

Course of development of the lithium-ion battery, and future outlook

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1. Development of the LIB **From initial research to commercialization**

2. Track record and current
positioning of the LIB

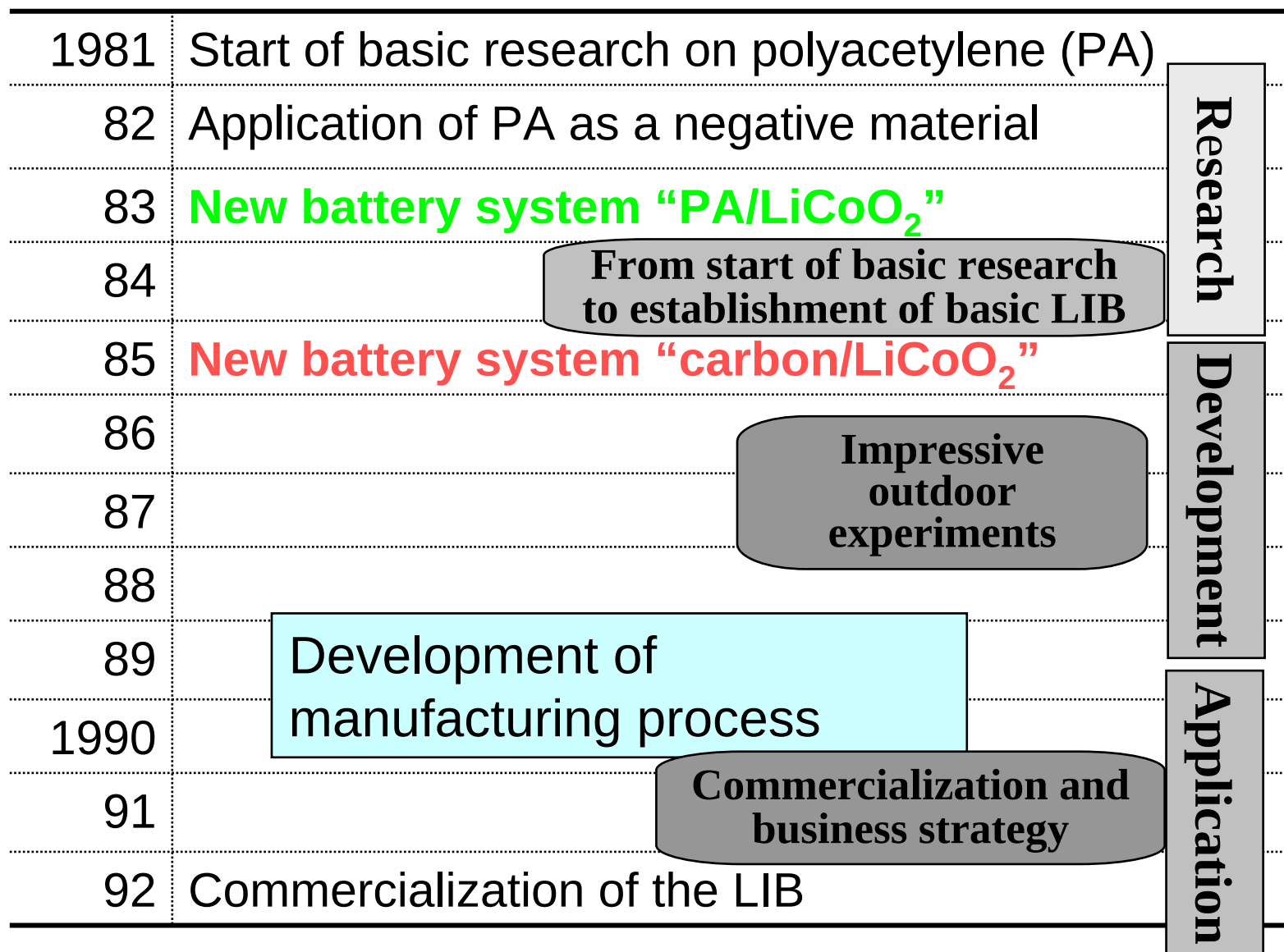
3. Future outlook
Results of the IT revolution and prospects
for the ET revolution

Classification of batteries and the positioning of the LIB

	Aqueous electrolyte battery	Nonaqueous electrolyte battery (high energy, high capacity, high voltage)
Primary battery	Manganese dry cell Alkaline dry cell	Metallic lithium battery
Secondary battery	Lead-acid battery, Ni-Cd battery, Ni-MH battery	Lithium-ion battery

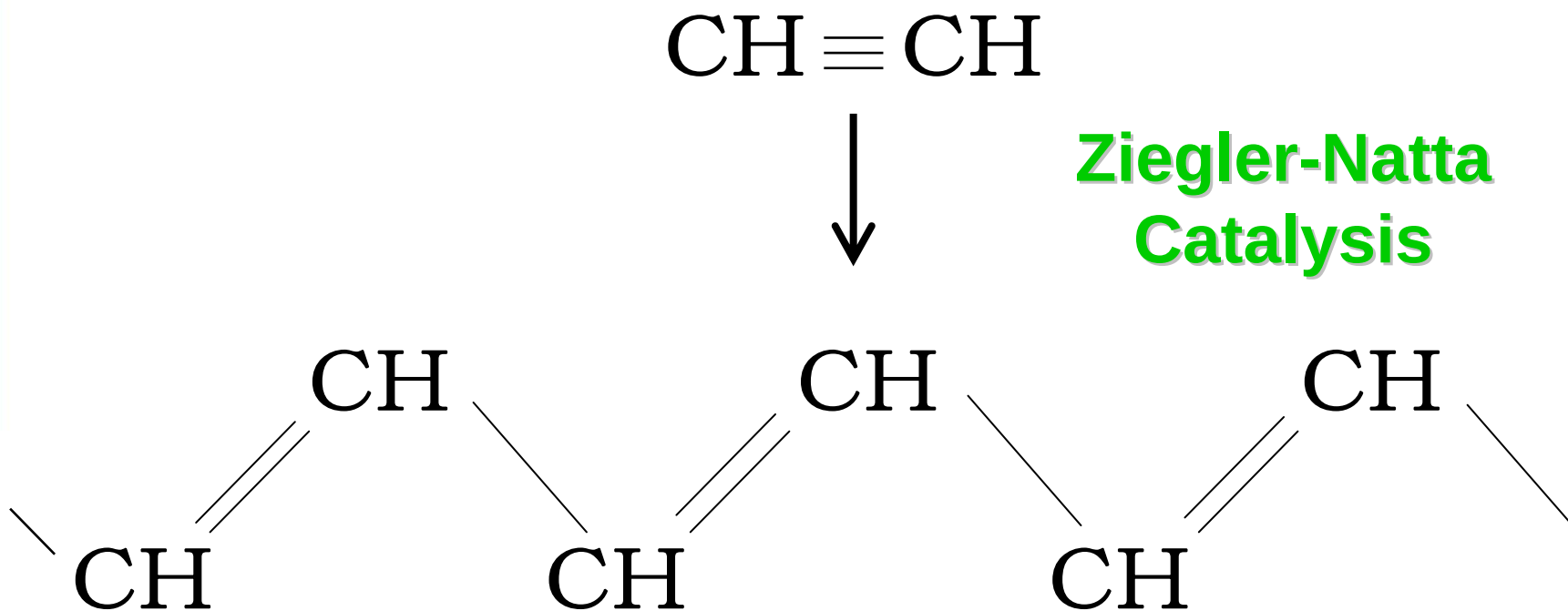
Brief history of LIB development

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The start of basic research on the LIB was with polyacetylene (PA)

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Discovered by

A.G. MacDiarmid, A.J. Heeger, H. Shirakawa

2000 Nobel Prize in chemistry laureates

The reason why I tried to apply PA as a negative material

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	Aqueous electrolyte battery	Nonaqueous electrolyte battery (high energy, high capacity, high voltage)
Primary battery	Manganese dry cell Alkaline dry cell	Metallic lithium battery
Secondary battery	Lead-acid battery, Ni-Cd battery, Ni-MH battery	Fatal issues with metallic lithium as negative electrode

Encounter with LiCoO_2 – the first positive material containing Li ion

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J.B. Goodenough et al.,
Material Research Bulletin, 15 (1980) 783

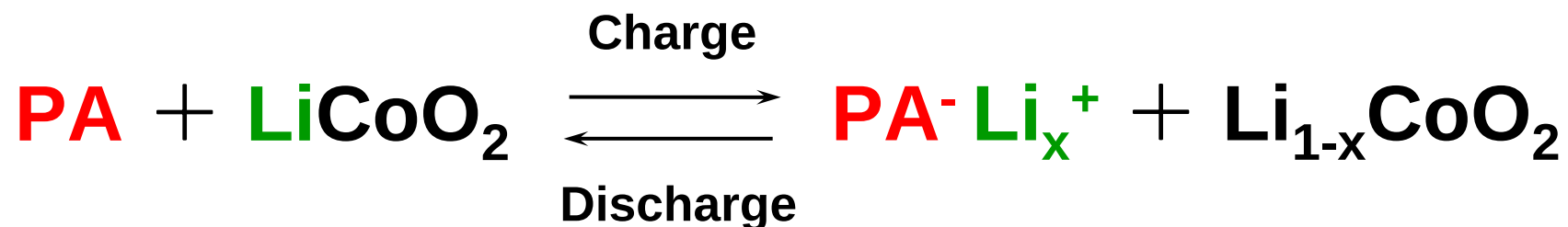
The first reported research on LiCoO_2 as a positive material for secondary battery

Prof. J. B. Goodenough
University of Texas



The origin of present LIB

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The origin of the present LIB
was the **PA** / **LiCoO₂** system
I invented in 1983

Shift from PA to carbon for negative electrode

Various shortcomings with PA

- Low real density of PA: $\rho \doteq 1.2 \text{ g/cm}^3$ (light weight but unable to shrink size)
- Low chemical stability

Carbonaceous material to replace PA

- I obtained a sample of VGCF (Vapor-phase Grown Carbon Fiber) from **Asahi Kasei's fiber R&D center in Nobeoka**
- This new material provided much better performance than other carbonaceous materials which were available in those days

Completion of the present LIB principle

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Completion of **C** / **LiCoO₂** system



Principle of present LIB, invented in 1985

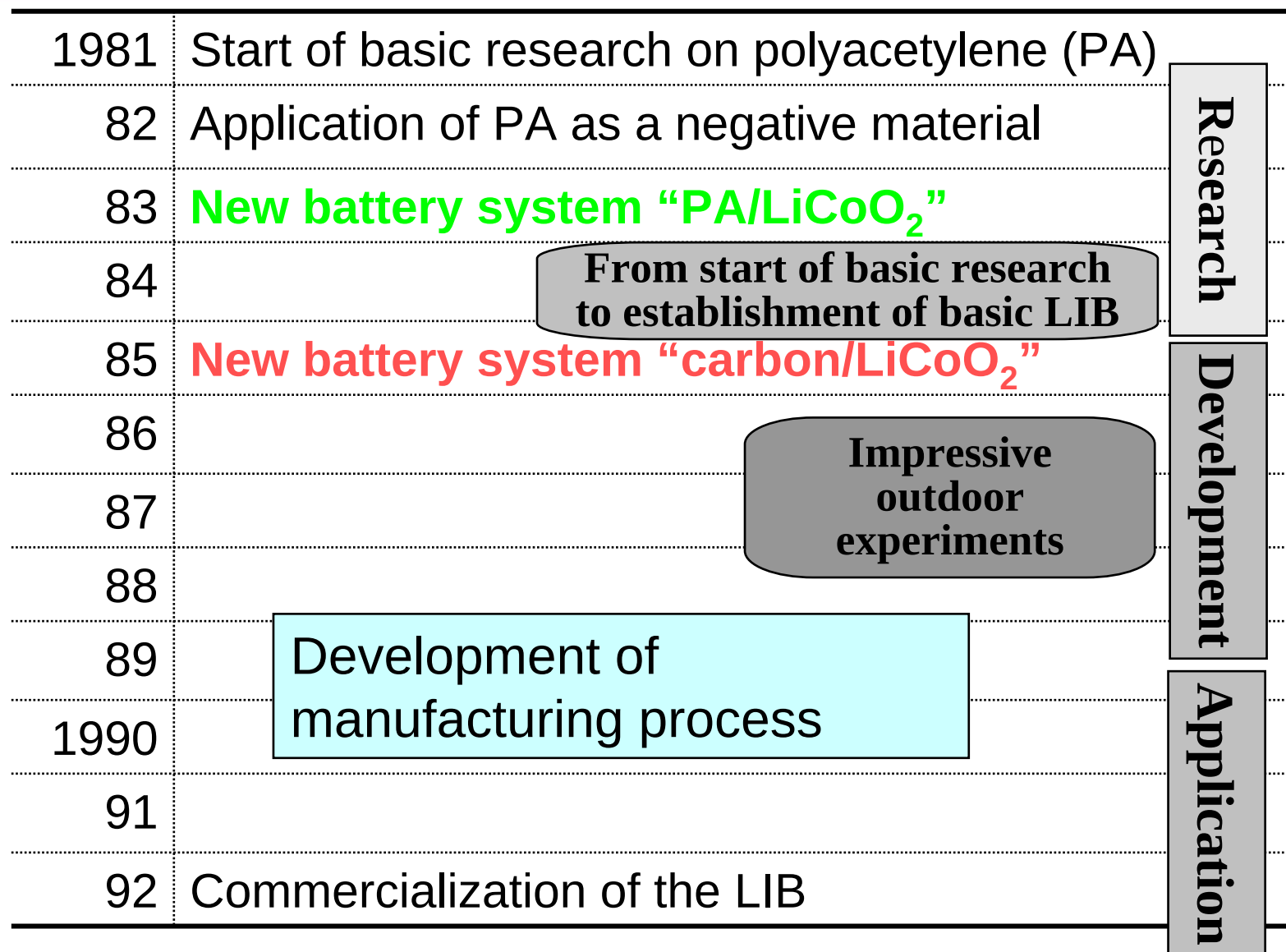
Patents

JP 1,989,293 USP 4,668,595 EP 205,856B2

JP 2,668,678

Brief history of LIB development

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Why there was no nonaqueous electrolyte secondary battery before AsahiKASEI

	Aqueous electrolyte battery	Nonaqueous electrolyte battery (high energy, high capacity, high voltage)
Primary battery	Manganese dry cell Alkaline dry cell	Metallic lithium battery
Secondary battery	Lead-acid battery, Ni-Cd battery, Ni-MH battery	The fatal issue was <u>SAFETY</u>

The world's first safety experiment with an LIB

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**In the summer of 1986,
at Asahi Kasei's explosives plant
in Nobeoka, Japan**

**A positive result was essential for
the commercialization of the new LIB**

Li metal primary battery



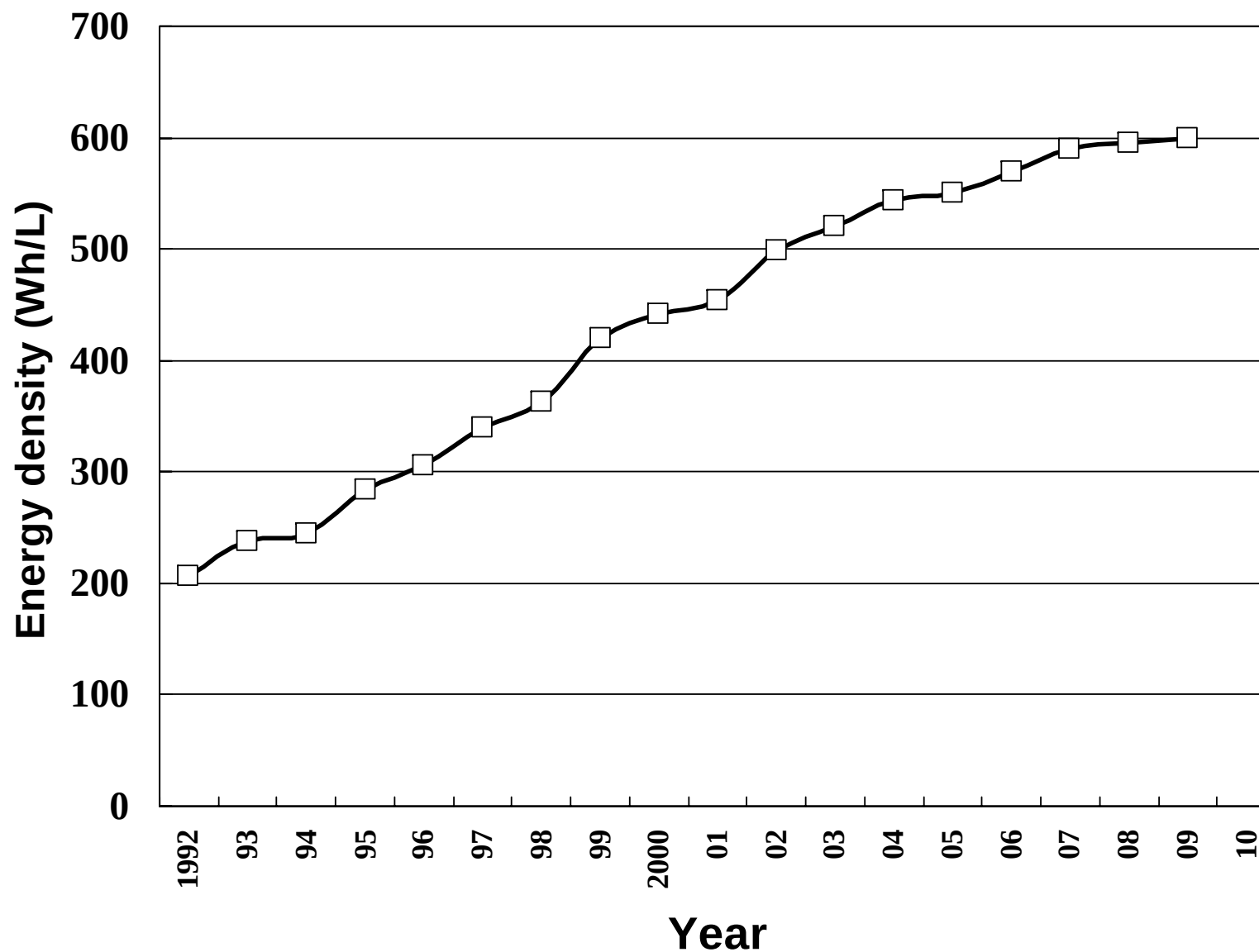
Prototype LIB



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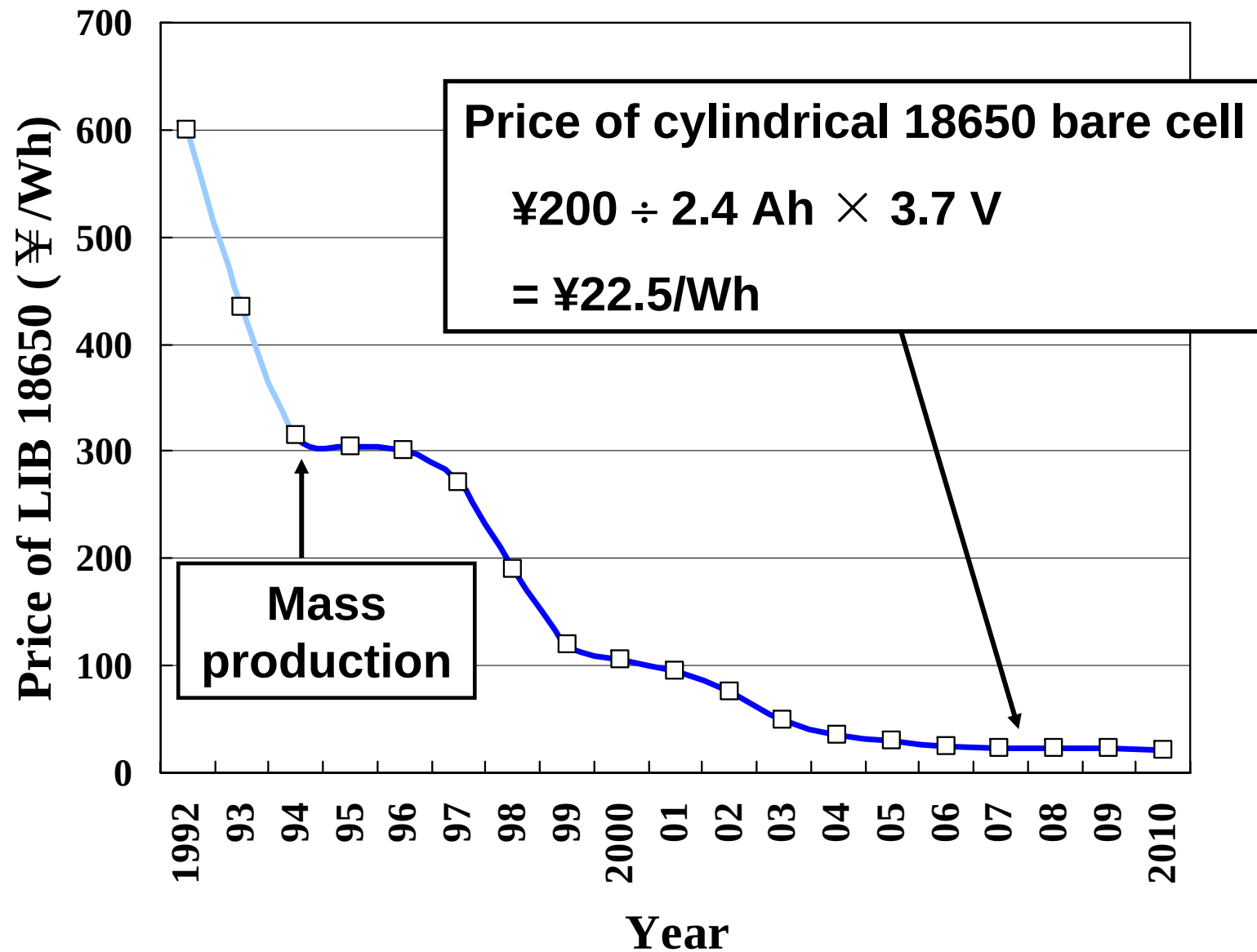
Enhancement of LIB energy density (cylindrical 18650)

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LIB price trend

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**Results of the IT revolution and prospects
for the ET revolution**
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LIB market and IT revolution

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1981	Start of research	Research (Devil's River)
1985	Invention of the current LIB	Development (Valley of Death)
1991-92	Commercialization	Application (Darwinian Sea)
1995	Market growth (start of the IT revolution)	
2000	When did the IT market become dominant? What was the key?	

Key factor for the rapid expansion of the LIB market

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Early 1990s

First-generation analog mobile phones

5.5 V to drive the ICs → either 5 Ni-MH cells
or 2 LIB cells

From 1995

Start of LIB market growth for IT devices

Second-generation digital mobile phones

3 V to drive the ICs → either 3 Ni-MH cells
or **one LIB cell**

**Reducing required voltage to 3 V enabled
mobile phones to use a single LIB cell**

2000 onwards

Rapid growth of the LIB market for IT devices

Third-generation mobile phones (IMT-2000)

LIB market and IT revolution

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1981	Start of research	Research (Devil's River)
1985	Invention of the current LIB	Development (Valley of Death)
1991-92	Commercialization	Application (Darwinian Sea)
1995	Market growth (start of the IT revolution)	Single cell LIB for mobile phones
2000	Rapid growth of the LIB market for IT devices = dominance of the IT market	

Outlook for the ET revolution

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2000

Research
(Devil's River)

2005

Development
(Valley of Death)

2010 Commercialization of ET products

Application
(Darwinian Sea)

2015 ET market growth (start of the ET revolution)

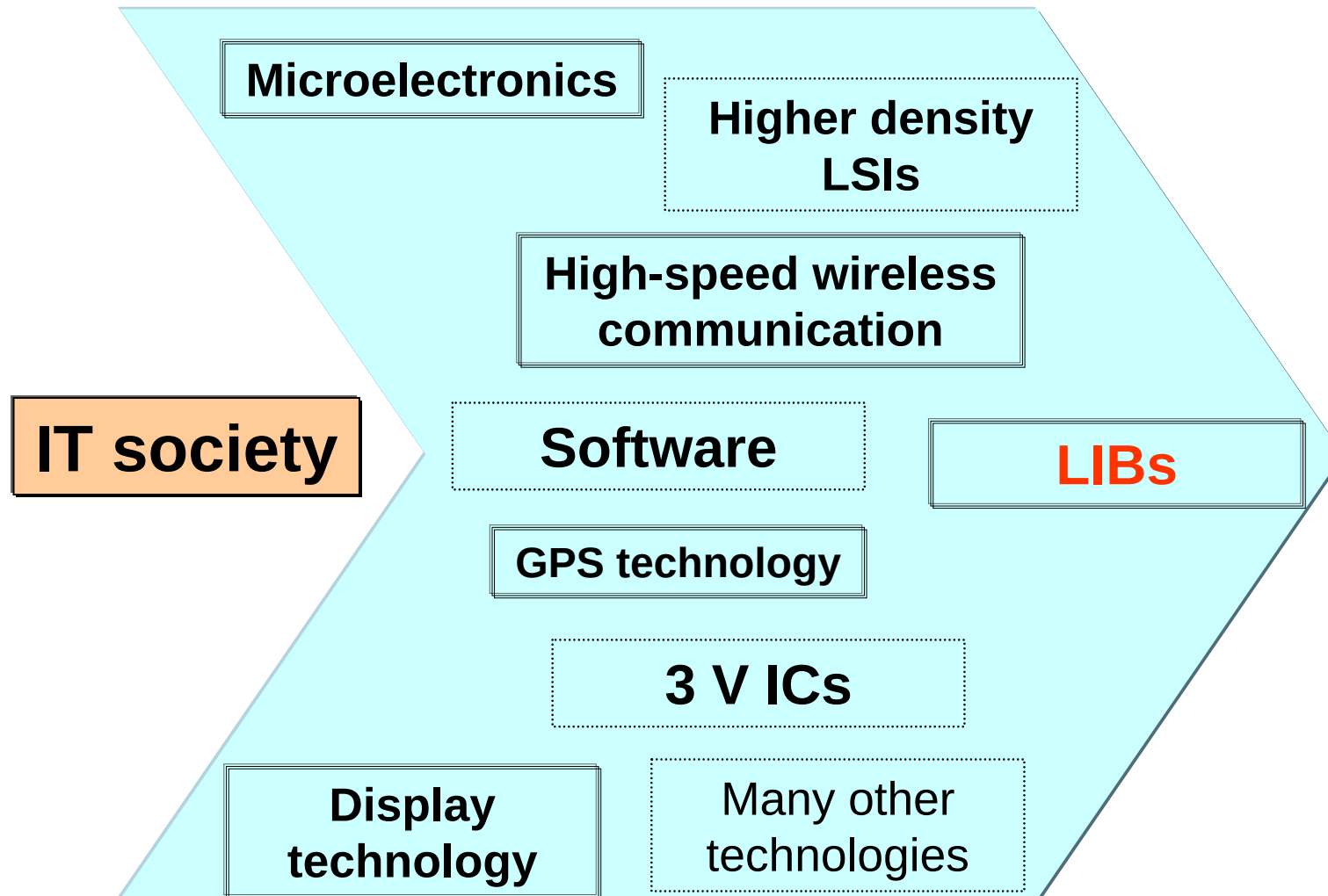
What is the key?

2020 Rapid growth of the LIB market for ET products
= dominance of the ET market

Key developments for ET devices

- Cell voltage in the 100s of volts?
 - New technology for bipolar electrodes
- Wireless charging technology?
 - Electromagnetic induction,
electric/magnetic field resonance,
radio wave reception
- Many other possibilities...

Key technologies that enabled the IT revolution



Key technologies that will enable the ET revolution (2020 onwards)

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