Can in-wheel powertrains reduce the costs of EVs?
ELECTRIC IN-WHEEL MOTOR POWERTRAIN PLATFORM

Elaphe Propulsion Technologies Ltd.
Benefits

- **Light weight:** Global leaders in specific torque with the lightest electromagnetic design for high-performance direct-drive (up to 100 Nm/kg)
- **Smarter packaging:** compact ring-shaped electromagnetic design (up to 460 Nm/liter) with less complexity
- **Modular & simple integration:** unified, modular platforms reducing vehicle manufacturing and R&D costs.
- **Direct drive:** no mechanical transmissions, less weight. Key benefits for optimizing precision and responsiveness

- Highest in-wheel performance on the market
- Manufacturing oriented design, short time-to-market
- A plug & play modular powertrain platform
- Use of standard rims, brakes and bearings
## Applications

<table>
<thead>
<tr>
<th><strong>SCALABLE</strong></th>
<th>Across size, weight, performance and function, Light EVs and motorcycles to alpine snow rescue vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VERSATILE</strong></td>
<td>From small city EVs, to performance cars, from delivery vehicles to people movers and large public transportation</td>
</tr>
<tr>
<td><strong>SW DRIVEN</strong></td>
<td>New business models, unlocking potential through advanced functions</td>
</tr>
<tr>
<td><strong>INTERCHANGEABLE</strong></td>
<td>New feature, new user value. Upgradable and interchangeable.</td>
</tr>
<tr>
<td><strong>CUSTOMIZABLE</strong></td>
<td>Technology concept designed for maximal flexibility of servicing and mechanical interfaces</td>
</tr>
<tr>
<td><strong>ENABLING TECHNOLOGY</strong></td>
<td>A solution that simplifies and enables new forms of mobility and new types of vehicles.</td>
</tr>
</tbody>
</table>

Industry went from **Automotive** ➔ **Mobility**. Elaphe enables **all** with solutions.
Components

- Custom development based on requirements
- Industrialized products off-the-shelf

Direct drive motors
- High-torque
- Standard brake integration possible
- Low voltage or high voltage
- Scalable

Power electronics
- Up to 200 kVA (high-performance)
- SW optimized for direct-drive

Multiple-Motor Control / ECU
- Traction control
- Torque vectoring
- Battery power control
- Condition monitoring
- Connected = DATA
- Autonomous-ready

HMI / Infotainment interface
- Driving mode selection
- User interface
- Propulsion control settings
Versatile in-wheel motor design

- Different applications of same product
- Scalable motor design
- Experience with wide variety of motor design (water/air cooling, integrated/on-board inverter, slim/standard bearing, in-wheel/near-wheel motor), etc.
State-of-the-art development with embedded innovations

- Based on cutting-edge in-wheel technology R&D projects
- Delivering the most performant motors in various vehicle segments
- Elaphe™ M700 in advanced stage of industrialization, L-type and S-type in design validation

<table>
<thead>
<tr>
<th>Elaphe™ S-type</th>
<th>Elaphe™ M-type</th>
<th>Elaphe™ L-type</th>
</tr>
</thead>
<tbody>
<tr>
<td>460 Nm peak torque</td>
<td>800 Nm peak torque</td>
<td>1500 Nm peak torque</td>
</tr>
<tr>
<td>Fits inside 14” rim</td>
<td>Fits inside 16” rim</td>
<td>Fits inside 19” rim</td>
</tr>
<tr>
<td>Low voltage (120 V)</td>
<td>Voltages up to 420 V</td>
<td>Voltages up to 420 V</td>
</tr>
<tr>
<td>7” Drum brake</td>
<td>Disc and 9” drum brake versions ready</td>
<td>Disc brake</td>
</tr>
<tr>
<td>Speed up to 1440 rpm</td>
<td>Speed up to 1500 rpm</td>
<td>Speed up to 1260+ rpm</td>
</tr>
</tbody>
</table>
Electronics

Condition monitoring & logging
Torque distribution
Wireless human-machine interface
Intelligent PCU
Elaphe Connected Car module

Multiple Motor Control Unit

THE POWERBRAIN MULTIPLE-MOTOR PROPULSION CONTROL

- Traction Control
- Torque vectoring
- Anti-lock regenerative braking system (ARBS)
- Configurable motor control
- Complete propulsion APIs

- Connected & Safely integrated
- Battery power control
- Condition monitoring
- Data logging & Drive analytics
- Various driving modes

Elaphe Propulsion Technologies Ltd.
©2019 ELAPHE Ltd. - All Rights Reserved.
From concept to mass production

Proprietary tool development, product development with state of the art CAE

Standards, requirements, validation plan, validation procedures, execution and analysis

Powertrain control unit, system engineering, vehicle level advanced functions

Production processes, machines and line
COST OF POWERTRAIN COMPONENTS

In-wheel
2x e-motor
2x inverter

Near-wheel
2x e-motor
2x inverter
2x reduction gear

E-axle platform
1x e-motor
1x inverter
1x reduction gear
Cons and pros – is there a need?

**Higher powertrain BOM cost**

- Durability
- Unsprung mass
- Front trunk possible
- No gearbox
- No half-shafts
- Advanced maneuvering capabilities
- SW upgradeable advanced functions add-ons

**Vehicle energy consumption**

- Powerful regenerative braking
- Short supply chain
- Integrated corner possible
- No mechanical losses
- Leader in space of the given segment
- Direct drive – superior grip control, unbeatable safety pro

**Weight reduction**

- Integrated cabin or battery space
- Shorter assembly lines

**Packaging**

- Other
In-wheel powertrain mass benefit

COST CASE:
Used average for large reductions: 10 EUR/kg
Used increased efficiency from less weight: 2-3% (assume 2%)

Total mass saving (single iteration):
• 150 kg powertrain weight reduction @ 2500 kg GVW: -1500 EUR
• Reduced battery cost @ 100kWh range: (-2kWh) -185 EUR
• Additional reduced vehicle weight from reduced battery size - additional 10-14 kg -120 EUR

• TOTAL saving: at least: -1805 EUR

E-axle:
Study with two OEM customers for an 4WD SUV shows:

4WD conventional powertrain = 312 kg
weight status BEV

• Current weight for power unit incl. side shafts and mounts:
  - e-motor/gearbox/inverter front: 130 kg
  - side shaft front: 16 kg
  - mounts/brackets for e-power unit front: 12 kg
  - e-motor/gearbox/inverter rear: 130 kg
  - side shaft rear: 16 kg
  - mounts/brackets for e-power unit rear: 8 kg
  - total: 312 kg

In-wheel motor powertrain:
Study with two OEM customers for an 4WD SUV shows:

4WD in-wheel powertrain = 150 – 160 kg

Weight status BEV
• Current weight for power unit
  - Front motors and inverters: 76 kg
  - Rear motors and inverters: 76 kg
  - Total: 152 kg
Packaging – parts (in-wheel)

COST CASE:
- On-board volume cost: 0.7 EUR/liter
- E-axle volume: 300 liter/axle x 2 axles
- IWM volume: 15 liter/axle x 2 axles

SAVING
- Volume cost (body + chassis): -400 EUR
- Reduced weight @10 EUR/kg: -1000 EUR
- Reduced battery cost @100 kWh range: -1 kWh
- Battery pack cost 111 USD/kWh: -93 EUR
- Battery weight: 5-7 kg/kWh (assume 5 kg/kWh): -5 kg
- Used average for large reductions: 10 EUR/kg: -50 EUR

TOTAL saving: at least: -1543 EUR

Continental

Continental study of space-saving technologies (small crash zones, in-wheel motors…) showed that an interior size of VW Golf can be achieved in the outer dimension of VW Up. So the difference is two classes of vehicle types. (Golf – Polo – Up).

Elaphe propulsion mule car conversion: Removed 565 kg of original drivetrain
Cycle Energy efficiency (not including weight benefits)

**COST CASE:**
- >2% better IWM overall efficiency
- Reduced battery cost @100kWh range:
  - Battery pack cost 111 USD/kWh
  - Battery weight: 5-7 kg/kWh (assume 5 kg/kWh)
- Used average for large reductions: 10 EUR/kg

**SAVING**
- 2 kWh
- 185 EUR
- 10 kg
- 100 EUR

**TOTAL saving:** at least: 285 EUR

**E-axle losses:**
- 1-5% inverter minimal losses
- 4-10% electric motor minimal losses
- 2-8% transmission minimal losses
- TOTAL: 78 – 93% e-axle efficiency @ OPTIMAL PEAK

**IWM losses:**
- 1-5% inverter minimal losses
- 6-9% motor minimal losses (inc. seal friction)
- 0% transmission losses
- TOTAL: 86 – 93% IWM axle efficiency @ OPTIMAL PEAK

Up to 8% better peak efficiency of IWM axle vs. e-axle!

Study with two OEM customers for an 4WD SUV shows:
- **E-axle:** 4WD conventional powertrain efficiency = 83%@WLTP
- **IWM:** 4WD IWM powertrain efficiency = 85%@WLTP

**Simulated EV Power Consumption**

Source: Drive System Design Ltd. (drivesystemdesign.com)

---

Elaphe Propulsion Technologies Ltd.
©2019 ELAPHE Ltd. - All Rights Reserved.
Other financial and cost benefits

- Torque vectoring, lower center of gravity and other performance and safety improvement benefits
- Vehicle development cost reduction
- Strong regenerative braking
- Ground clearance increase
- Advanced steering and redundancy
- Modularity of IWM platform
- Chassis simplification
- Powertrain modularity
- Shorter vehicle assembly line
- Lower investment into production line
- Supply chain savings

**TOTAL saving: 1500 EUR**
How to combine this data, know-how?

GOALS and ASSUMPTIONS

• Qualitative -> Quantitative
• Rough estimations
• Combination of drawbacks and benefits
• Averages for the early majority
• Time: State of the Art -> implemented in the future
The mathematical model

**INPUT**

- Cost
- OEM need
- Mass
- Space
- Efficiency
- Other
- @ different Vehicle types
- & changing with time (years)

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CostDiff</td>
<td>Need</td>
<td>Mass</td>
<td>Space</td>
<td>Energy</td>
<td>Other</td>
</tr>
<tr>
<td>1</td>
<td>2010,0</td>
<td>-20,00</td>
<td>-10,00</td>
<td>1,6</td>
<td>1,5</td>
<td>0,3</td>
</tr>
<tr>
<td>2</td>
<td>2015,0</td>
<td>-10,00</td>
<td>-5,00</td>
<td>0,00</td>
<td>0,00</td>
<td>0,10</td>
</tr>
<tr>
<td>3</td>
<td>2018,0</td>
<td>-5,00</td>
<td>-4,00</td>
<td>0,10</td>
<td>0,00</td>
<td>0,20</td>
</tr>
<tr>
<td>4</td>
<td>2019,0</td>
<td>-3,00</td>
<td>-2,00</td>
<td>0,15</td>
<td>0,00</td>
<td>0,30</td>
</tr>
<tr>
<td>5</td>
<td>2020,0</td>
<td>-2,00</td>
<td>-2,00</td>
<td>0,20</td>
<td>0,10</td>
<td>0,40</td>
</tr>
<tr>
<td>6</td>
<td>2021,0</td>
<td>-1,50</td>
<td>-1,00</td>
<td>0,25</td>
<td>0,15</td>
<td>0,50</td>
</tr>
<tr>
<td>7</td>
<td>2022,0</td>
<td>-1,20</td>
<td>-1,00</td>
<td>0,30</td>
<td>0,20</td>
<td>0,60</td>
</tr>
<tr>
<td>8</td>
<td>2023,0</td>
<td>-1,00</td>
<td>-1,00</td>
<td>0,35</td>
<td>0,25</td>
<td>0,65</td>
</tr>
<tr>
<td>9</td>
<td>2024,0</td>
<td>-1,00</td>
<td>-0,50</td>
<td>0,40</td>
<td>0,30</td>
<td>0,70</td>
</tr>
<tr>
<td>10</td>
<td>2025,0</td>
<td>-1,00</td>
<td>-0,50</td>
<td>0,45</td>
<td>0,35</td>
<td>0,75</td>
</tr>
<tr>
<td>11</td>
<td>2030,0</td>
<td>-1,00</td>
<td>0,00</td>
<td>0,60</td>
<td>0,40</td>
<td>0,85</td>
</tr>
<tr>
<td>12</td>
<td>2035,0</td>
<td>-1,00</td>
<td>0,00</td>
<td>0,70</td>
<td>0,45</td>
<td>0,90</td>
</tr>
<tr>
<td>13</td>
<td>2040,0</td>
<td>-1,00</td>
<td>0,05</td>
<td>0,80</td>
<td>0,60</td>
<td>0,95</td>
</tr>
<tr>
<td>14</td>
<td>2045,0</td>
<td>-1,00</td>
<td>0,10</td>
<td>0,90</td>
<td>0,70</td>
<td>1,00</td>
</tr>
<tr>
<td>15</td>
<td>2050,0</td>
<td>-1,00</td>
<td>0,10</td>
<td>1,00</td>
<td>0,80</td>
<td>1,00</td>
</tr>
</tbody>
</table>
IN-WHEEL MOTOR BASED PLATFORM

Prepare for uncertainty
Leverage partnerships
Drive transformational change
Redefine the value proposition

Thank you!

CONTACT
Gorazd Lampic, CEO
gorazd@elaphe-ev.com