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# Electric and Electronic Systems for Traction

**Umidov Lazizkhon**
Department of Mechanical and Aerospace Engineering, Turin Polytechnic University in Tashkent,17, Little Ring Road street, Tashkent, Uzbekistan
lazizkhon.umidov@polito.uz

**Annotation**
The transition from conventional internal combustion engine (ICE) vehicles to electric and hybrid alternatives is a pivotal step toward achieving global sustainability and reducing vehicular emissions. This document explores the motivations, technical foundations, and challenges associated with electric powertrains. It delves into the roles of electric machines (EM), battery storage technologies, and various hybrid architectures, such as series and parallel configurations, including plug-in hybrid electric vehicles (PHEVs). While electric motors provide high efficiency, zero local emissions, and favorable torque characteristics for traction, battery limitations—especially in terms of energy density, cost, and charging time—remain significant barriers to widespread adoption. Hybrid configurations aim to balance the strengths of electric and ICE systems to improve performance and fuel economy. The study concludes by assessing the current viability of electric powertrains and the areas requiring further research and development.

**Keywords:** Technology Integration, Science Subjects, Student Learning Outcomes.



## Introduction

The increasing environmental impact of transportation, particularly due to greenhouse gas emissions and urban air pollution, has spurred global interest in alternative propulsion technologies. Electric and hybrid vehicles are central to this shift, offering pathways to reduce dependency on fossil fuels and to meet stringent emission regulations.

Electric powertrains, which utilize electric machines for propulsion, present numerous advantages over traditional ICE-based systems. They offer high efficiency, excellent controllability, and the potential for zero local emissions. Furthermore, the incorporation of regenerative braking allows for partial energy recovery during vehicle deceleration, further improving overall energy efficiency.

Despite these advantages, electric vehicles (EVs) face significant challenges—most notably related to energy storage. Current battery technologies, though improving, exhibit lower energy densities compared to liquid fuels and involve higher costs and longer recharging times. These limitations have led to the development of hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs), which combine the benefits of electric propulsion with the extended range and fast refueling capability of ICEs.

This document systematically explores the components, configurations, and performance metrics of electric and hybrid powertrains, highlighting their advantages, limitations, and the ongoing research efforts required to enable their broader adoption.

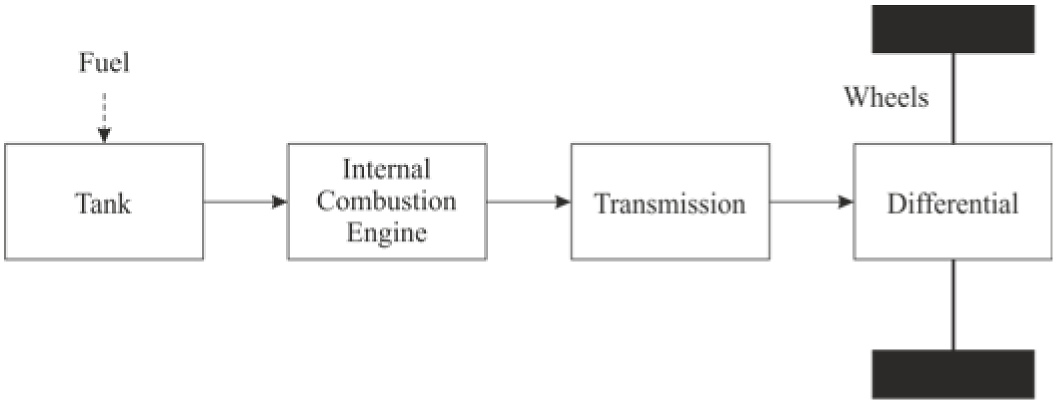
## Electric Powertrains

### Motivations for Electrification

- Development of **Zero Emission Vehicles (ZEVs)** to address environmental concerns.
- Electric motors provide **high efficiency** and **excellent performance** for traction applications.
- Capability of **regenerative braking**, improving energy efficiency.
- Despite these advantages, several **technical challenges** remain, primarily related to **energy storage (batteries)**, driving continued research.

### Conventional ICE-Based Vehicles

- The **Internal Combustion Engine (ICE)** generates mechanical power, a portion of which is converted into electric power by an **alternator**.




- Electric power is used to:
- ✓ Supply vehicle **E/E (electrical and electronic) systems**
- ✓ Power the **starter motor** during cranking
- **Electric power is not used for propulsion**.

### Pure Electric Vehicle (EV)

- **Only electric power is used for traction.**
- **Electric energy from the grid** is stored in a **battery**.
- An **Electric Machine (EM)** converts this energy into **mechanical power**.
- The EM can operate bidirectionally:
- ✓ **Motor mode**: for traction
- ✓ **Generator mode**: for regenerative braking
- A **power converter** manages the energy flow between battery and motor.

**Advantages of Electric Machines (EMs) in EVs**

- **Zero tailpipe emissions**
- **High efficiency** (>90%)
- **Excellent torque-speed characteristics**
- ✓ Eliminate the need for complex multi-speed transmissions
- **High torque at standstill**
- ✓ No need for a separate starter motor or idle operation
- **Bidirectional power flow**
- ✓ Enables **regenerative braking**

**Limitations: Battery Technology**

- EV range is limited by **battery capacity**.
- Batteries have **much lower energy density** than fossil fuels (≈10× lower).
- **Li-Ion batteries**, although dominant, are:
- ✓ **Expensive**
- ✓ **Heavy and bulky**
- ✓ **Slow to recharge** compared to fuel refilling

**Battery Requirements – Driving Range Calculation**

Assuming:

- Constant vehicle speed v
- Constant tractive power P
- Battery efficiency η
- Maximum energy stored in battery Emax

**Battery Discharge Time:**

$$t = \frac{\eta E_{\max}}{P}$$

**Driving Range:**

$$d = v \cdot t = \frac{\eta E_{\max}}{P}$$

**Battery Storage Required for a Target Range d∗d^*d∗:**

$$E_{\max} = \frac{P \cdot d^*}{\eta v}$$

**Example Calculations (for η=0.9\eta = 0.9η=0.9):**

| Scenario | Speed | Tractive Power | Target Range | Required Battery Energy |
|---|---|---|---|---|
| Urban Drive | 50 km/h | 5 kW | 100 km | ~11 kWh |
| Highway | 130 km/h | 35 kW | 100 km | ~30 kWh |

**Battery Performance Parameters**

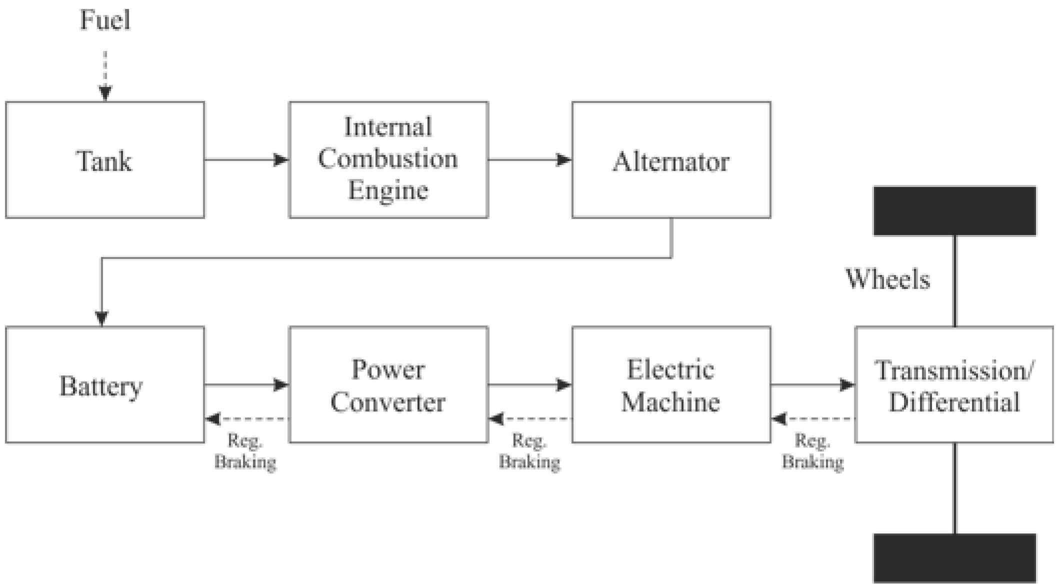
| Parameter | Lead-Acid | Li-Ion |
|---|---|---|
| Specific Energy (Wh/kg) | 35 | 200 |
| Energy Density (Wh/l) | 70 | 200 |
| Specific Power (W/kg) | 70 | 500 |
| Cost (2020, $/Wh) | N/A | 0.2 |

**Example Battery Sizing and Cost:**

| Energy (kWh) | Li-Ion Mass | Lead-Acid Mass | Li-Ion Vol | Lead-Acid Vol | Li-Ion Cost |
|---|---|---|---|---|---|
| 11 | 55 kg | 314 kg | 55 l | 157 l | $2200 |
| 30 | 150 kg | 857 kg | 136 l | 428 l | $6000 |

**Hybrid Electric Vehicles (HEV)**

- ➢ Combine ICE and EM to leverage benefits of both:
- ✓ Reduced fuel consumption
- ✓ Lower emissions
- ✓ Increased flexibility




**Hybridization Levels:**

- ➢ **Full Hybrid**: EM and ICE of similar power
- ➢ **Mild Hybrid**: EM < 50% of ICE power
- ➢ **Micro Hybrid**: EM < 10% of ICE power

### HEV Architectures

#### Series HEV

- Only EM provides traction
- ICE drives an **alternator**, which:
- ✓ Supplies energy to the **battery**
- ✓ Acts as a **range extender**
- Operates like a full EV in terms of traction

#### Parallel HEV

- ICE and EM are **mechanically coupled** to the drivetrain
- Both contribute to propulsion
- EM can recover energy (regenerative braking)
- Coupling methods:
- ✓ **Conventional Gear** (constant speed ratio)
- ✓ **Epicyclic Gear** (constant torque ratio)

#### Plug-in Hybrid Electric Vehicles (PHEV)

- Similar to HEV but with:
- ✓ **Larger battery**
- ✓ **Plug-in charging** from the grid
- ✓ **Extended electric-only driving range**
- Often series-type architecture

### Conclusion

- **Electric powertrains** offer a compelling solution to reduce environmental impact.
- **Electric Machines** are highly suitable for traction due to their superior performance and efficiency.
- **Battery technology** remains the main bottleneck and is under active development.
- **EVs** are currently ideal for specific applications (e.g., urban transport), but limitations remain for broader use.
- **HEVs and PHEVs** serve as transitional technologies, combining benefits of electric and conventional propulsion systems.

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