— Toward Carbon Neutrality —

Toyota’s Battery Development and Supply

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The meaning of carbon neutrality

Carbon neutrality means zero life cycle CO₂ emissions
Toward carbon neutrality

Change in world’s concentration of CO₂*

To immediately reduce CO₂ emissions:

➢ Areas in which renewable energy will be widely used going forward

Rapid electrification
1 BEV has the reduction effect of 3 HEVs

➢ Areas in which renewable energy is already widely used

Acceleration of the widespread use of ZEVs

* TMC summarized based on the data from Japan Meteorological Agency and World Meteorological Organization, etc.
Electrified vehicle lineup toward carbon neutrality

- HEV
- PHEV
- BEV
- FCEV

Electrified vehicle sales volume forecast for 2030

Electrified vehicles 8 million units

including BEVs + FCEVs 2 million units

Providing our customers around the world with sustainable and practical products
Dissemination of HEVs has efficiently reduced CO\textsubscript{2} emissions with a small volume of batteries.

Advancing BEV & PHEV technologies for further dissemination

Cumulative HEV global sales*: 18.1 million units

Battery volume: Approx. 260,000 BEVs

CO\textsubscript{2} emissions reduction effect: Approx. 5.5 million BEVs

Volume of HEV CO\textsubscript{2} reduction converted to units of BEVs

*As of the end of July 2021
Technologies supporting full lineup of electrified vehicles

Core electrification technologies
- Electric motors
- Batteries
- Power control units

Fuel cell stacks + High-pressure hydrogen tanks → FCEV

Chargers + Engines → BEV

PHEV

HEV

CO₂-free fuel
- e-fuel
- Biofuel
## Full lineup of batteries

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<thead>
<tr>
<th>Year</th>
<th>Toyota Group and partners</th>
<th>HEVs</th>
<th>PHEVs</th>
<th>BEVs</th>
</tr>
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<tbody>
<tr>
<td>1997</td>
<td>Toyota Group and partners</td>
<td>1st-gen. Prius</td>
<td>1st-gen. Prius PHV</td>
<td>Affordable, high-quality products</td>
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<td>2011</td>
<td>Evolution of nickel-metal hydride batteries</td>
<td>Prius α</td>
<td>C-HR/IZOA</td>
<td>Increased endurance</td>
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<tr>
<td></td>
<td>Evolution of lithium-ion batteries</td>
<td>Yaris</td>
<td>bZ4X</td>
<td>New lithium-ion batteries</td>
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<tr>
<td>2021</td>
<td>Toyota Group</td>
<td>Expanded use of bipolar nickel-metal hydride batteries featuring new structure</td>
<td>Practical BEV development based on BEV-dedicated platform</td>
<td></td>
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<td>2025</td>
<td>Toyota Group</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2030</td>
<td>Toyota Group</td>
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</table>

**Focused on instantaneous power**

**Focused on endurance**

- Evolution of current lithium-ion batteries
- Innovation in battery structure
- Solid-state batteries
Battery development concept
Common to all batteries for HEVs, PHEVs, BEVs, and FCEVs

Security

- Safety
- Long service life
- High level of quality

Aiming to create safe batteries that can be used with peace of mind always and for their entire lifetime, have high resale value, and contribute to the building of a resource-recycling society

- Affordable, high-quality products
- High-level performance

Giving electrified vehicles meaning through dissemination
Increasing customer choice

Highly balancing 5 elements to provide reliable batteries
Safety: Battery control systems

Verification of effect of high loads on battery internals

- Simulated experiments to measure polarization of electrolyte components (which generates heat) during charging and discharging

Construction of principle-based theoretical model

- Confirmation of certainty and reliability based on vast amounts of experimental data

Control by multiple monitoring of voltage, current, and temperature

Example: Voltage monitoring of C-HR/IZOA BEVs

- Control by multiple monitoring
- Cell monitoring
- All cell monitoring
- Block monitoring
- Total voltage monitoring

Multiple monitoring of voltage, current, and temperature to detect signs of and prevent abnormal heat
Long service life

Battery capacity maintenance rate
(Cruising range)

World-class durability performance target (90%)

C-HR/IZOA
2nd-gen. Prius PHV
1st-gen. Prius PHV

Aiming for world-class endurance with the TOYOTA bZ4X
Long service life: Applying HEV-honed technologies to BEVs

Suppress degradation in battery materials, pack structure, control systems, etc.

Inhibiting formation of degraded materials on anode surfaces
- Appropriate anode surface treatment to prevent degradation
- Design and production technology that prevents moisture contained in battery materials from being introduced into the battery
- Adoption of structure that ensures uniform cooling of battery
- Construction of control system that prevents load from being applied to the entire battery

One key to extending battery life

- Degraded materials containing lithium
- Current collector
- Electrolyte (organic solvent)
- Separator
- Motor
- Cathode
- Lithium compound
- Anode
- Graphite or silicon
- Ion
- Approx. 50 nm
High-level quality: Control of metallic foreign matter

Effect on batteries of metallic foreign matter

Battery failure due to contact between the anode and cathode

The need to control foreign matter

Effect of size and shape of metallic foreign matter on occurrence of abnormalities

Area of occurrence of battery failure

Area in which battery failure does not occur

Determining the size and shape of foreign matter that can cause battery abnormalities and controlling the effect of foreign matter
In the new Aqua — world’s first use as a vehicle drive battery

Doubled power density

Taking up the challenge of innovating battery structure for more powerful acceleration

Bipolar nickel-metal hydride battery

Previous Aqua

Battery stack

Battery module

Conventional structure

Bipolar structure

Current collector

Anode

Separator

Cathode

Case
Next-generation BEVs

**RAV4 L EV** 1996

**RAV4 EV** 2012

**C-HR / IZOA** 2019

**TOYOTA bZ series**
First model: Toyota bZ4X

To launch by mid-2022

A unique Toyota BEV that utilizes technology cultivated through years of HEV development
Battery cost targets: Integrated vehicle-battery development

**Battery development**

- Greater than 30% reduction in cost of single battery
  - Development of low-cost materials: cobalt-free, nickel-free, and new electrode materials
  - Manufacturing process innovation: New development of battery manufacturing processes and battery material processes
  - New structure: Integrated structure of battery cells and packs to match the vehicle
  - Evolution of battery control model: Fuller use of battery capacity with focus on safety, security, and long service life

**Vehicle development**

<table>
<thead>
<tr>
<th>Vehicle model</th>
<th>kWh / km</th>
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<tbody>
<tr>
<td>C-HR/IZOA</td>
<td></td>
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<tr>
<td>TOYOTA bZ4X</td>
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<tr>
<td>Future BEVs</td>
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30% improvement in power efficiency = 30% reduction in battery capacity (30% cost reduction)

Achieve the following by utilizing and developing technologies cultivated through 18.1 million electrified vehicles:
- Reduction of vehicle driving resistance to suit electrified vehicles
- Further expansion of energy regeneration
- Optimal energy/thermal management of entire vehicle and components
- Optimal efficiency design and control of entire powertrain system

**Reducing cost by 30% by improving power efficiency and reducing cost of battery development by 30% ⇒ 50% reduction in battery costs (per vehicle)**

- In the second half of 2020s
Next-generation lithium-ion battery

[Aims]

- Longer service life
- Greater energy density
- More compact size
- Lower cost

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<th>Evolution in liquid-based battery materials</th>
<th>Innovation in liquid battery structure</th>
<th>All-solid-state batteries</th>
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<td>Composition</td>
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<tr>
<td>Structure</td>
<td>Prismatic</td>
<td>New structure</td>
</tr>
</tbody>
</table>

Taking on the challenge of developing a wide range of batteries for the second half of the 2020s
Providing BEVs equipped with batteries with improved characteristics that enable driving with peace of mind
Characteristics of all-solid-state batteries

- Simple ion movement (fast)
- High voltage tolerance
- High temperature tolerance
- High output
- Long cruising range
- Shorter charging time
Progress in development of all-solid-state batteries

- All-solid-state battery prototype vehicle built and driving data obtained
- Now identifying the merits and challenges of use in vehicles

Obtained license plate registration in August 2020 and conducted test drives
Future Development and Challenges of All-Solid-State Batteries

[Merits of all-solid-state batteries]

- Simple ion movement (fast)
- High voltage tolerance
- High temperature tolerance

Early realization of use in HEVs

- Utilizing ion speed for high-output batteries
- Development of process for bonding solid materials

R&D for future use in BEVs

- Key issue: Securing the service life of high-capacity batteries

Initial stages

- Now developing materials to reduce the occurrence of gaps

After long-term use

- Solid electrolyte
- Active anode material
- Gap

- First considering vehicles that utilize all-solid-state battery characteristics
- Overcoming challenges and envisioning rollout from HEVs to BEVs
Battery procurement and collaboration structure

Future direction based on local conditions

- Strengthen collaboration with partners and consider new cooperative structures
- Rapid start-up of production within the Toyota Group
Toyota’s battery strategy by 2030

**Development**
Cost reduction through integrated development of vehicles and batteries to provide reasonably priced vehicles

**Target costs for future batteries**
Aim for **50% reduction** (per vehicle)

**Supply**
Build a flexible supply network and production system based on small basic units

**Aiming to flexibly respond to increasing battery demand**
More than 200 GWh

**Investment in batteries:** 1.5 trillion yen

**Spread of electrified vehicles, including BEVs**
Sustainable & Practical
TOYOTA