Magnesium Recycling Society

Takashi Yabe

Professor Emeritus, Tokyo Institute of Technology

Tokyo Institute of Technology : Graduate, Research Assistant
Osaka University,
Institute of Laser Engineering, Associate Professor
Kernforschngs Zentrum Karlsruhe (Germany), Guest Professor
Tokyo Institute of Technology : Professor

1999 : Bicentenary Memorial Lecture at Royal Institution of Great Britain
2009 : Chosen as Heroes of Environment in TIME
2009 : Finalist of World Technology Award, Fellow

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Preface

Now that global warming is becoming more serious, there is a need for an energy system that does not rely on fossil fuels. Solar energy is the ultimate renewable energy, but due to its instability, such as being limited to daytime and being used only in sunny weather, it is not a major energy source to replace thermal power plants. In addition, a large-capacity energy storage system is essential for use at night.

As a method of such energy storage, Yabe proposed in 2004 to use the chemical energy of magnesium, which exists in seawater as much as 1,800 trillion tons (equivalent to 100,000 years of oil). This magnesium recycling society has been covered by many media.

Another problem is water shortage. The world's population is expected to grow from 6 billion in 2020 to 9.73 billion by 2050, which will require 2.2 trillion tons of new water per year. This water is not for drinking water, but for industry, agriculture, etc. Water shortages are also food shortages.

If this water were to be taken from seawater, there would be 2.86 billion tons of magnesium in 2.2 trillion tons of seawater. In fact, 2.86 billion tons of magnesium are generated for energy, which is 19.7 trillion kWh, which is equivalent to the current global power generation of 27 trillion kWh.

In this way, the magnesium recycling society proposed by Yabe is a society in which all countries can be self-sufficient in energy, water, and food.

Yabe has devoted himself to the development of solar-pumped lasers, seawater desalination equipment, laser refining, magnesium drive engines, and magnesium fuel cells, which are the basis of this recycling-oriented society, and has obtained numerous patents.

Since 2006, he published his experiment on a magnesium recycling society in a world-renowned academic journal. In 2009, he was named the top Environmental Hero scientist and inventor by Time magazine. He was also a finalist in the World Technology Awards, sponsored by Time, CNN, Fortune and Science, and is currently a Fellow. All of these technologies have been improved for practical use over a period of more than 10 years, and all that remains is to bring together a group of companies.

Problems with Traditional Technology

Photovoltaic power generation

The problem with solar power generation in Japan is that there are seasons when cloudy days last for more than one week. If it has been cloudy for a week, this portion must be stored.

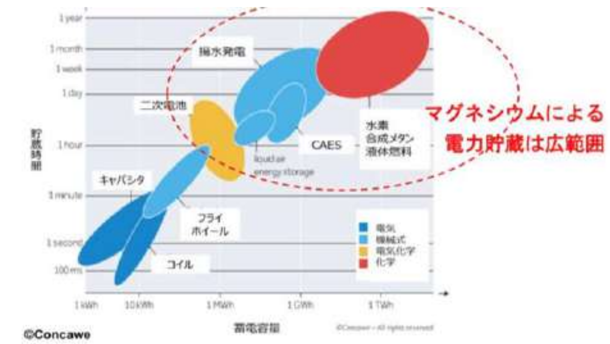
The worst case scenario is that, as shown in Fig. 1, if it continues to be cloudy for one week, then there is only one sunny day, and then it

Figure 1

continues to be cloudy again, the solar light receiving area to supply Japan energy will need 42% of the national land area.

Storage of Electricity

Even if the area of sunlight is secured, another question arises: can this electricity be stored and provided on cloudy days?



図表2.1.9-1　各種電力貯蔵方式の貯蔵容量と貯蔵時間[2)]

(Concawe資料を基にCRDSで追記)

Figure2

Figure 2 is an example of the storage method described in the JST report. Here, it should be noted the yellow secondary battery. It is supposed to be able to use 1 MWh of energy to store at most one day. A normal thermal power plant is 1 million kilowatts = 1 GW, and one day is 24 GWh, so you can see that 1 MWh is too little. The reason for this low number seems to be that the price of large rechargeable batteries is too high and not economically commensurate.

The same is true for wind power. The utilization rate of solar cells is 15%, and onshore wind power generation is said to be 29%. Therefore, it is important to store electricity on a large scale when it is not in operation.

Hydrogen fuel cells

Hydrogen is difficult to store. A 700 bar cylinder cannot be held for several years of waiting. This is because hydrogen gradually leaks out. Storage at -253 ° C is required for storage as liquid.

There are not enough materials for hydrogen storage alloys. In order to convert it into a hydrocarbon compound, transport it, and generate hydrogen when needed, such as Chiyoda Corporation, 30% of the hydrogen electricity is required, so it cannot be used in places without electricity.

The only solution announced by Yabe in 2006 is to generate hydrogen by the reaction of magnesium and water.

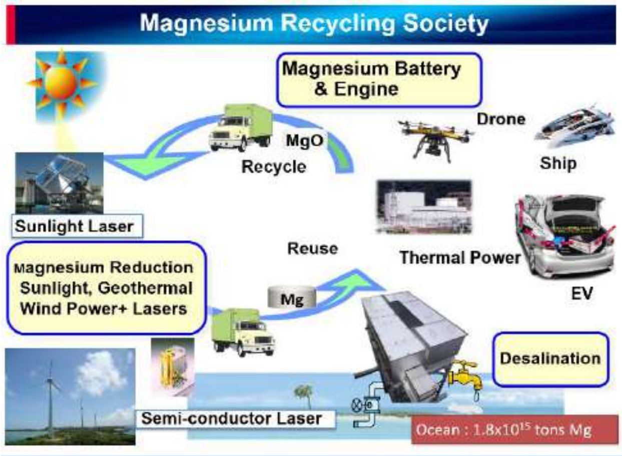


Figure 3

Magnesium Recycling Society

There exist 1,800 trillion tons of magnesium in ocean. Magnesium is abundant even on land where the sea is raised by tectonic movements. In 2004, Yabe proposed to use it for energy circulation.

The concept is to extract magnesium by desalination of seawater, use it for thermal power generation, magnesium batteries, etc., and regenerate the spent fuel with lasers using natural energy such as solar, wind, geothermal, and hydroelectric power to return it to the original magnesium (Fig. 3).

For this, it was necessary to manufacture the device at each stage. Over the past decade or so, we have developed the following five technologies.

Magnesium-fired power generation
Magnesium fuel cell
Seawater Desalination Equipment
Laser refining equipment
Solar-pumped laser

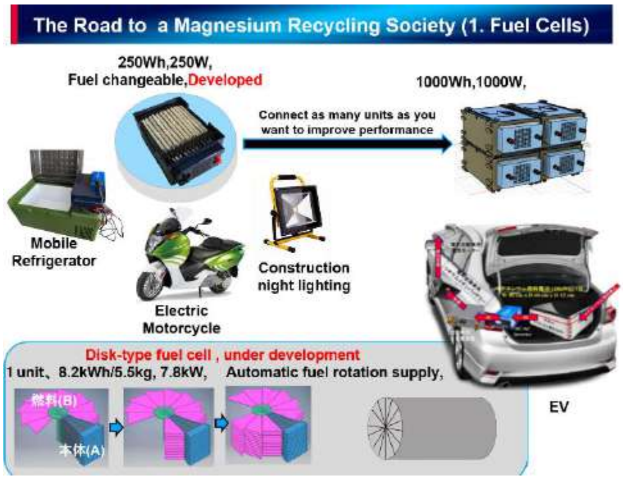
In the following, we will describe the current status of each technology.

Magnesium Fuel Cell

The closest product to practical use is batteries. Yabe has a battery concept as shown in Figure 4. The first is a small battery that manually inserts and removes magnesium. Then, gradually proceed to a device where magnesium fuel is automatically inserted.

Small battery

Lithium-ion batteries are made by bundling small modules to form a large battery. This product also aims to increase the size by bundling a large number of modules.



This smallest module has a capacity of 250Wh and a maximum power output of 250W (Figure 5). This size is 20 cm x 14 cm x 10 cm.

The fuel is not disposable, but it is a fuel-injected power feeder that can be used as many

Figure5

times as you like by replacing the magnesium fuel cassette. We are also promoting the recycling of spent fuel.

Auto-Feed Fuel Cell

Battery capacities are compared in Wh/g. It is the capacity accumulated per unit weight. The lithium-ion battery is only 0.176 Wh/g. On the other hand, the amount accumulated in a single magnesium sheet is 1.5 Wh/g, which is nine times as much.

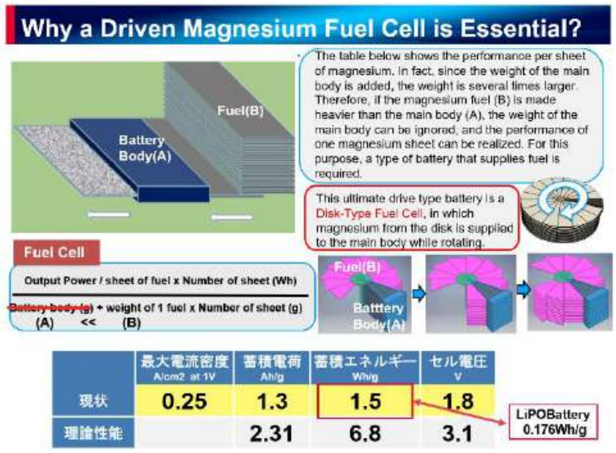


Figure 6

But usually the weight is the weight of the entire battery. If magnesium is contained in the main body as shown in Fig. 6, the weight includes both, so it is much smaller than 1.5 Wh/g.

But there is a way to solve this. As shown in the upper left of Figure 6, let's assume that fuel is outside the main unit and fuel is inserted into the main body sequentially. At this time, in a situation where the fuel becomes heavier than the main unit (A<<B), the weight of the main unit becomes negligible, and the electrical capacity of one magnesium can be realized. These batteries are called fuel cells. It is the same as a gasoline car that burns gasoline to generate power.

Yabe has devised and patented a number of such fuel-injected batteries, but finally came up with the ultimate fuel cell called a disk type.

The red part in Figure 7 is magnesium fuel. The blue part is the battery itself. Magnesium is injected into the battery body while rotating, and exits when the reaction is complete.

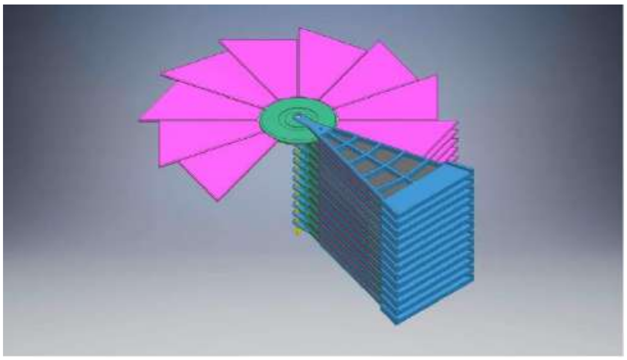


Figure 7

Medical Applications

This battery can be expected to have various applications. For example, a dialyzer (Figure 8). The dialyzer needs 1.5kW and must be used per person for 4 hours (6 kWh). In the event of a power outage or in places where there

Figure 8

is no electricity, batteries are required, but lithium-ion batteries are expensive and cannot treat multiple people when they cannot be charged.ニ

One Yabe battery weighs 5.5 kg and can deliver 8.2 kWh, as shown in Figure 8. We are planning to make the entire fuel cell the size of Figure 9 so that it can be removed. In this way, the six units can be replaced sequentially and supplied with electricity as many times as you like.

Figure 9

Electric Vehicle

Once such a system is completed, it can be used for electric vehicles. The Nissan LEAF has a battery of 40 kWh, so a capacity of 49.2 kWh can be achieved with 6 units. Moreover, with this capacity, the lithium-ion battery weighs more than 200 kg, but the Yabe battery weighs only 33 kg.

One unit of fuel weighs only 5.5 kg, so if you load a lot of it, you can run without worrying about charging stations.

In addition, the 1mm thick magnesium plate has been proven not to burn even after a few minutes of lit lighter, making it an extremely safe power source even when stored in large quantities.

Electric vehicles are currently being popularized by loading lithium-ion batteries and charging them at charging stations. However, charging a 60 kWh battery currently takes several hours. Some people say that if the battery is

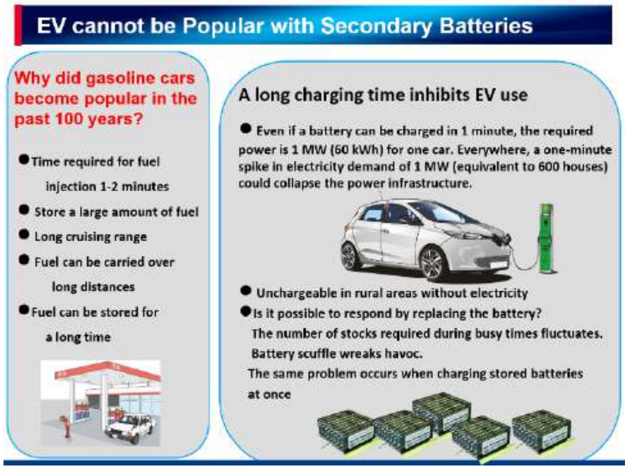


Figure 10

improved, it will be able to charge in one minute, so there is no problem, but the problem is not the battery. Take a look at Figure 10. If you try to charge a 60 kWh battery in 1 minute, you need 1 MW of power. This is enough electricity for about 600 houses. If this is used for a minute all over town, there will suddenly be a 1MW power request spike everywhere. Such a power system is impossible.

You might think you could just store the charged batteries at the station and reload them, but that doesn't change the situation. First of all, the question is how many batteries to store. You never know when and how many cars will come at once, and when the stored batteries run out, you will need to charge them in the same short time. I think many people have experienced a line of refueling vehicles at gas stations in the city only for a certain amount of time.

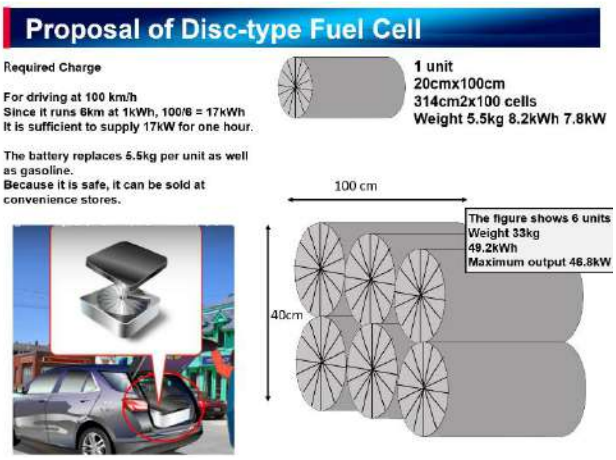


Figure 11

Figure 12

The usefulness of disc-type batteries does not stop there. Magnesium batteries cannot be stopped once battery reaction occurs. You have to use it up until the end. If an oxide film forms on the surface and is left as it is, even if you try to start it again, the oxide film will interfere and the battery reaction will not occur.

Drones & Flying EVs

Currently, drones use lithium polymer LiPO batteries, but they all have a flight time of about 20 minutes. If you load your luggage on it, all of them will fly for only a few minutes. The electrical capacity per weight is only 0.176 Wh/g for lithium polymer batteries. On the other hand, magnesium batteries are currently 1.5 Wh/g. In the future, it will increase to 6.8 Wh/g. With this, even at present, it is possible to fly for 3 hours. Such performance is essential for traffic jams and package delivery. The future is promising.

Up Close Water Famine

The world's population is expected to grow from 6 billion in 2020 to 9.73 billion by 2050, which will require 2.2 trillion tons of new water per year. This water is not for drinking water, but for industry, agriculture, etc. Water shortages are also food shortages.

At this time, the amount of water to be produced will be 6 billion tons per day. Typical reverse osmosis desalination equipment has a daily production capacity of 400,000 tons, so we must make 15,000 units by the end of 27 years. This would be impossible. In addition, RO uses 13 trillion kWh/year of electricity to produce 2.2 trillion tones of fresh water per year, which is about half of the world's total electricity use.

Rather, Yabe aims to produce 600 million small freshwater devices with a daily production capacity of 10 tons. It is possible to produce 600 million refrigerator-sized units. The desalinated seawater contains 2.86 billion tons of magnesium annually. This is 1/3 of the 10 billion tons of fossil fuels currently used worldwide per year. Therefore, in three years, magnesium will replace energy in the world. We will continue to work toward this goal.

Compact, energy-saving seawater desalination equipment

For this purpose, the seawater desalination equipment developed has the following three main features:

High-Efficiency Evaporation Method at Atmospheric Pressure

This desalination device uses the phenomenon of rapid evaporation of water by crushing and atomizing it by rotating blades. Evaporation occurs in a short time, even at atmospheric pressure, in an environment below 100 degrees. Therefore, the device can be made of inexpensive materials such as plastic.

There is a common misconception, but boiling and evaporation are different. Evaporation is a phenomenon in which water leaves the surface of water. On the other hand, boiling is a phenomenon in which bubbles form inside water. The boiling temperature is called the boiling point. However, evaporation also occurs at temperatures as low as below the boiling point.

Figure 13

As can be seen from the fact that sweat dries (evaporates) even when the ambient temperature is 30 degrees Celsius when humans sweat, evaporation occurs even at low temperatures (Fig. 13). However, the evaporation rate is very slow, so in order to rapidly evaporate that only occurs from the surface, it is necessary to increase the surface area extremely. For this, it is necessary to make the water droplets extremely fine.

This miniaturization method is almost the same as the microbubble generation principle that Yabe invented in 1973 in his research on fish farming to supply sufficient oxygen to water. As shown in Fig. 14, unglazed tubes are often used to supply oxygen to goldfish, and fine bubbles are released when air is pumped into them.

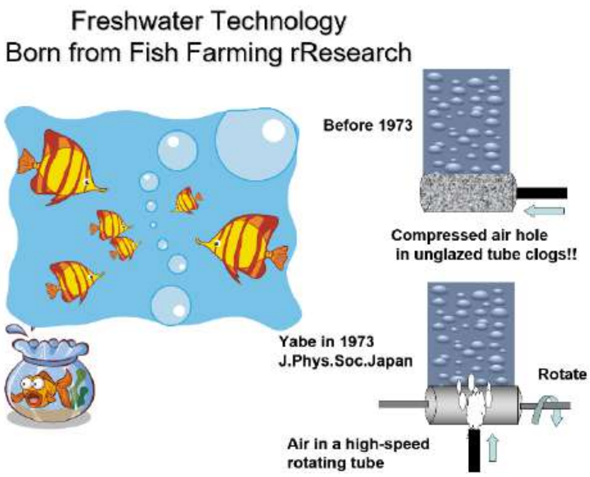


Figure14

However, where a large number of fish are farmed, the micropores of this unglazed grill become clogged with dirt and become unusable. Instead, Yabe et al. found that when air is applied to a cylinder rotating at high speed from below, it is pulverized by rotation and becomes a microscopic bubble, and the bubble diameter decreases in inverse proportion to the square of the number of revolutions. In freshwater equipment, the roles of water and air are reversed, generating microscopic water droplets and increasing the evaporative surface area.

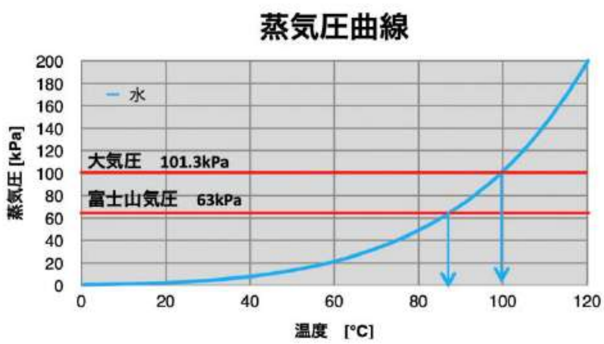


Figure 15

The conventional multi-stage flash method does not use such fine water droplets, so boiling is used. As shown in Fig. 15, the boiling point is 100 degrees Celsius at 1 atm, but it drops to about 87 degrees Celsius at 0.63 atm at the summit of Mt. Fuji. Using this, they use a low-pressure container to lower the boiling temperature.

Unlike this, Yabe desalination equipment evaporates even at atmospheric pressure, so the container can be plastic, which is very easy and inexpensive to manufacture.

Membrane-Free Filtration Method

In reverse osmosis membrane methods, salt water is filtered using a membrane. But if the salt gets on the membrane surface, it becomes unfilterable, so this must be washed off. In addition to salt, various components contained in seawater are discharged into seawater at high concentrations, resulting in pollution of the surrounding oceans.

For Yabe's desalination equipment, we devised a completely new filtration method that does not use membranes. With no pressure loss, even ultrafine particles can be removed.

This device was made for the purpose of recovering magnesium, so it does not release any high-concentration seawater to the outside. Inclusions such as magnesium and salt can be recovered as solids.

Single-Stage Heat Recovery

It takes 24 GJ of energy to evaporate 10 tons of water. This is an enormous amount of energy that requires 278 kW of electricity in 24 hours.

24 GJ of energy is required for evaporation,

and the same 24 GJ of energy is released when this is condensed. If this energy can be used for evaporation, almost no electricity is required. However, heat cannot move from cold to hot.

This is achieved using a method called multi-stage flash (MSF). The heating energy can be reduced by the number of stages. For example, if you use 5 stages that change the temperature from 50 to 100 degrees Celsius in 10 degrees Celsius at each stage, you only need 278/5 = 55.6 kW, which is 1/5 the energy.

Can this be 50 steps at a time? If possible, the energy requirement will be reduced to 1/50, but it is not so easy. It is not efficient to move a single-stage low-pressure device with a difference of only one degree. The cost of building a 50-stage device is also enormous.

Yabe devised a way to achieve the effect of infinite stages in one stage. For this reason, it was the world's first desalination method to be performed at atmospheric pressure. Therefore, it became possible to create energy-saving and inexpensive equipment.

Since evaporation is carried out by external heating, various heat sources such as solar heat, gas combustion, and waste heat can be used.

Figure 16

As shown in Fig. 16, the heat boiled in a solar water heater can supply the heat necessary for evaporation, so it can be used in places without electricity.

Harvesting Magnesium

Seawater desalination produces not only water but also salt and magnesium. However, the current reverse osmosis membrane method and multi-stage flash method cannot collect magnesium. This is because:

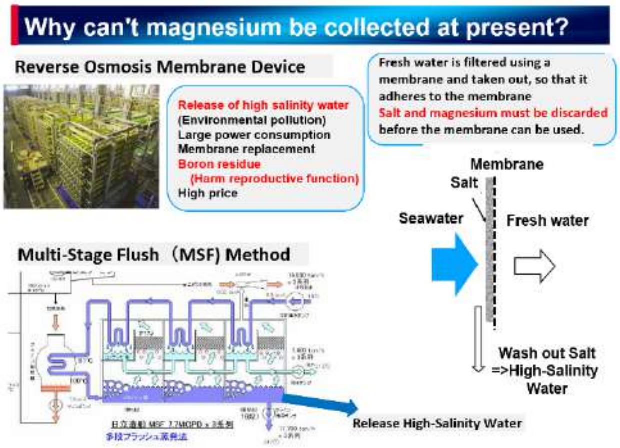


Figure 17

In the reverse osmosis membrane method, salt is taken by a membrane with micropores, but when salt covers the surface of the membrane, it loses its function and salt must be constantly washed away. Only one-third of the seawater becomes fresh water, and the rest becomes

Figure 18

highly concentrated seawater and must be returned to the sea. In this way, magnesium, which is a valuable resource, cannot be extracted.

On the other hand, the Yabe method is specialized for collecting magnesium, and magnesium and salt can be collected in solid form.

It is not to say that there has been no way to extract magnesium from the ocean until now. Take a look at Figure 19. Earlier, there was an electrolysis method. Magnesium chloride is extracted by electrolysis.

However, what is contained in the sea is hydrous magnesium chloride, which is a strong connection between water and magnesium chloride. As it is, electrolysis is not possible. So, when this is heated, it separates into hydrochloric

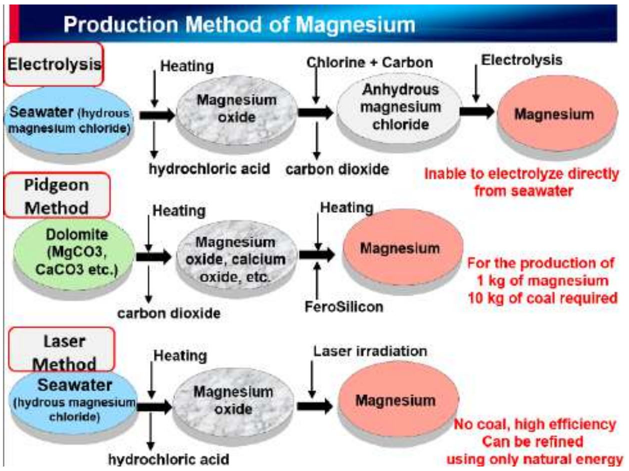


Figure 19

acid and magnesium oxide.

When chlorine and carbon are added to this, anhydrous magnesium chloride is formed, which can finally be electrolyzed. In order to carry out such a complex process, a large amount of electricity was required, and the main method of burning coal called the Pigeon method to reduce magnesium oxide to obtain magnesium became the main. The Pigeon method requires 11 kg of coal to make 1 kg of magnesium, so it has a large environmental impact.

Yabe devised a completely new laser method to create a magnesium recycling society.

Example of Execution

Figure 20 shows a photograph of an experiment conducted at a sewage treatment plant in Taizhou, China. Although it is a small device of about 30 cm, it is an example of completely distilled sewage water.

Figure 20

Laser refining equipment

Magnesium refining can be broadly divided into thermal reduction methods such as the Pigeon method and electrolysis methods. Due to the low manufacturing price, more than 80% of the magnesium currently sold is the heat reduction method by China.

However, since this method uses 11 kg of cokes to make 1 kg of magnesium, using this magnesium in batteries and power generation will cause severe environmental pollution.

Yabe suggested using a laser for this reduction. At first glance, it seems inefficient and expensive, but the advantages of the laser showed that this is not the case. Magnesium oxide is above 4000 degrees and separates into magnesium and oxygen. Including the energy to be separated, energy equivalent to 20,000 degrees Celsius is required.

The heat reduction method tries to do this at

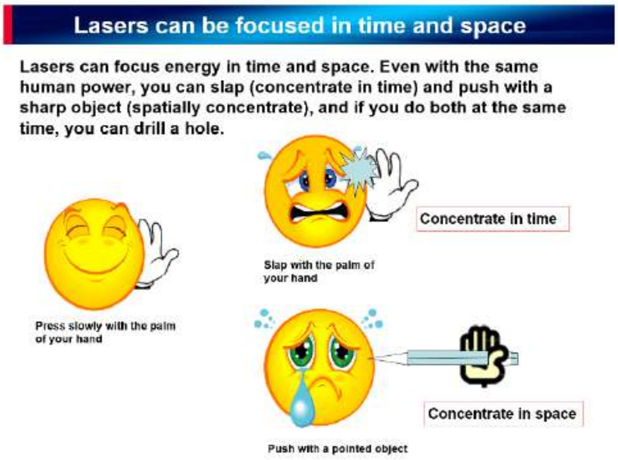


Figure 21

a temperature of about 1200 degrees. In fact, even though it is called temperature, there is a region of high energy distribution at the base of the energy distribution, which contributes to the separation of magnesium. This is one of the reasons why the heat reduction method is inefficient.

See Figure 21. It does not hurt to press the cheek with the palm. It gives pain when you slap the cheek. This is temporal concentration. In addition, it hurts to pierce the cheek with a sharp object such as a pencil. This is spatial concentration. If you do this at the same time, you will get holes, so be careful. In this way, there is no other feature of a laser that can concentrate energy in time and space.

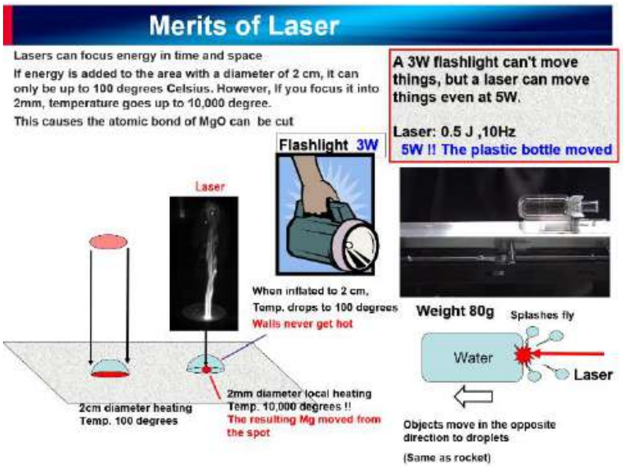


Figure 22

This was used in the experiment shown in Fig. 22. In this experiment, a plastic bottle containing 80 g of water was irradiated with a laser and moved. The laser used at this time uses a pulse of 0.5 J ,10 times per second. It's 5J per second, so it's 5W. Considering that the flashlight 3W hardly moves the object, the experiment that laser is able to move an 80g object at 5W is phenomenal. The experiment was widely reported in Nature and the New York Times. NASA and the U.S. Air Force are researching Yabe's method as one of three possibilities to use it to launch rockets.

In this way, lasers can concentrate energy in tiny areas. As shown in the figure on the left of

Fig. 22, even if the area with a 1 cm diameter is only 100 degrees, if this can be concentrated on the 1 mm diameter, the area will be 1/100, so the same energy will be 10,000 degrees. This allows ultra-high temperatures to be achieved with less energy and efficient separation of magnesium.

Through this experiment, we achieved magnesium production of 20 mg/kJ. This is four times higher than the heat reduction method of 5 mg/kJ. Moreover, we have achieved purity that is not a problem even as a fuel.

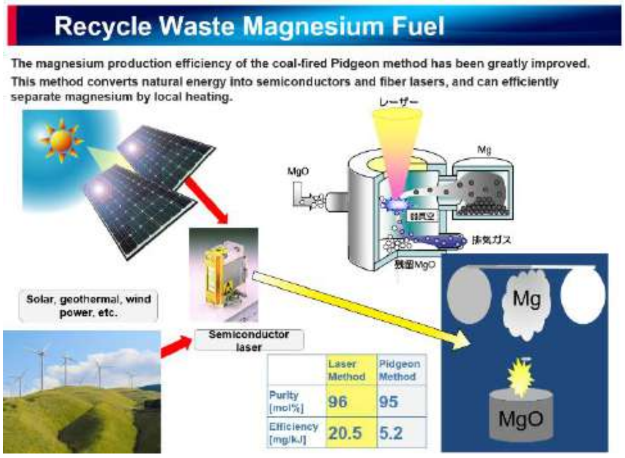


Figure 23

Yabe is pursuing two possibilities for this laser. One is a solar-pumped laser that directly converts sunlight into a laser. The other method is to power semiconductor lasers and fiber lasers with renewable energy such as solar, wind, geothermal, and hydroelectric power. This makes it possible to store unstable natural energy in the form of magnesium for a long time, and it is an environmentally friendly refining method.

When we think of lasers, we think that they are inefficient, but it has been reported that the latest semiconductor lasers operate at 90% efficiency. Even those currently on the market are 50% efficient.

Figure 24 shows a model that combines this commercially available laser and wind power generation, but if the equipment cost of 700 million yen can be used for 20 years, if the production volume is simply divided by the equipment cost, the magnesium production cost will be 56 JPY / kg, which is much cheaper than the current magnesium price of 300 JPY / kg.

In the figure, waste heat not used in a laser with an efficiency of 50% is proposed to be used in the evaporation part of the seawater desalination system. As a result, water and salt can be sold, and sales of 37.6 billion JPY can be secured in one year. In this way, magnesium can be sold at almost zero prices.

The price of semiconductor lasers decreases dramatically as the number of diodes required increases. It is well known that semiconductor prices have plummeted due to mass production. Recently, cheap fiber lasers have become available, and lasers will become dramatically more efficient and cheaper in the future.

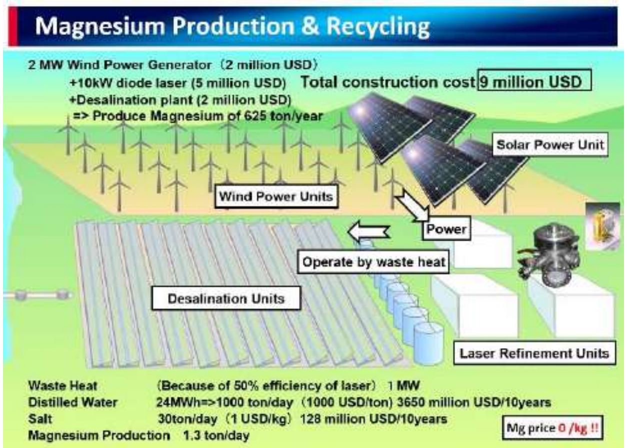


Figure 24