Hybrid Cars

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What are Hybrid Vehicles?

A hybrid vehicle is a vehicle that uses two or more distinct power sources to move the vehicle.

Power Sources-> Gasoline, Hydrogen, Ethanol, Biomass, Electricity, muscle power, etc
Why Hybrid Vehicles?

- Declining fuel reserves
- Increasing Demand
- Environmental Degradation

An electric-powered car cannot go more than 100 miles (161 km) between recharging, is difficult to re-charge and doesn't drive beyond 60 mpg, although it emits little pollution

Hence, Hybrid Vehicles

Hybrid Vehicles (increased drive train efficiency ~ 30-40%)
- Reduce emission
- Increase fuel economy
Why Hybrid Vehicles?

Operating Characteristics of ICE

Conventional Car

Hybrid Electrical Vehicle

Operating Characteristics of ICE
• ICE only vehicle is inefficient at idle speeds - consumes fuel without providing the propulsion power
• Conventional vehicle -- only 10%–15% of the energy contained in gasoline is converted to traction
• ICE -- Perform exceedingly well at constant speeds
• Electric traction motors-> can provide quick acceleration
• Therefore, Hybrid Electric Vehicle -- the drive train efficiency can potentially be improved to about 30%–40%
Main Features and Working

- Engine receives help from motor for extra acceleration, allowing use of smaller efficient engine.

- The engine and motor convert gas to energy stored in batteries, to be used later at optimal times.

- Regenerative braking also converts energy into electricity stored in the battery.

- At low speeds or idle, the battery provides all the necessary energy. The engine is dormant.
Main Features and Working

**HEV Efficiency Factors:**

- Engine Stop/Start when vehicle at standstill
- Regenerative Braking to charge batteries
- Smaller engine size and reduced emissions
- Vehicle weight and aerodynamic design
- Using low rolling resistance tires

**Important Features**

- Atkinson Cycle Engine
- Permanent Magnet motor
- Micro-converter and micro-inverter
- Nickel-Metal Hydride/Lithium-Ion battery
Topologies

• **Series**
  
  **Advantages**
  
  • ICE running mostly at optimal speed and torque
  • ICE can be turned off in zero emission zone
  • Low floor possible
  • Low fuel consumption
  • High fuel efficiency

  **Disadvantages**
  
  • Many energy conversions -> energy loss
  • More suitable for city driving

![Diagram of Series Hybrid Topology]
Topologies

• Parallel

Advantages

• ICE directly connected to wheels -> fewer power conversions
• Electric machine and gearboxes present -> ICE working pt. can be chosen freely

Disadvantages

• ICE & electrical machines must be mounted together -> no low floor
Topologies

• Power Split

Advantages

• ICE can be turned off
• ICE speed can be chosen by adjusting generator speed

Disadvantages

• Power vicious cycle may occur leading to low efficiency
• Relatively complex
• Expensive

Toyota Prius
Topologies

• **Power Split**

  **Planetary Gear**

  • Distribution of the power produced by the gas/petrol engine to the drive train and to the generator

  • Consisting of a ring gear, pinion gears, a sun gear and a planetary carrier.

  Courtesy: www.hybridsynergydrive.com
Hybrid is defined in different levels: micro, mild, full, and plug in hybrid.

**Micro and micro/mild hybrid**
- DC/DC Boost Converter
- 14V battery
- ICE
- DC/AC Micro Inverter

**Mild and full hybrid**
- 120/400V
- DC/DC Boost Converter
- 650V DC
- DC/AC Micro Inverter
- E Motor
- ICE

**Plug in hybrid and EV**
- 120/400V
- DC/DC Boost Converter
- 650V DC
- DC/AC Micro Inverter
- E Motor
- ICE
- AC/DC Charger
- 14V battery
Hybrid Levels: **Mild Hybrid**

**Key Features:**

- A special starter, turns off engine when the car brakes, coasts or stops, and then seamlessly restarts -> saves fuel
- Electric motor in a mild hybrid cannot (and does not) actually propel the vehicle on its own.
- Acts as a power booster

**Advantage:**

- More fuel efficient (10-15%) compared to conventional gas powered car
- Less expensive than fully hybrid

**Disadvantage:**
Less fuel efficient than fully hybrid
Hybrid Levels: Plug-in hybrid

Key Features:

- Rechargeable batteries
- Electric motor -> primary power source, gasoline engine -> supplemental motivation
- Require deeper battery charging and discharging cycles than conventional hybrids
- Charging topologies
  - On-board chargers
  - Off-board chargers
  - Using electric motor's inverter and inductance
- Modes of Operation
  - Charge-depleting mode
  - Charge-sustaining mode
  - Mixed mode
Hybrid Cars

Hybrid Levels: **Plug-in hybrid**

**Advantages:**
- Energy resilience and petroleum displacement
- Fuel efficiency
- Lower greenhouse gas emissions
- Lower operating costs
- Range anxiety elimination
- Reduction of smog
- Vehicle-to-grid electricity

**Disadvantages:**
- Cost of batteries
- Recharging outside home garages
- Emissions shifted to electric plants in some countries
- Lithium availability and supply security
## Hybrid Levels

Comparison between Electric vehicle, micro, mild, full and plug-in hybrid

<table>
<thead>
<tr>
<th>Functions</th>
<th>Micro &amp; Micro-Mild hybrid</th>
<th>Mild Hybrid</th>
<th>Full Hybrid</th>
<th>Plug in hybrid (PHEV)</th>
<th>EV</th>
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</thead>
<tbody>
<tr>
<td>Start/Stop</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<td>Regenerate braking</td>
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<tr>
<td>Additional electric power for few seconds</td>
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<td>Electric power for long distance &amp; recharge on grid</td>
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<tr>
<td>Energy Savings</td>
<td>5-10%</td>
<td>10-25%</td>
<td>25-40%</td>
<td>50-100%</td>
<td>100%</td>
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<tr>
<td>Energy Savings</td>
<td>(upto 25% in city traffic)</td>
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<tr>
<td>Electric Power</td>
<td>1.5-10KW</td>
<td>5-20kW</td>
<td>30-75kW</td>
<td>70-100kW</td>
<td>30-100kW</td>
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<tr>
<td>Car Examples</td>
<td>PSA C2</td>
<td>Honda Civic</td>
<td>Toyota Prius</td>
<td>GM Volt</td>
<td>Nissan leaf</td>
</tr>
</tbody>
</table>

Hybrid Vehicle Battery

Key Features:
• Electrolyte ->
  – liquid, gel, or solid material.
  – acidic or alkaline, depending on the type of battery
• advanced batteries -> a gel, paste, or resin
• Pb-acid, NiMH, and Lithium (Li)-ion batteries

Salient points for traction batteries:
• one charge to provide a long range or mileage
• stable power with deep discharge characteristics to allow for acceleration and ascending power capability of the EV
• Long cycle life with maintenance free and high safety mechanisms built into the battery
• Wide acceptance as a recyclable battery from the environmental standpoint
Hybrid Vehicle Battery

Nickel Metal Hydride Battery

Pros
• energy density of 30-80Wh/kg
• can have exceptionally long lives if used properly
• Faster charging

Cons
• poor efficiency
• high self-discharge
• very finicky charge cycles
• poor performance in cold weather

Courtesy: http://batterydata.com/
Hybrid Vehicle Battery

Lithium Ion Battery

Pros
• High energy density
• Solid electrolyte
• Typically 40% smaller and weigh half than NiMH
• Open circuit voltage (OCV) of approximately 3-4V at full charge
• Lesser charge discharge time
• More environment friendly

Cons
• Overcharging may cause damage to electrodes
• Dangerous if not handled carefully
• Safety features required for both cell and battery pack

Courtesy: http://batterydata.com/
Power Electronics Module (PEM)

- **power inverter and charging system**

- Increase in power output compared to first-generation electric cars (o/p ~ 200kW at peak accl.)
- Control charge and discharge rates
- Controls voltage levels, the motor's RPM, torque and the **regenerative braking system**
- Aluminum heat dissipation fins and a rear-mounted ventilation port -> overheating protection
Power Electronics Module (PEM)

Main Components

• **Resistors** used in:
  - Inrush Current Limiting Resistors
  - Battery Charging Systems
  - Inverters
  - Load Dump and Transient Resistors
  - Capacitor Discharge
  - Fuel Cell Load Dump and Management
  - Active Battery Cell Balancing
  - Current Sense
  - Power Management on High Voltage Buses
  - Resistive Heaters

• **High voltage capacitors** to filter and maintain the charging system voltage

• **Position sensors** -> inductive type

• **Inverters** and **converters** to provide power at voltage levels to support the BAS from the vehicle charging system

• Inverters (DC -> AC) for electric motor
• Converter (AC/DC to different voltage value)
Power Electronics Module (PEM)

Main Electronic Components

- Windscreen Wipers
- Camshaft / Crankshaft Sensor
- Surge Protection Resistors for Wiper & Control Module
- Lights
- Braking System / Wheels
- Steering Sensors
- Thermal Mgt System & Cooling Pumps (Engine Detail)
- Water Pump
- Air Con, Heaters & Dashboard Display
- Air Temperature Sensor
- Windows
- LEDs - Internal and Exterior
- Brake Position Sensor
- In-wheel Motor Drive Module
- Steering Torque & Position Sensor
- Current Sense Resistors, Window Lifts, Doors, & Seat Belt Tension

Courtesy: www.ttelectronics.com
Power Electronics Module (PEM)

Main Electronic Components

**DC-DC Converters**
- Boost Inductor
- Flyback Transformer
- Current Sense Resistors

**Inrush Current Limiting Resistors**
- Voltage Converter

**Inverters**
- Opto Isolators for HV Power Management
- HV Resistors for Voltage Control

**Power Electronics Module (PEM)**

- Batteries
- Battery Pack Heater
- Inrush Current Limiting Resistors
- Precision Resistors for Voltage Monitoring
- Air Temperature Sensor
- Power Resistors for Load Dump
- Battery Ballast Modules
- Flyback Transformer for Battery Power Management

Courtesy: www.ttelectronics.com

Hybrid Cars
Inverters and Converters

Inverters and converters combined into one unit manage the power and recharging circuits in hybrids and electric vehicles

- Direct current is supplied by the battery and must be converted by power electronics to the alternating current required by the motor

- Both hybrids and EVs use relatively low voltage DC batteries (about 210-V) to keep the physical size (and cargo space consumed) down

- Generally use highly efficient, and high voltage (about 650V) AC motor/generators

- The inverter/converter unit choreographs how these divergent voltages and current types work together

- These may have their own dedicated cooling system independent from engine’s cooling system
Inverters and Converters

Inverter

High-Voltage DC from HV battery

Inverter

3-Phase AC for motor

Inverters are roughly the same for full hybrid, plug in hybrid and EV cars with an average power of 50kW.

Device/Material Choice

**IGBT**

- high power applications
- High efficiency
- Fast switching
- **Problem** – dissipation of heat generated

**SiC**

- better power density
- less losses
- higher operating temperature – low cooling costs
- **Problem** - Cost

**GaN**

- better performance/cost ratio compared to SiC
Inverters and Converters

Inverter

- Converts DC from battery to AC for running the motor
- The inverter assembly includes a separate inverter for the air conditioning system
- Converts 201.6V DC into 201.6AC (Toyota Prius) to power the AC system’s electric inverter compressor

Inverter Assembly Diagram

Courtesy: www.autoshop101.com
Inverters and Converters

**Converter**

- **Voltage-Boosting Converter**
  - steplessly increases the normal 201.6 V DC supply to feed the electric motors and the generator as required
  - more power can be generated from a small current to bring out high performance from the high output motors
  - enhancing overall system efficiency
  - also means that the inverter could be made smaller and lighter

- **DC/DC Converter**
  - steps down the 201.6 V supply voltage from the battery to 14 V to be used by ancillary systems and electronic devices like the ECU.

DC/DC Converter  (Courtesy:www.autoshop101.com)
Vehicle System Controller

• The brains of the vehicle

• built into the powertrain control module

• manages charging, drive assist and starting

• Regenerative Braking

• Controls operation of hybrid transaxle

• The electronically-controlled, continuously variable transmission (eCVT) controls the ICE and electric motors to drive the wheels and affords smooth accelerations, upshifts and downshifts

• It oversees the operation of the inverter and converter as they balance the power requirements of the vehicle’s many 14-volt components and the high voltage components of the hybrid system powertrain
The choice of energy source(s) for a particular HEV is governed by the HEV strategy of the vehicle.

One area which is monitored and controlled by the HEV strategy is the state of the batteries.

Therefore, a well designed algorithm could optimise the process, and help to increase the benefits of the HEV application.
## Available Hybrid Car Models

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Toyota Prius</th>
<th>Honda Civic Hybrid</th>
<th>Nissan Altima Hybrid</th>
<th>Ford Escape Hybrid</th>
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<tbody>
<tr>
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<td>1.5</td>
<td>1.3</td>
<td>2.5</td>
<td>2.5</td>
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<td>Cylinder</td>
<td>4</td>
<td>4</td>
<td>4</td>
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<td>VMODE VLKUP</td>
<td>EMS</td>
<td>EMS</td>
<td>VLKUP</td>
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<td>Fuel Economy estimates</td>
<td>Average of 25 cars 4.6</td>
<td>Average of 14 cars 5.1</td>
<td>Average of 5 cars 7.1</td>
<td>Average of 5 cars 6.8</td>
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<td>(from drivers)</td>
<td>2.9 (lo)  5.9(hi)</td>
<td>3.7(lo)  6.2(hi)</td>
<td>6.2(lo)  9.4(hi)</td>
<td>6.4(lo)  7.4(hi)</td>
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<td>Annual Petroleum</td>
<td>7.4 Barrels</td>
<td>8.2 Barrels</td>
<td>10.1 Barrels</td>
<td>10.7 Barrels</td>
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<td>Consumption</td>
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<td></td>
<td></td>
<td></td>
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<td>Metric tonnes of CO₂</td>
<td>3.7</td>
<td>4.1</td>
<td>5.0</td>
<td>5.3</td>
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<tr>
<td>emitted(p.a.)</td>
<td></td>
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<td></td>
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</tbody>
</table>

Courtesy: [www.fueleconomy.gov](http://www.fueleconomy.gov)
Indian Hybrid Car Models

REVA NXP

Speed : 104 km/h
Distance : 160 km
Weight(empty) : 700 kg
E-motor : 13kW (max.)
Battery : 72 V (14 kWh) Li-ion or 48 V Pb-acid
Energy recuperation
Future of Hybrid Cars

Pros

• Environment Friendly
• Fuel Efficient
• Reduced Noise
• Better Performance
• Financial Benefits – Govt. aid

Cons

• Car can be expensive – high maintenance cost
• Different drive experience – heavier car
• Less Power
• Low fuel mileage on highway
• Safety - risk of exposure to high voltage wires in case of crash
• Disposal of Hybrid car battery
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Hybrid Cars : Atkinson’s Cycle

Ideal Atkinson’s cycle :
1-2 Isentropic or reversible adiabatic compression
2-3 Isochoric heating ( Qp )
3-4 Isobaric heating ( Qp' )
4-5 Isentropic expansion
5-6 Isochoric cooling ( Qo )
6-1 Isobaric cooling ( Qo' )

Goal :
• to allow the pressure in the combustion chamber at the end of the power stroke to be equal to atmospheric pressure
• thus, all the available energy has been obtained from the combustion process.
• the greater expansion ratio => more energy to be converted from heat to useful mechanical energy ∴ the engine is more efficient.

Disadvantage :
Reduced power density
Hybrid Cars: An Example

“Two-mode” hybrid transmission:

**Input-split mode** —
- Low speeds – either electric motor/generators, the internal combustion engine, or both (full hybrid)
- All accessories still remain functioning on electric power,
- the engine can restart instantly if needed
- one of the motor/generators (M/G 1) acts as a generator, while the other operates as a motor (M/G 2)
- operational for the two continuously variable ranges (*input split and compound split*) of the transmission

**Compound-split mode** —
- Higher speeds or heavier loads – the internal combustion engine always runs
- the system uses advanced technologies like Active Fuel Management and late intake valve closing to optimize engine and fuel efficiency

Jointly developed by General Motors, Daimler, and Chrysler LLC, with BMW joining in 2005
Hybrid Cars: **Topologies**

<table>
<thead>
<tr>
<th>Component:</th>
<th>Series:</th>
<th>Parallel:</th>
<th>Strigear:</th>
<th>Power split:</th>
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<tr>
<td>ICE</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Electric machine</td>
<td>2</td>
<td>1 (2)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Battery</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Gearbox</td>
<td>1</td>
<td>1 (2)</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Power electronics</td>
<td>2</td>
<td>1 (2)</td>
<td>2</td>
<td>2</td>
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<tr>
<td>Clutch</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Planetary gear</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>

Number of components included in the presented topologies. Figures in parenthesis mark possibility for divergent number of components.
Hybrid Cars: Components Detail

Internal Permanent Magnet Motor

• Internal permanent magnets embedded within the rotor to create the superior flux density and distribution that gives the improvement in torque density.

• Typical applications will be those where high torque is required such as lifts/elevators cranes/hoists and machine tool axes and spindles. However the new IPM motors also offer advantages where large amounts of energy are consumed such as in continuous-duty fans, pumps and compressors.

• In direct-drive spindles for machine tools the heat-rise characteristic of the motors is one-third that of a conventional ac induction motor. Minimising heat losses not only saves energy but also helps maintain the precision of the machine tool.

• IPM takes up lesser space and has simpler speed control.

• Moreover the IPM motor is more efficient converting 97.5 percent of the available electricity into motive energy in assist mode which compares with 94.6 per cent previously.

Courtesy: www.yaskawa.com
Hybrid Cars: **Regenerative braking**

**Regenerative Braking:**
Slows vehicle by converting its kinetic energy into another form

**Conventional Braking:**
Kinetic energy converted to heat by friction in brake linings and wasted

**Limitations:**
- The regenerative braking effect drops off at lower speeds
- Friction Brake required as backup
- Friction based braking required in cases of adverse conditions in two-wheel drive vehicles
- It is normal to also incorporate dynamic braking to absorb the excess energy
- Friction braking is required to absorb the surplus energy in order to allow an acceptable emergency braking performance
Hybrid Cars: Regenerative braking

The electric motor reverses direction, becoming a generator (dynamo) which then stores the energy in the vehicle’s battery.
Hybrid Cars: Active battery cell balancing

Multi cell battery prevented from giving its maximum energy output due to cell imbalance.

Causes of cell imbalance:
• non-uniform thermal stress
• impedance deltas
• poor cell capacity matching
• and chemical variations.

Solutions:
• cell choice
• good pack design.

Methods:
• **Passive cell balancing** – uses a straightforward cell discharge path that provides a current bleed for higher voltage cells until all cell voltages are equal
• **Active cell balancing** – uses capacitive or inductive charge shuttling to transfer charge between battery cells

Courtesy: [http://www.powerdesignindia.co.in/STATIC/PDF/201002/PDIOL_2010FEB16_PORTP_TA_01.pdf?SOURCES=DOWNLOAD](http://www.powerdesignindia.co.in/STATIC/PDF/201002/PDIOL_2010FEB16_PORTP_TA_01.pdf?SOURCES=DOWNLOAD)
Hybrid Cars: ‘Dual Battery’

GE Global Research Centre has come up with a new type of battery – ‘dual battery’ for hybrid vehicles.

The system combines a high-energy density sodium battery with a high-power lithium-ion battery. It’s betting the technology accelerates the electrification of buses, delivery trucks and other large heavy-duty fleet vehicles.

Why?

Because the combination of high-energy and high-power storage capacity could achieve optimal range and performance requirements for large vehicles in a battery of reasonable size and price.

Lithium ion batteries provide lots of power for optimal acceleration at the expense of storage capacity — aka range. Sodium batteries can store lots of energy but aren’t optimized for power.
Hybrid Cars: Plug-in Hybrid Vehicles

Charging Topologies

**On-board chargers** which are mounted inside the vehicle. The connector to the grid is standardized, so that the hybrid can be charged at home as well as at charging stations in the cities. The on-board charger spends place and weight of the vehicle, and so the power for charging via grid is limited to a few kilowatts.

**Off-board chargers** are much bigger and more heavier than on-board chargers, so they are mounted stationary, for example in the garage. They have more power and can charge the vehicle's battery more faster. Off-board chargers are adapted to the vehicle's battery (voltage, charging method,...) and need special connectors to the vehicle.

**Using electric motor's inverter and inductance** has the advantage, that no much extra space and weight is required. The charging method is on-board, grid flexible with standard connector, cost efficient and with high power capacity. The electric machine must be designed for this method, and the inverter needs some extensions. AC Propulsion for example uses this charging method.
Modes of Operation

**Charge-depleting mode** allows a fully charged PHEV to operate exclusively (or depending on the vehicle, almost exclusively, except during hard acceleration) on electric power until its battery state of charge is depleted to a predetermined level, at which time the vehicle's internal combustion engine or fuel cell will be engaged. This period is the vehicle's all-electric range. This is the only mode that a battery electric vehicle can operate in, hence their limited range.

**Charge-sustaining mode** is used by production hybrid vehicles (HEVs) today, and combines the operation of the vehicle's two power sources in such a manner that the vehicle is operating as efficiently as possible without allowing the battery state of charge to move outside a predetermined narrow band. Over the course of a trip in a HEV the state of charge may fluctuate but will have no net change. The battery in a HEV can thus be thought of as an energy accumulator rather than a fuel storage device. Once a plug-in hybrid has exhausted its all-electric range in charge-depleting mode, it can switch into charge-sustaining mode automatically.

**Mixed mode** describes a trip in which a combination of the above modes are utilized. This contrasts with a charge-depleting trip which would be driven within the limits of a PHEV's all-electric range. Conversely, the portion of a trip which extends beyond the all-electric range of a PHEV would be driven primarily in charge-sustaining mode, as used by a conventional hybrid.