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Prototype Micro Fuel Cell for FOMA Terminals

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As FOMA terminals become increasingly sophisticated, they consume more power. We have investigated and manufactured a prototype micro fuel cell as a promising high-capacity replacement for current lithium-ion batteries.

1. Introduction

Freedom Of Mobile multimedia Access (FOMA) terminals now incorporate a video phone function, and the introduction of unlimited-packet-use services are promoting increased use of i-motion and i-appli applications, and these consume more power. There are also plans to develop applications in support of digital television, and these are expected to further increase the demand for power. While it's true that lithium-ion batteries, the current power source for mobile terminals, have made a great contribution to the spread of mobile terminals because of their high energy density, they cannot be expected to provide a significant increase in battery capacity.

From the background above, research on the application of high-capacity have seen much recent years, environment-friendly micro fuel cells to mobile devices like notebook computers. Compared to conventional fuel cells that were used in relatively large equipment like own generators (several hundred kilowatts and higher), new proposals for micro fuel cells of the Direct Methanol Fuel Cell (DMFC) type raise the possibility of compact batteries with capacity of several watts. With the aim of developing an optimal fuel cell for FOMA terminals, we have performed technical studies on what performance this fuel cell must provide and have manufactured a prototype for evaluation.

This article describes the current state of conventional lithium-ion batteries and new micro fuel cells for mobile terminal, presents the results of a study and prototype manufacturing for one type of the latter, and our future plans for micro fuel cells.

2. Current State of Batteries and Chargers for Mobile Terminal

Figure 1 shows the configuration of a typical power supply system for mobile terminals [1]. An Alternating Current (AC) is converted to Direct Current (DC) via AC adapter, and then input into mobile terminal. This power is then input to the lithium-ion battery pack via a charge control circuit and used for battery charging. This type of battery has significantly contributed to the downsizing of mobile terminals because of its high-energy-density and high-voltage (about 3.6 V) features. But the increase in the energy density of these batteries has recently started to slowdown (**Figure 2**), and the appearance of an alternative battery is anticipated. One promising candidate is the fuel cell.

The AC adapter for mobile terminal described above has historically been different from one mobile terminal manufacturer to the another since charging and battery specifications differed. With the aim of making the use of mobile terminals more convenient and lowering the cost of AC adapters, we decided to establish common charging specifications for FOMA terminals. We therefore realized an AC adapter that can be used in common by all future FOMA terminals.

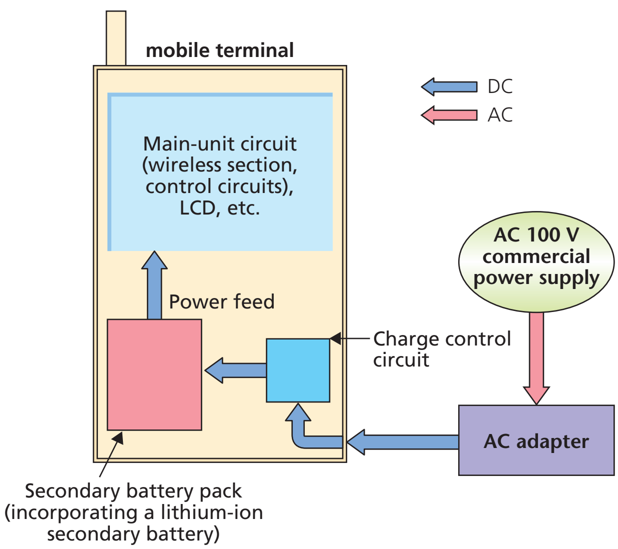


Figure 1 Power supply system for mobile terminals

3. Overview and Current State of Fuel Cells

Table 1 indicates types of fuel cells. In terms of operating temperature, fuel type and ease of manufacture, DMFC is a candidate fuel cell for application to compact devices like mobile terminals. **Figure 3** shows the operation principal of this type of fuel cell. Whereas conventional fuel cells use hydrogen for fuel, DMFC uses methanol (CH_3OH). Here, a platinum catalyst reaction on the fuel-electrode side generates hydrogen ions (H^+) resulting in a power-generating reaction on the air-electrode side according to the following chemical equations.

fuel electrode: $CH_3OH+H_2O \rightarrow CO_2+6H^++6e^-$

air electrode: $6H^++3/2O_2+6e^- \rightarrow 3H_2O$

This fuel-cell scheme supplies fuel and air (oxygen) naturally by a self-breathing method. Compared to conventional fuel cells that require large-scale auxiliary equipment such as fuel-supply pumps and reformers, this simple configuration is quite applicable to small electronic devices like mobile terminals. The DMFC type of fuel cell is also advantageous in terms of safety as it eliminates the need to deal with dangerous hydrogen gas that must be managed appropriately. As shown in **Figure 4**, methanol has high energy density compared to hydrogen (gas/liquid) and is consequently expected to greatly increase

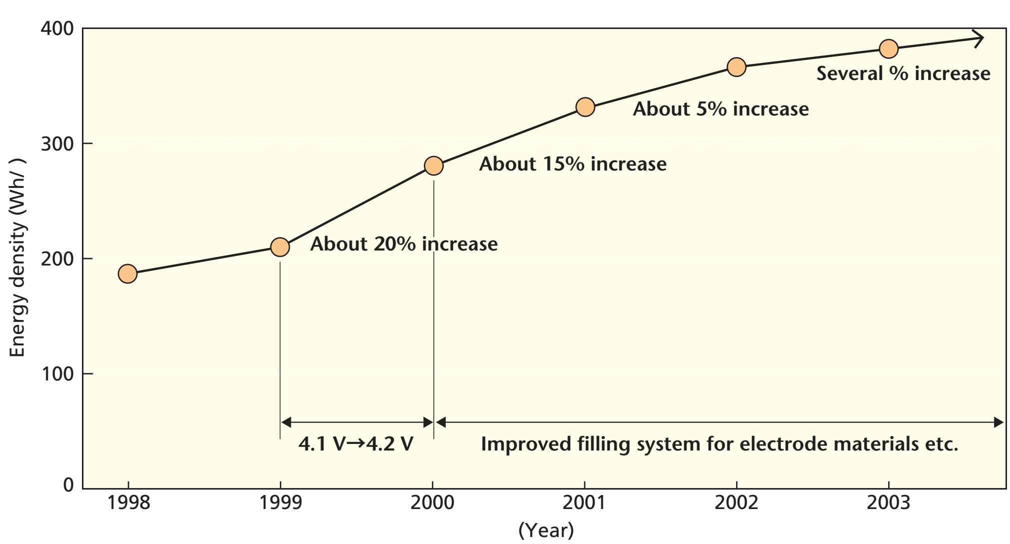


Figure 2 Change in energy density of lithium-ion batteries

Table 1 Types of fuel cells

	Phosphoric Acid Fuel Cell (PAFC)	Molten Carbon Fuel Cell (MCFC)	Solid Oxide Fuel Cell (SOFC)	Polymer Electrolyte Fuel Cell (PEFC)	Direct Methanol Fuel Cell (DMFC)
Fuel	Hydrogen (reformed gas)	Hydrogen (reformed gas), carbon monoxide (reformed gas)	Hydrogen (reformed gas), carbon monoxide (reformed gas)	Hydrogen (reformed gas)	Methanol aqueous solution
Electrolyte	Phosphoric acid	Lithium-carbonate/ potassium-carbonate	Stabilized zirconia	Ion-exchange membrane	Ion-exchange membrane
Ion conductor	Hydrogen ion	Carbonic acid ion	Oxygen ion	Hydrogen ion	Hydrogen ion
Operating temperature	About 200°C	About 650°C	About 1000°C	Room temp.–about 100°C	Room temp.–about 50°C

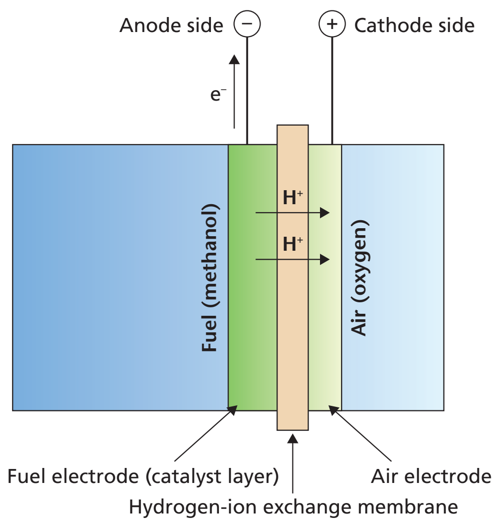


Figure 3 Principle of DMFC-type fuel cell

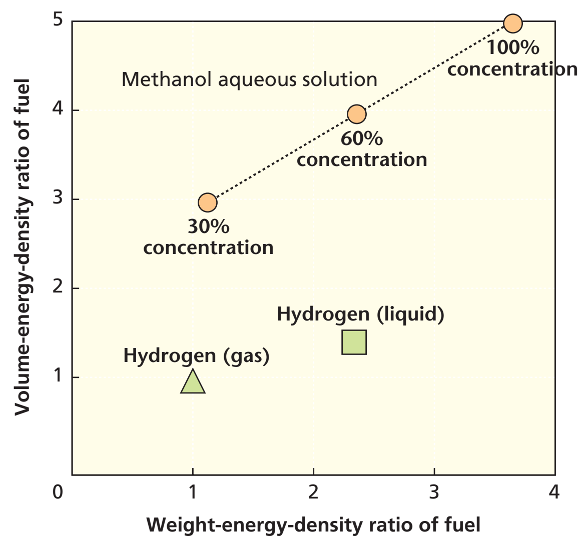


Figure 4 Energy densities of hydrogen and methanol

battery capacity.

Prototypes of a methanol-based fuel cell especially for notebook computers have been announced, and this fuel cell incorporates a pump to drive fuel and air forcibly to raise output density ("DMFC with auxiliary equipment"). For FOMA terminals, the main type of fuel cell under development is the self-breathing DMFC, but as some problems still remain to be solved including difficulty of output, there have been few prototype announcements [2] [3].

4. Requirements of Micro Fuel Cells for Mobile Terminals

Compared to fuel cells for notebook computers that are now being heavily researched and developed, requirements for fuel cells for mobile terminals are considerably tougher. **Table 2** summarizes the main issues of fuel cells for mobile terminals.

"Direction-free" of Table 2 is a capability of operating in arbitrary direction. Taking notebook computers as an example, it is generally assumed that they will be placed on a desk or other horizontal surface during use. Prototype fuel cells for this type of device will therefore be designed for operation in nearly one direction only and no other direction guaranteed. Mobile terminals, on the other hand, calling and standby operations must be possible in any direction according to the way they are used and stored. In short, fuel for mobile terminals must be able to generate electricity in any direction. Furthermore, the small amount of water vapor generated when a fuel cell generates electricity must be prevented from condensing and forming moisture. And if moisture should be generated, it must be possible by some contrivance to reuse that moisture in fuel cell reactions not to let it escape to the outside.

As for lifetime (cycle characteristics), a basic property of a battery, a fuel cell for mobile terminals must be able to be charged and recharged about 500 times, as same as an ordinary lithium-ion battery. Next, noting that output density per unit area corresponds to the capacity of a fuel cell, the output density must be improved for mobile terminal purposes. A previous prototype of a typical self-breathing DMFC fuel cell has an output density of 10–20 mW/cm^2, but at the least, 30–50 mW/cm^2 is needed. It is therefore essential that the output density of the ion-exchange membrane be improved, and to this end, methanol crossover phenomena (in which methanol as opposed to hydrogen ions passes through the hydrogen-ion exchange membrane) must be suppressed. This calls for the development of a membrane that can be easily permeated by hydrogen ions but difficult for methanol to pass through.

Meanwhile, the booster circuit must be able to control voltage and current in line with common FOMA charging specifications. Here, we can consider a circuit configuration that uses switching-power-supply technology to perform such control operations at high efficiency.

5. Prototype Micro Fuel Cell and Evaluation

Referring to the development issues of micro fuel cells for mobile terminals described in the previous chapter, we conducted a study and manufactured a prototype fuel cell that can be used with FOMA terminals.

Table 2 Main development issues of fuel cells for mobile terminals

Development item		Importance
Mechanism-related	Direction-free	◎
	Anti-condensing	◎
	Small and light	◎
Performance of ion-exchange membrane	Lifetime	◎
	Output density	○
	Temperature characteristics	○
	Startup time	○
Booster circuit	Common charging specifications, high efficiency	◎

Figure 5 shows a block diagram of the prototype device, **Photo 1** shows an external view of the actual prototype and **Table 3** lists its specifications. As shown in Fig. 5, six sets of two reaction cells connected in parallel are connected in series (6-series/2-parallel configuration). The center section of this arrangement consists of a fuel layer, which is sandwiched by fuel electrodes of the reaction cells. Here, the air electrodes of the reaction cells are placed on the outside (top and bottom) to supply air (oxygen). Each reaction cell generates an electromotive force of above 0.6 V making for a total generated voltage of about 3.6 V for this 6-series/2-parallel configuration. To boost this voltage to the 5.4 V needed by FOMA terminals, we adopt a booster-type switching power supply (DC/DC converter) that can provide stable output power at high efficiency.

This prototype fuel cell for use with FOMA terminals has been designed for charging FOMA terminals and for providing power assistance while calling. These two functions are achieved by adopting a cradle-type format that enables the FOMA terminal to dock with the fuel cell so that the latter can be used for either charging or calling. For this prototype, moreover, we've adopted a system that feeds a methanol aqueous solution of 30% concentration from a fuel cartridge to the reaction-cell section. One cartridge holds about 22 cc of fuel making for about 3 Wh of generated power (the amount of power needed for charging an 800 mAh lithium-ion battery pack one time). When fuel runs out, the user needs only to replace the fuel cartridge to restart power generation in a relatively short time (several minutes). This signifies a great improvement compared to the charging time of about 90 min for conventional lithium-ion

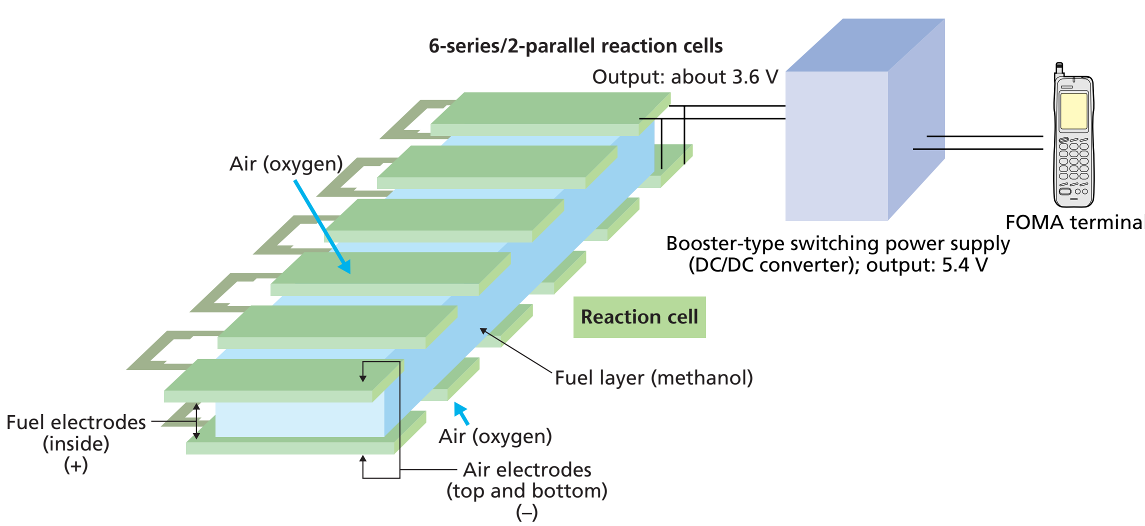


Figure 5 Prototype device for FOMA terminals

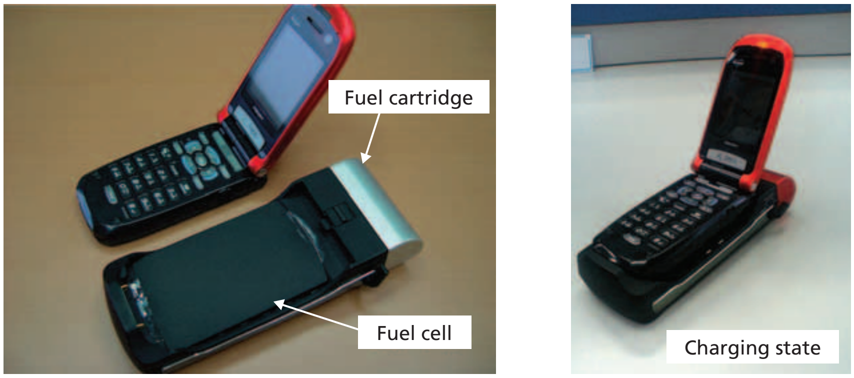


Photo 1 External view of prototype device

Table 3 Specifications of prototype fuel cell

Type	DMFC (direct methanol)
Size	About 180 cc
Fuel	Methanol aqueous solution 22 cc (30% concentration)
Fuel supply method	Cartridge
Output capacity	About 3 Wh (22 cc)
Output voltage	5.4 V

batteries.

Figure 6 shows output characteristics during power generation by one reaction cell of this prototype device. It can be seen that voltage decreases with increase in current density, and that output density, the product of current and voltage, exhibits a maximum value. We therefore adopted a reaction-cell output density of about 50 mW/cm^2, which satisfies our target range of 30–50 mW/cm^2 described in the previous chapter.

Figure 7 shows current and voltage characteristics when charging a lithium-ion battery used by FOMA terminals by this prototype device. This power generation corresponds to about 800 mAh, which is a level of performance capable of charging one battery pack.

Figure 8 shows the reaction-cell configuration for achieving direction-free operation, which is one of the development issues of fuel cells for FOMA terminals discussed earlier. For a 6-series/2-parallel arrangement of reaction cells, the fuel level may change as device orientation and the amount of fuel itself change. Dividing up the fuel cell into multiple reaction cells (6-series/2-parallel), however, provides an optimal arrangement (optimal setup of liquid level and fuel electrodes) for maintaining the minimally required contact area between fuel and reaction cell and preserving the amount of power generated even if the liquid level changes. Furthermore, while output voltage may change due to change in liquid level, the fuel cell is configured so that the amount of change in voltage can be compensated for by the DC/DC converter. This means that required power can still be generated even for the device orientation of Fig. 8 (b) in which fuel is deficient and in contact only with the lower section of the reaction cells.

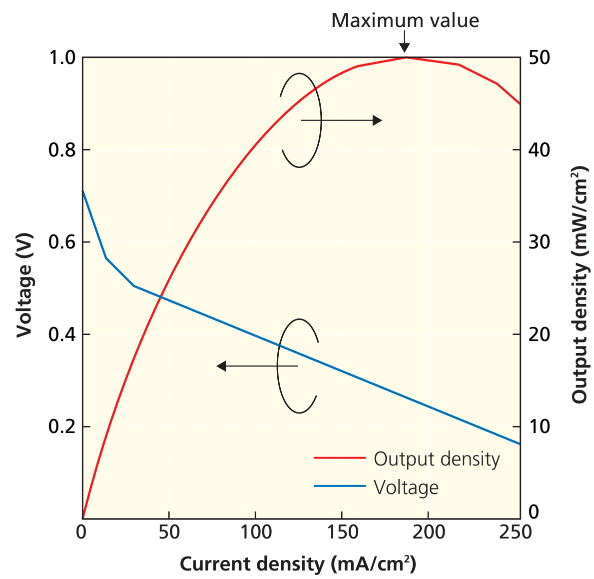


Figure 6 Output characteristics of prototype device

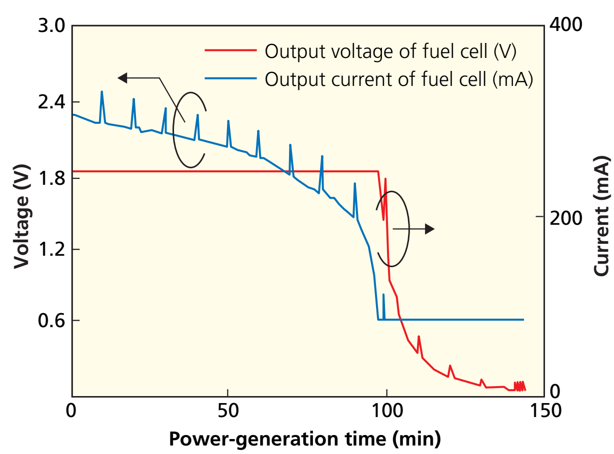
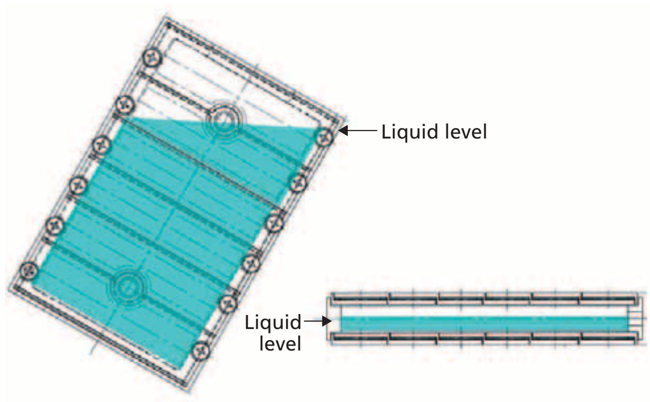


Figure 7 Current and voltage characteristics of prototype fuel cell



(a) When fuel is deficient (tilted) (b) When fuel is deficient (horizontal)

Figure 8 Direction-free reaction-cell configuration

Next, in terms of reducing methanol crossover, we decided to replace the fluorine-based solid electrolyte membrane (Nafion) [2] used by many past DMFC-type fuel cells with an aromatic hydrocarbon membrane [4] (**Table 4**). This new material results in a methanol penetration speed of about 1/10 that of the past membrane. The end result is reduced crossover and less wasted fuel thereby improving output density.

Figure 9 shows temperature characteristics, an important issue in fuel cells, for this prototype device. The device was operated while holding the operating temperature of the internal reaction cell to about 45ºC, but it can be seen from this plot that output will drop at operation startup and in a low-temperature environment. Preventing such temperature change requires a mechanism that can use the heat generated during reaction to maintain the temperature of the reaction cell (such as by introducing heat-insulating material). Such a mechanism would prevent thermal diffusion to the outside and, as a beneficial side effect, suppress a rise in temperature in the outside case.

One filling of fuel gives this prototype fuel cell the capacity of one built-in battery of a FOMA terminal. Accordingly, when using the fuel cell to provide power assistance while calling, calling time can be doubled in conjunction with the mobile terminal's built-in battery. We aim to improve energy density to achieve a capacity of three built-in batteries with one filling. This would effectively quadruple calling time in conjunction with the mobile terminal's built-in battery, a feature that should have commercial prospects.

6. Future Issues and Plans

The prototype device introduced here represents a micro fuel cell developed for external use with a FOMA terminal. For the future, we plan to make the cradle-type fuel cell more commercially attractive and to develop a built-in version of the fuel cell for FOMA terminals as depicted in **Figure 10**. Many issues, however, must be solved before the built-in batteries of FOMA terminals can be replaced with fuel cells. These include making the fuel cell smaller and more efficient, increasing its capacity, achieving an effective fuel-supply system, and dealing with generated heat and exhaust gas.

Table 4 Features of fuel cell's hydrogen-ion exchange membrane

Ion-exchange membrane	Methanol penetration speed	Average output voltage (V)
Nafion (conventional fuel cells)	1	0.45
Aromatic hydrocarbon membrane (material used here)	0.1	0.39

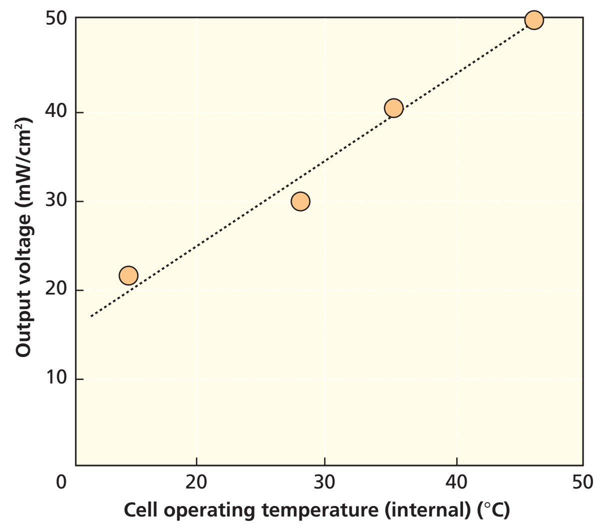


Figure 9 Temperature characteristics of fuel cell

Safety is also an important issue in the field of fuel cells. In parallel with the above plans, we intend to establish a safety assessment method for fuel cells with reference to established procedures for assessing the safety of conventional batteries [5]. **Table 5** lists proposed safety-assessment items that should be considered in the case of fuel cells for FOMA terminals. Our plan is to define mechanical, electrical and environmental test items in accordance with the usage format of FOMA terminals. We also plan to promote the standardization and commercialization of fuel cartridges, and will conduct a survey of regulations restricting the possession of fuel cells aboard airplanes and current worldwide efforts at easing those restrictions.

7. Conclusion

In this article, we described the current state of micro fuel cells, the specifications required of fuel cells applicable to

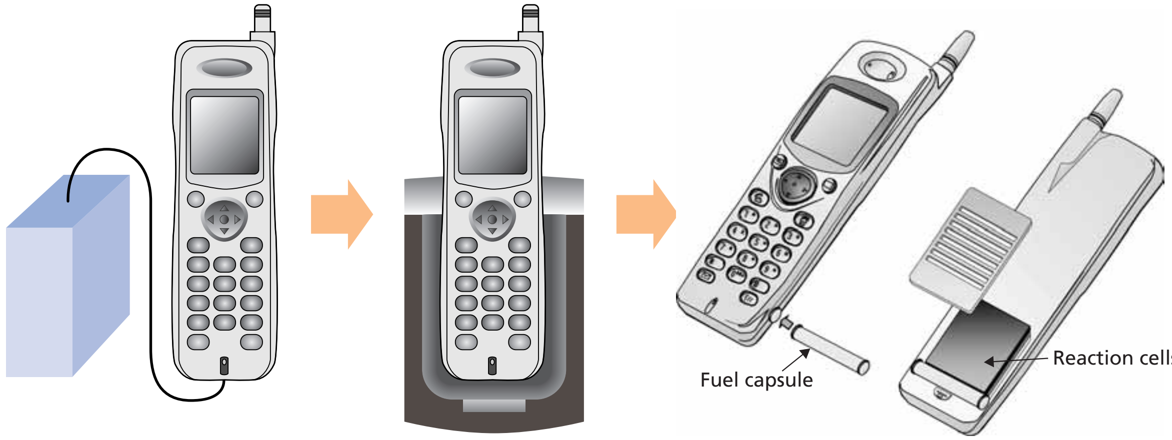


Figure 10 Fuel-cell development plans

Table 5 Proposed safety-assessment items for fuel cells

Safety check items (proposed)	Action	Criteria (proposed)
Mechanical items	Destroy, crush	No heating, fire or explosion
	Drop, vibrate	No heating, fire or explosion
Electrical items	Produce internal /external shorting	No heating, fire or explosion
	Generate over-current, over-discharge	Protection circuit operates
Environmental items	Perfom high/low temperature tests	No heating, fire or explosion
	Submerge and perform leakage test	Operates normally

FOMA terminals and the results of evaluating a prototype fuel cell based on those specifications. Our plans for the future are to increase the number of charging cycles of this prototype device and to conduct studies on the safe operation and a built-in micro fuel cell.

References

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Abbreviations

AC: Alternating Current
DC: Direct Current
DMFC: Direct Methanol Fuel Cell
FOMA: Freedom Of Mobile multimedia Access
MCFC: Molten Carbonate Fuel Cell
PAFC: Phosphoric Acid Fuel Cell
PEFC: Polymer Electrolyte Fuel Cell
SOFC: Solid Oxide Fuel Cell