area</td>
<td>2.1</td>
<td>2.0 m²</td>
</tr>
<tr>
<td>drag coefficient</td>
<td>0.23</td>
<td>0.29</td>
</tr>
<tr>
<td>mass without drive train</td>
<td>650 kg</td>
<td>595 kg</td>
</tr>
</tbody>
</table>
Battery capacity?

- normal charging should be done overnight and completed in approximately 8 hours (“while I am sleeping my car is charged”)

- assumption: single phase charging (230 V/16 A)
  - slow charging is more efficient than fast charging
  - existing infrastructure at home can be used, cheap adaptations
  - costs of electricity are ever increasing, energy efficiency is key
  - occasional fast charging for longer trips (extending the range)

- within these limits: go for the maximum battery capacity for usability, flexibility and range. A large battery also has advantages with respect to efficiency/heat development and cycle life/degradation over time

our answer:

  27 kWh, 300 V, 273 kg
  (equivalent to 10.8 L petrol)
Motor/gearbox?

- Adequate performance, **highway compatibility**
  - not too slow, exploit benefits of the electric motor!
  - not too fast, resist building a race car/dragster...

- Keep the weight down and avoid complexity!
  (conventional gearbox/clutch eliminated)
The actual conversion...

front of the car

rear of the car
A battery electric vehicle with interesting specifications is being developed!

<table>
<thead>
<tr>
<th>Model</th>
<th>seats</th>
<th>mass [kg]</th>
<th>top speed [km/h]</th>
<th>acc. 0-100 km/h [s]</th>
<th>battery [kWh]</th>
<th>range [km] @100 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>TU/e Lupo EL</td>
<td>4</td>
<td>1030</td>
<td>130</td>
<td>12</td>
<td>27</td>
<td>170</td>
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<tr>
<td>Think City</td>
<td>2+2</td>
<td>1040</td>
<td>100</td>
<td>25</td>
<td>22-28</td>
<td>120-140</td>
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<tr>
<td>i-Miev</td>
<td>4</td>
<td>1080</td>
<td>130</td>
<td>14</td>
<td>16</td>
<td>105</td>
</tr>
<tr>
<td>Tesla</td>
<td>2</td>
<td>1235</td>
<td>200</td>
<td>4</td>
<td>53</td>
<td>280-350</td>
</tr>
<tr>
<td>EV-1 (NiMH)</td>
<td>2</td>
<td>1320</td>
<td>130</td>
<td>9</td>
<td>26.4</td>
<td>220</td>
</tr>
<tr>
<td>Mini-E</td>
<td>2</td>
<td>1465</td>
<td>152</td>
<td>8.5</td>
<td>35</td>
<td>175</td>
</tr>
<tr>
<td>Nissan Leaf</td>
<td>4/5</td>
<td>1525</td>
<td>144</td>
<td>12</td>
<td>24</td>
<td>125</td>
</tr>
<tr>
<td>RAV-4 (NiMH)</td>
<td>4/5</td>
<td>1580</td>
<td>125</td>
<td>18</td>
<td>27.4</td>
<td>130</td>
</tr>
</tbody>
</table>
Do you have it running already?

- mechanical conversion finished
- electrical systems nearly completed
- software/control system under development
Formula Student Electric

Formula Student:
• competition between universities
• design, built and race your own single seater racing car

Formula Student Electric started in 2010

rules:
• motor power: 75 kW maximum
• battery capacity: 7.25 kWh maximum
• voltage: 400 V maximum
• many safety regulations…
University Racing Eindhoven (URE)

- existing chassis converted to all electric: URE05e
- torque vectoring:
  two motors to drive each rear wheel independently
- compact battery box replacing the engine
- performance:
  75 m sprint in 4.2 sec.
  top speed: > 100 km/h
- vehicle weight: 268 kg
  (ICE: 231 kg)
Results 2010

winner Audi design contest, best formula student electric design
UK Silverstone, class 1A: 3rd
Germany Hockenheim, FS electric: 2nd
Austria Wachauiring: 1st electric car (4th overall, 30 cars)

photo: FSG2010, Almonat
Other activities

HTAS projects:
• lightweight suspension + in-wheel motors
• range extenders
• power train control
• hybrid truck with in-wheel motors
• …

Various departments are involved:
• mechanical engineering (powertrain, vehicle dynamics,…)
• electrical engineering (power electronics, grid management,…)
• chemical engineering (battery testing, modelling, development)
• computer science (vehicle software)
Final note

recent news in some Dutch newspapers: in China EVs exist that can drive 800 km due to “miracle” batteries...

...ultimately the EV industry will be better of by making realistic claims on the performance of their vehicles!
Dr.Ir. Igo Besselink

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