

Electric Vehicle Introduction

EVs and HEVs

Diagnostics of Electric and Hybrid Vehicles · Topic 1

BSc (1st cycle) in Sustainable Transportation · Year 4, Semester 7 · 6 ECTS

Sustainable Transportation within the Framework of Green Deal - SPHERE

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ORIENTATION

Course context & learning objectives

The nine lecture topics

1 · EV & HEV introduction (today)

2 · Safety rules & high-voltage precautions

3 · Tools, equipment & on-board diagnostics

4 · Mechanical systems: ICE & transmissions

5 · Braking & climate system diagnostics

6 · Vehicle electrical systems

7 · Electric drives, DC–DC converters, inverters

8 · Traction batteries & BMS

9 · ADAS diagnostics & calibration

By the end of Topic 1 you will be able to:

- ▶ Distinguish ICEV, BEV, HEV, PHEV and FCEV by energy source and power path
- ▶ Describe the primary EV/HEV powertrain components and how energy flows between them
- ▶ Compare electric-motor and IC-engine torque/power characteristics from an engineering view
- ▶ Classify hybrid architectures — series, parallel, series–parallel and P0–P4
- ▶ Explain degree of hybridization (micro / mild / full) and charge-sustaining vs depleting
- ▶ Use well-to-wheel reasoning to compare EV, HEV and ICEV efficiency
- ▶ Identify the new fault domains that make EV/HEV diagnostics distinct

AGENDA

What we will cover today

1

Drivers & definitions

Why electrify; ICEV vs BEV/HEV/PHEV/FCEV terminology

2

A short history

From 1830s experiments to today's mass market

3

Engineering fundamentals

Energy conversion, powertrain, motor vs engine characteristics

4

EV architecture

BEV system, transmission paths, powertrain configurations

5

HEV architecture

Series, parallel, power-split, degree of hybridization, P0–P4

6

System comparison

Well-to-wheel efficiency, EV vs ICEV, energy storage

7

Why it matters for diagnostics

New fault domains and the bridge to the rest of the course

The thread running through it all

ENERGY SOURCE Fuel · battery · H₂



CONVERSION Engine · motor · fuel cell



POWER PATH Mechanical and/or electrical



WHEELS Tractive effort

MOTIVATION

Why electrify road transport?



Emissions & air quality

Road transport is a major source of CO₂ and urban NO_x / particulates. A BEV emits roughly one-half to one-third of the well-to-wheel CO₂ of a comparable petrol car.



Energy efficiency

Electric powertrains reach ~75–90% tank-to-wheel efficiency; a gasoline ICE powertrain can be as low as ~15–25%.



Energy security

Electricity can be generated from diverse and renewable domestic sources, reducing dependence on imported oil.



Regulation & incentives

ZEV mandates, fleet CO₂ limits (notably in the EU) and purchase incentives are dominant market drivers — often more than technology alone.

VOCABULARY

The vehicle families — precise definitions

ICEV

Internal-combustion-engine vehicle

Propulsion solely from an IC engine burning liquid fuel. Our baseline for comparison.

BEV

Battery electric vehicle

Tractive effort solely from one or more electric machines, fed by an on-board battery. No engine.

HEV

Hybrid electric vehicle

Two power sources — an IC engine and one or more electric machines. Never plugged in (charge-sustaining).

PHEV

Plug-in hybrid EV

An HEV with a larger battery chargeable from the grid; runs electric-only for a useful range, then as an HEV.

FCEV

Fuel-cell electric vehicle

An EV whose on-board energy comes from a hydrogen fuel cell that generates electricity for the motor.

HISTORY · 1

The first electric age (1830s – 1912)

1831

Faraday's law of induction → DC motor

1859

Lead–acid storage battery (Planté)

1897

Krieger EV: 24 km/h, ~80 km range

1900

US car sales:
40% steam · 38% electric · 22% petrol

1912

34,000 EVs — outnumber petrol cars 2 : 1

At its peak the electric car was the premium, refined choice — quiet, clean and easy to drive.

Why it then collapsed in the 1920s:

- ▶ **Electric starter (1911)** the petrol car no longer needed hand-cranking — its biggest drawback vanished
- ▶ **Mass production** Ford's Model T fell to ~\$260 by 1925 vs ~\$850 for an EV — petrol became far cheaper
- ▶ **Infrastructure** rural areas had petrol but little electricity to recharge batteries
- ▶ **Energy density** liquid fuel stored far more energy per kg than lead–acid cells — longer range, fast refuelling

HISTORY · 2

Decline, revival and the modern era

1920s–50s

Eclipse

EVs disappear from the mass market; the IC engine dominates road transport for half a century.

1960s

First stirrings

Smog concerns prompt GM's Electrovan (induction motor, SCR inverter) and Ford research.

1970s

Oil shock

The 1973 oil embargo revives interest; the US 1976 EV R&D Act funds development.

1990s

ZEV mandate

Power electronics + microprocessors mature; California's ZEV rules force EV programmes (e.g. GM EV1).

2000s

Hybrids arrive

Mass-market HEVs make the electric powertrain commercially normal.

2010s →

BEV scale-up

Li-ion + fast charging + CO₂ regulation drive rapid global BEV growth.

MARKET

Where the market stands

2 M+

global EV sales per year (from 2018),
growing ~60% year on year

China

the largest market — driven by
incentives and micro-EVs

EU

strict fleet CO₂ limits push PHEVs and
48 V mild hybrids

US

regulation (ZEV/CARB) is the primary
motivator

Adoption is shaped by four forces — not technology alone

- ▶ **Technology** range, charging speed and cost determine which segments are viable
- ▶ **Regulation** emission limits and ZEV mandates open or force the market
- ▶ **Incentives** purchase subsidies and tax breaks drive early uptake
- ▶ **Regional need** dense cities, grid availability and local industry shape the mix

FUNDAMENTALS

Energy conversion and the powertrain

Three primary energy-conversion devices



IC engine

Heat engine: chemical → mechanical energy



Electric machine

Bidirectional: electrical ↔ mechanical (motor / generator)



Fuel cell

Electrochemical: chemical → electrical energy

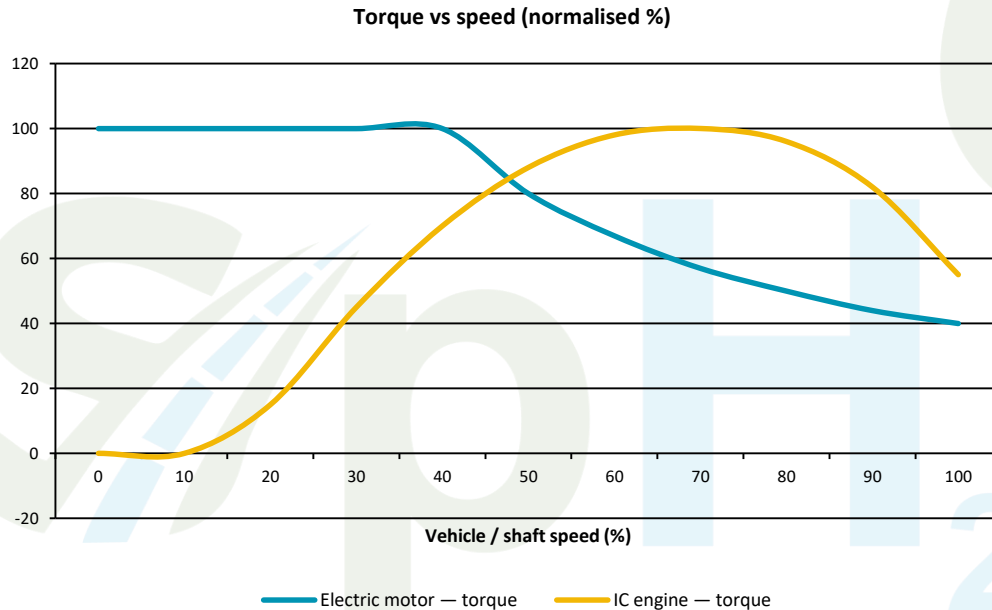
The **powertrain** is the path of energy from source to wheels. In EVs/HEVs it can be **bidirectional** — regenerative braking returns energy to storage.

Devices that make them work

- ▶ **Energy storage** high-capacity battery pack (also ultracapacitor / flywheel in research)
- ▶ **Electric drive** power electronics + controller; converts fixed DC to variable-voltage, variable-frequency supply
- ▶ **DC–DC converter** links voltage levels (HV bus ↔ 12 V), bidirectional; key to the fuel-cell interface
- ▶ **Transmission & coupling** gears match machine speed to wheel speed (or hub motors, direct)
- ▶ **Supervisory controller (VSC)** the 'brain' coordinating every ECU over the CAN bus

ENGINEERING CORE

Electric motor vs IC engine characteristics



Why this matters

- ▶ **Motor** full torque from zero speed — strong launch, no clutch needed
- ▶ **Motor** constant power over a wide range → a single fixed gear (≈10–15:1) suffices
- ▶ **Engine** no useful torque below idle; needs a multi-ratio gearbox to stay in its band
- ▶ **Motor** can briefly deliver 2–3× rated torque for acceleration
- ▶ **Motor** higher power & torque density; speeds up to ~15,000 rpm

ARCHITECTURE

Primary EV / HEV components



Energy storage

Battery pack (Li-ion); buffers and supplies electrical energy



Electric machine

Traction motor / generator; provides and recovers torque



Power electronics

Inverter & motor-drive; DC $\leftrightarrow$ variable AC for the machine



DC-DC converter

Links HV bus to 12 V loads; bidirectional voltage matching



IC engine (HEV)

Downsized heat engine; drives wheels and/or a generator



Transmission

Fixed gear / coupling matching machine speed to wheels



Charger

Restores battery charge from the grid (BEV / PHEV)



Supervisory ctrl

VSC coordinates all ECUs over the CAN network

ENERGY FLOW

Two power-transmission paths

Mechanical path (MPTP) — conventional ICEV



Energy flows one way only.

Electrical path (EPTP) — battery EV

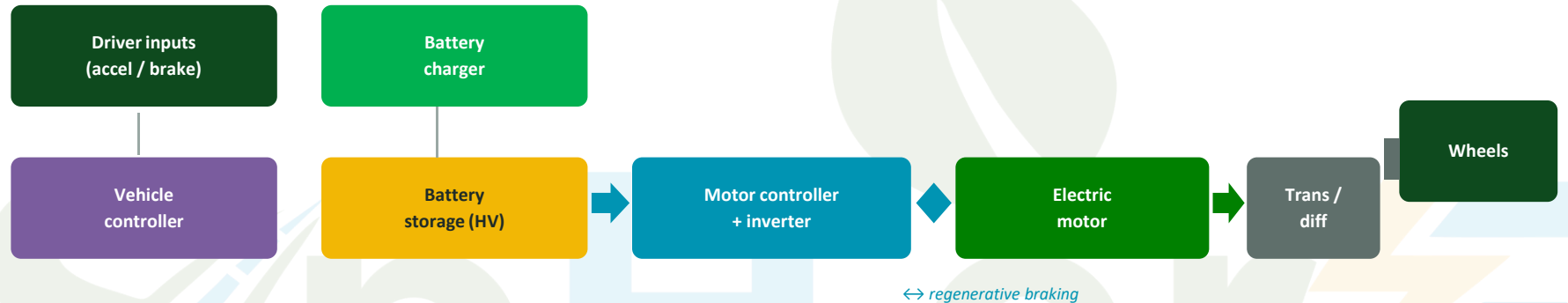


Energy flow is **bidirectional** — the machine recovers kinetic energy under braking (regeneration).

HEVs contain **both paths**. How the mechanical and electrical paths are arranged — series, parallel or combined — defines the hybrid architecture, the subject of the next slides.

BEV

Battery-electric vehicle: system architecture



Reading the diagram

- ▶ **Four primary components** HV battery, motor controller/inverter, electric motor, single-speed transmission
- ▶ **The inverter link is bidirectional** powers the motor when driving, rectifies generated current when regenerating
- ▶ The vehicle controller interprets pedal demand; the charger restores pack energy from the grid

BEV LAYOUTS

BEV powertrain configurations

Converted

Motor + battery dropped into an existing ICE platform; transmission and differential kept. Simple but heavy, with performance and packaging penalties.

Dedicated

Body and chassis purpose-designed for a BEV. Greater freedom in motor count and placement; lighter, better packaging, easy AWD.

Motor placement & drive options



Out-wheel, single

Motor + fixed gear + differential on one axle (RWD or FWD)



Dual out-wheel

Two motors, no differential — independent wheel-torque control, better stability



In-wheel (hub)

Motor inside each wheel — no driveshaft/differential; high unsprung mass

MACHINES

Traction electric machines

Machine type	Strengths	Watch-outs
DC (brushed) — legacy	Simple control	Brush wear; low power density
Induction (IM)	Rugged, magnet-free, low cost	Size/weight penalty at high speed
PM synchronous (PMSM)	High efficiency & power density	Cost & supply of rare-earth magnets
Switched reluctance (SRM)	Robust, potentially low cost	Acoustic noise; torque ripple

What a traction motor must offer

- ▶ High starting torque & torque-to-inertia ratio
- ▶ Peak $\approx$ 200–300% of continuous rating
- ▶ High power-to-weight density
- ▶ Wide constant-power speed range
- ▶ High efficiency over the drive cycle
- ▶ Tolerance of a varying DC-bus voltage
- ▶ Low noise, low EMI, fault tolerance

HEV

Hybrids: three ways to classify

A hybrid blends an IC engine with one or more electric machines. We classify hybrids along three independent axes:

By architecture

How the power paths are arranged

Series • Parallel • Series-parallel (power-split)

By degree of hybridization

How much the engine is downsized / electrified

Micro • Mild • Full

By charging mode

Whether the pack is charged externally

Charge-sustaining (HEV) • Charge-depleting (PHEV / BEV)

ARCHITECTURE · SERIES

Series hybrid

The engine never drives the wheels — it only generates electricity. All tractive effort is electric.



Advantages

- ▶ Engine runs at its best-efficiency point, decoupled from road speed
- ▶ Mechanically simple drivetrain; flexible engine-generator placement
- ▶ Well suited to stop-go and urban duty cycles

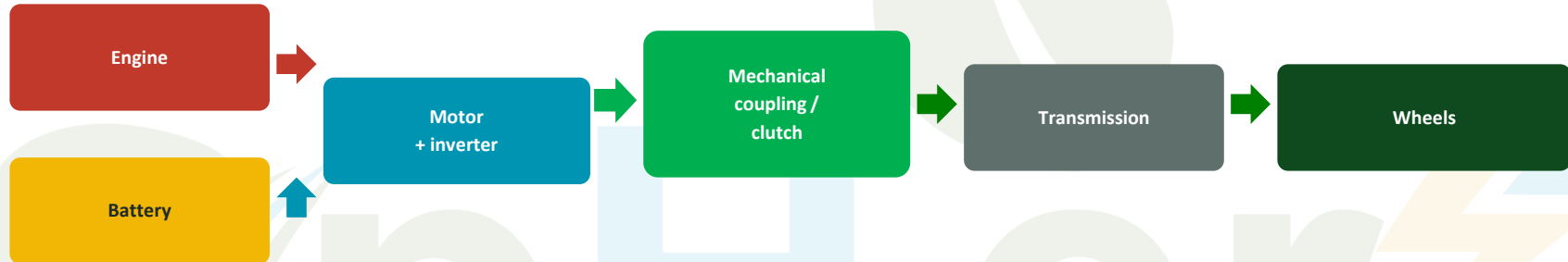
Disadvantages

- ▶ Needs three machines: engine, generator and traction motor
- ▶ Motor must be sized for full sustained power (e.g. long climbs)
- ▶ Double conversion (mech→elec→mech) adds losses at speed

ARCHITECTURE · PARALLEL

Parallel hybrid

Both the engine and the motor can drive the wheels; their torques are blended through a mechanical coupling.



Advantages

- ▶ Engine drives wheels directly — efficient at cruise; one electric machine
- ▶ Smaller motor than series (engine shares the load)
- ▶ Performance can match a conventional car

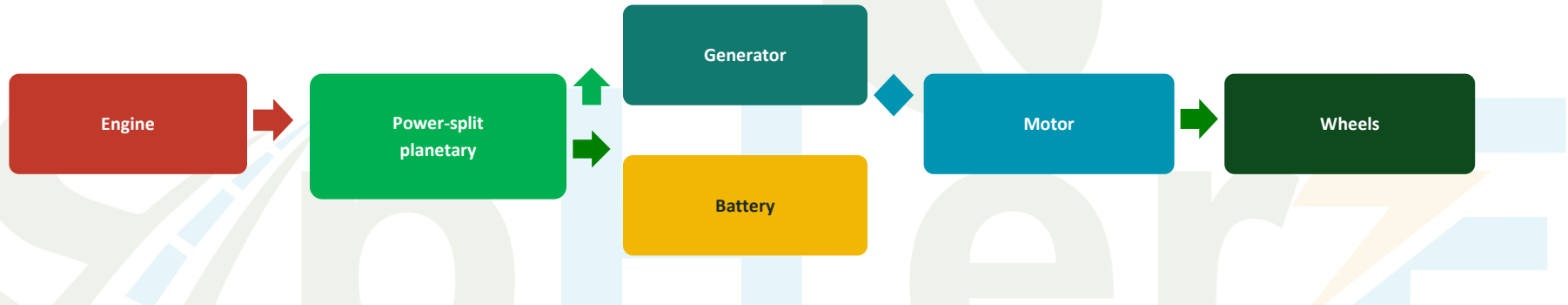
Disadvantages

- ▶ Engine speed tied to road speed — less freedom to optimise
- ▶ More complex torque-blending control
- ▶ Engine still needs a multi-ratio transmission

ARCHITECTURE · COMBINED

Series–parallel (power-split) hybrid

Combines both: a power-split device (usually a planetary gear) routes engine power partly to the wheels and partly through a generator–motor electrical path. The controller chooses the best blend continuously.



Why it dominates full hybrids

- Behaves like a series hybrid at low speed and a parallel hybrid at cruise — best of both
- The planetary set acts as an electrically-variable transmission (e-CVT): no conventional gearbox
- Two electric machines give fine control of engine operating point and seamless power blending

DEGREE OF HYBRIDIZATION

Micro · Mild · Full — and 48 V

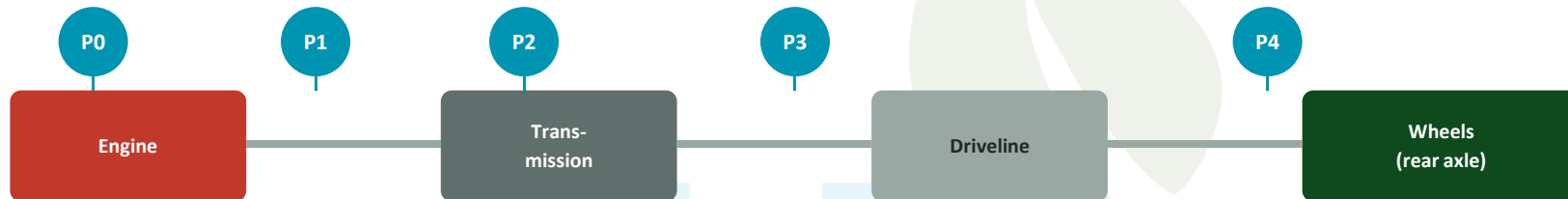
	Micro	Mild	Full
Typical voltage	12 V	48 V	200–400 V+
Stop–start	Yes	Yes	Yes
Regen braking	Limited	Yes	Yes
Torque assist / boost	No	Yes	Yes
Electric-only drive	No	Very limited	Yes
Engine downsizing	Minimal	Moderate	Significant

48 V mild hybrids are popular in Europe as a low-cost route to meeting fleet CO₂ targets.

MOTOR POSITION

P0–P4 hybrid architectures

Parallel hybrids are also named by where the electric machine sits in the driveline:



Where the machine sits changes what it can do

- ▶ **P0** belt-driven starter-generator at the engine front — cheapest, mild assist & regen (common 48 V)
- ▶ **P1** machine fixed to the crankshaft — assist and regen but cannot decouple from the engine
- ▶ **P2** between clutch and gearbox — can drive electric-only by opening the clutch; popular for full hybrids
- ▶ **P3** on the gearbox output — efficient regen, electric drive independent of gear ratio
- ▶ **P4** on a separate axle — electric all-wheel drive and strong regen, axle-decoupled from the engine

CHARGING MODE

Charge-sustaining vs charge-depleting

Charge-sustaining (HEV)

- ▶ Never plugged in — all energy ultimately comes from fuel
- ▶ Small battery; on-board engine + generator keep state-of-charge within a band
- ▶ The pack buffers energy: stores regen, supplies boost
- ▶ Conventional full and mild hybrids

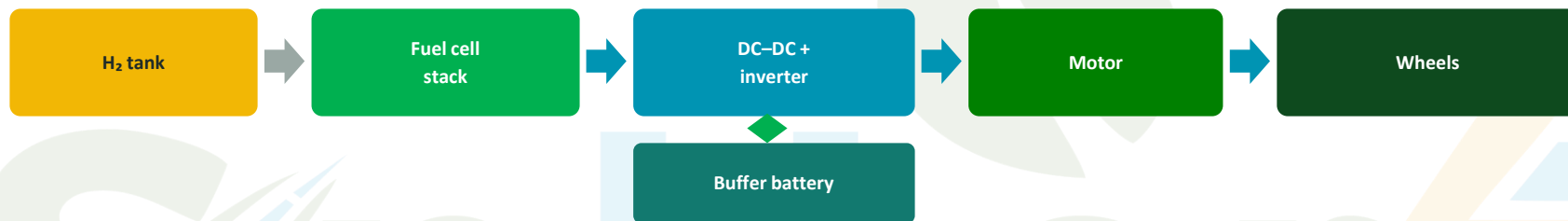
Charge-depleting (PHEV / BEV)

- ▶ Larger battery charged from the grid
- ▶ **PHEV** runs electric-only for a useful range, then operates as an HEV
- ▶ **BEV** the extreme case — no on-board generation at all
- ▶ Lower local emissions when running on grid energy

FCEV

Fuel-cell electric vehicles

An FCEV is an EV whose primary energy comes from hydrogen: a fuel cell generates electricity on board to drive the motor.



Model	Motor	Battery buffer	Fuel economy (mi/gge)
Toyota Mirai	113 kW	245 V NiMH	67
Hyundai Nexo	120 kW	240 V Li-ion	57–61
Honda Clarity FC	130 kW	346 V Li-ion	68

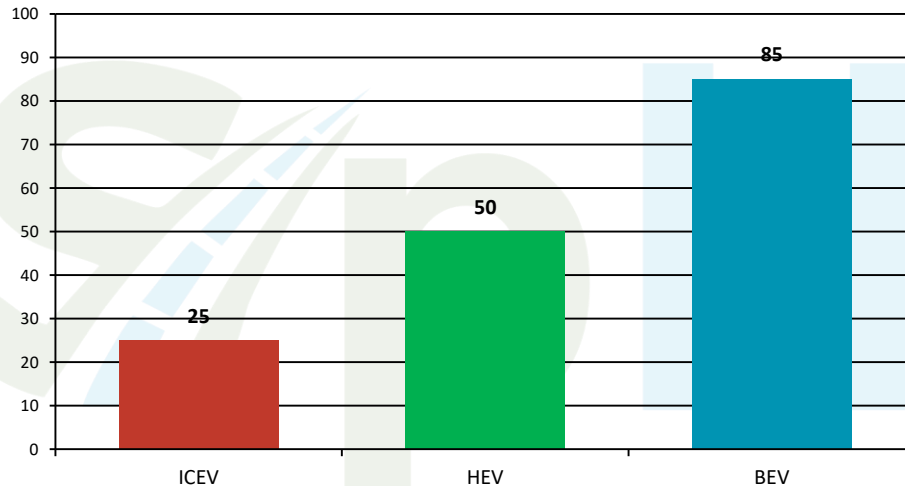
Model-year 2020 examples (Husain, 2021). A small buffer battery handles transients and regen.

SYSTEM VIEW

Well-to-wheel efficiency

Overall efficiency = **Well-to-Tank** (fuel production & delivery) × **Tank-to-Wheel** (on-board, source → wheels).

Typical tank-to-wheel efficiency



The catch

- ▶ On-board (TTW), the electric powertrain is far ahead: ~80–90% vs ~25% for an ICE
- ▶ But add well-to-tank losses and the gap narrows — electricity is often generated from fossil fuel
- ▶ Whole-system WTW efficiencies of EV, HEV and ICEV can end up similar
- ▶ A PHEV's result depends on its grid-vs-fuel share
- ▶ **Conclusion** judge vehicles on the full chain and the local energy mix, not the tailpipe alone

COMPARISON

EV vs ICEV — the engineering balance

Advantages of the EV



Efficiency

75–90% drive efficiency; recovers braking energy



Emissions

Zero tailpipe; lower well-to-wheel CO₂ (mix-dependent)



Maintenance

Fewer moving parts — no clutch, no multi-speed gearbox, no exhaust



Control

Fast, precise motor torque aids stability & safety systems

Current limitations



Energy density

Batteries store far less energy per kg than liquid fuel



Recharge time

Minutes to refuel fuel vs ~30 min–8 h to recharge



Range

Shorter per charge; improving with battery development



Cost & mass

Battery packs are heavy and expensive

ENERGY STORAGE

From lead–acid to lithium-ion

Lead–acid

First EVs (e.g. GM EV1, 1996). Cheap but heavy, low energy density.



NiMH

Workhorse of early hybrids. Robust, better density than lead–acid.



Lithium-ion

Today's standard for EVs and HEVs. High energy & power density; many chemistries.

Pack characteristics

- ▶ Many cells in series build the high-voltage bus (~240–400 V+)
- ▶ Series + parallel arrangement sets voltage and capacity
- ▶ A battery-management system (BMS) monitors cell voltage, temperature & balance
- ▶ Other stores: ultracapacitors, flywheels (mostly research / buffering)

The open challenges

- ▶ Energy density still far below liquid fuel
- ▶ Charge time and charging infrastructure
- ▶ Pack cost, mass and thermal management
- ▶ Lifetime, state-of-health and safe handling

THE BRIDGE

Why this matters for diagnostics

Electrification removes some familiar faults and introduces entirely new fault domains.



High-voltage battery & BMS

Cell imbalance, state-of-health, thermal faults, isolation



Power electronics

Inverter / DC-DC converter switching, cooling, control faults



Electric machines

Insulation, bearings, position-sensor and phase faults



Regenerative braking

Blending electric and friction braking correctly



Networked control

VSC and ECUs over CAN — software & communication faults



Mech-elec interaction

Faults that cross both domains (e.g. power-split units)

Everything that follows in this module — safety, tools, mechanical and electrical diagnostics, drives, batteries and ADAS — builds on the architecture you have seen today.

WRAP-UP

Key takeaways

1

Every vehicle is energy source → conversion → power path → wheels; EVs, HEVs and ICEVs differ only in what fills those boxes.

2

The electric machine's torque-from-zero, constant-power behaviour makes EV drivelines mechanically simpler — single gear, no clutch.

3

Hybrids are classified on three independent axes: architecture (series / parallel / power-split), degree (micro / mild / full) and charging mode.

4

P0–P4 names where the machine sits in a parallel driveline and dictates its capability.

5

Compare vehicles on whole-system well-to-wheel terms, not tailpipe efficiency alone.

6

Electrification opens new fault domains — HV battery, power electronics, machines, networks — that drive the rest of this module.

SOURCES

References & further reading

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Thank you for your attention!

A large, faded version of the SPHER2 logo, featuring the word "SPHER2" in a stylized font with a green leaf icon above the "H" and a blue lightning bolt icon above the "E".