Interpretive Article

"Towards the Future Materialization of an Environment Friendly Railway"

Yukio Arimori
Managing Director, Manager of Technical Planning and Director of the Research and Development Center, JR East Group
JR East Railway Company

The company is undertaking research and development into themes that have to do with the environment with the following three objectives: reduction of CO2 gas emissions, achievement of zero emission, and harmony with the environment along railway routes. Advances in technology are rapid and this age is one of fierce technical innovation that makes it possible within the next five to ten years to accomplish things used to be thought beyond our capability. We conduct our development efforts firmly believing that things that may seem to be but a dream will become reality in the future.

1 Introduction

I will first speak about how JR East Railway Company is contributing to the environment from the technical perspective. The company is undertaking research and development into themes that have to do with the environment with the following three objectives: reduction of CO2 gas emissions, achievement of zero emission, and harmony with the environment along railway routes.

2 Environment Friendly Trains

2.1 Hybrid Vehicle NE Train (New Energy Train)

This is a vehicle (Fig.1) that employs a hybrid system under the concept of reducing the burden on the environment exerted by vehicles through innovation in the propulsion system. The vehicle was completed in the spring of 2003 and is currently undergoing operation testing. The use of fuel cells in the future is kept in perspective and the objective of the development effort is energy saving, reduction of exhaust gas and noise, reduction of maintenance needs, and improvement of operational performance. The biggest issues that must be addressed when developing a new vehicle are safety and stability and in the case of this new train, the main truck and transmission system utilizes the mass-produced E231 Series. For this reason, the train may be operated commercially as soon as the performance of the engine generator or storage batteries have been confirmed.

Upon startup of operation, electric power is supplied from the storage battery. When the speed of the vehicle reaches 25 km/h or more, the engine begins to operate and to generate electricity that is then used to provide motive power to the vehicle. The engine generates electricity at a fixed rotation speed which provides optimum performance and the energy generated is stored in the storage battery.

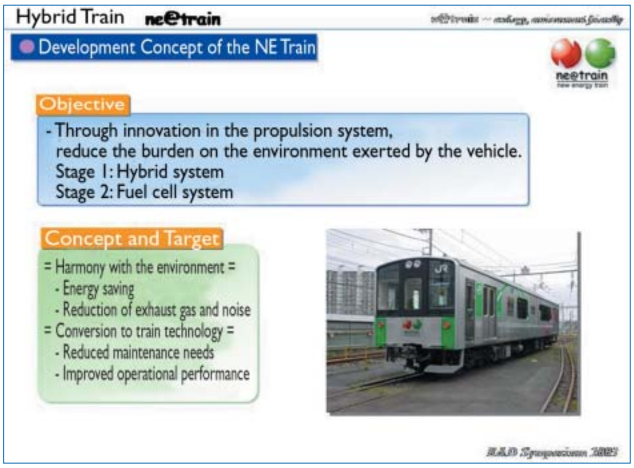

Fig.1: Development Concept of the NE Train

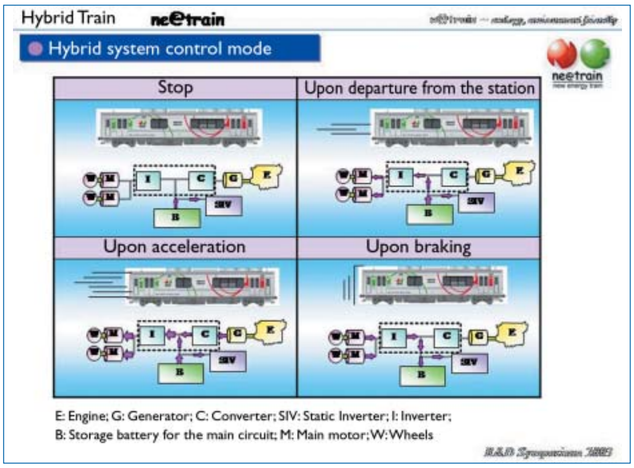

Fig.2: Hybrid System Control Mode

Upon braking, electricity that is produced by the regenerative motor charges the storage battery. Energy that could not be regenerated in legacy rail cars may be stored in the battery as energy and this targets a significant reduction of energy use (Figure 2).

The results of the tests thus far show that the target value of reduction of energy consumption by 20% is close to being met. With respect to operational performance, the train is able to provide acceleration of 2.3 km/h/s at a speed of 35 km/h and this is about on par with normal trains. Since the engine stops when the train stops at stations or is being operated at a low speed, noise at the station platform may also be reduced.

2.2 AC Train: the Next Generation Commuter Train

The development of the AC train has targeted cost reduction, improved stability of transportation, improved services to passengers, barrier free construction, and ecology (Figure 3). Operation testing in excess of 100,000 kilometers has been conducted since last year. The train has a new type of motor called DDM (Direct Drive Motor) and with respect to this, in addition to tests conducted on the prototype train, accelerated tests are being conducted at the Omiya research and development center using a truck testing device repeating run and stop in cycles of 70 seconds. This represents durability test equivalent to 250,000 kilometers of actual operation.

Targeting system change and cost reduction, the structure of the car that has been employed is the articulated structure rather than the bogie structure that is mainly employed in railway vehicles at the present. The motor is DDM and employs a structure whereby the energy from the rotating shaft is conveyed directly to the wheels, thus improving energy efficiency. As there is no gear box, noise is also reduced. With respect to barrier free construction, both the wheelchair slope and wheelchair step are operating in a satisfactory manner. From the perspective of ecology, zero emission has been achieved by using materials that are all recyclable and reusable. Improved services involve the positioning of information service displays in the door pockets to convey various information and advertising to the passengers. With the articulated structure, there is no partitioning between cars and since the length of each car has been reduced, the car structure allows larger car space. Moreover, the AC train uses a conveyance system called LON that reduces wiring by about 60%. This allows for greater safety in that, for example, if one device for closing the doors should break down, the doors can still be operated normally using a different device. ATS-P safety devices are installed in both driver cabs on each end of the train, so that control is possible even in the case of a breakdown. Each system is independent, decentralized, and capable of self-diagnosis.

The AC train employs the articulated structure in order to achieve lighter vehicle weight (Figure 4). In the case of the normal bogie structure of a 10 car configuration, four of the cars provide the driving power. Or in terms of axles, there are 16 drive-axles. There was a problem in that if this car, which is driven by the so-called 4M6T style drive-power, were to be made any lighter, the axle weight of the bogie structure would become too light, and not be able to provide the required degree of traction. For this reason, the articulated structure was employed targeting a lighter weight than the E231 Series

Fig.3: AC Train: the Next Generation Commuter Train

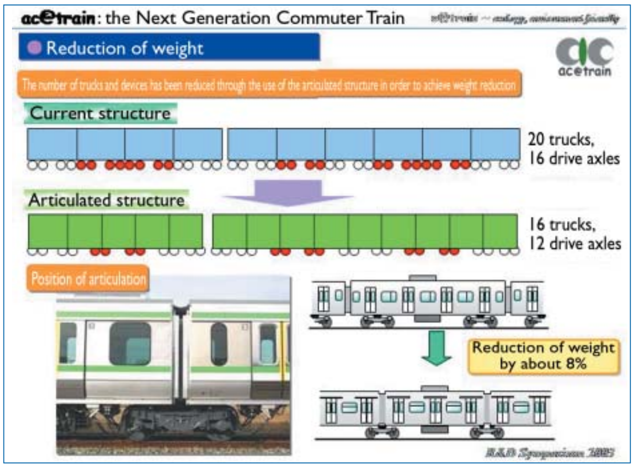

Fig.4: Articulated structure

and reducing the number of drive axles. Since the length of each car is shorter, the number of cars in a train configuration will increase, but with the same total length of 200 meters, there is the merit of a train configuration that is currently being driven by 16 axles being driven instead by 12 axles. The weight of a car as a whole has been reduced by 8%.

The DDM system connects the motor directly to the drive axles (Figure 5). Since the wheels are driven directly, there is no need for a gear box. In other words, the train is operated at the rotation speed of the motor without implementing any step down in the rotating speed. Since the motor rotates at a low speed, the noise from the motor itself is reduced and since there is no gear box, there is no gear box noise. Moreover, a system that does away with the need to intake external cooling air has been devised. As a result, the train is capable in principle of being operated for 13 years without maintenance and the use of DDM has resulted in energy saving of about 10% and reduction of noise of 5 dB compared to the E231 Series.

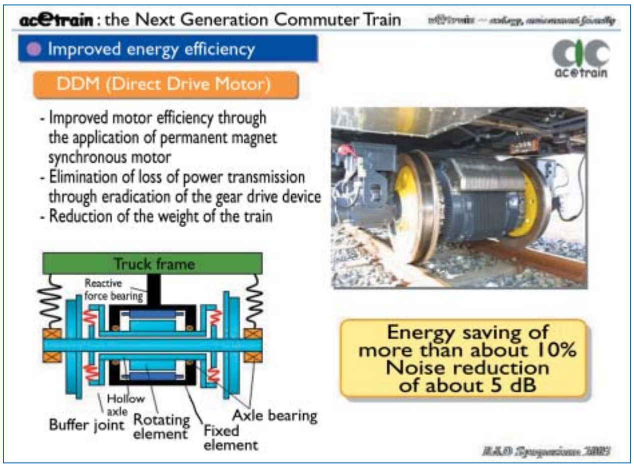

Fig.5: DDM (Direct Drive Motor)

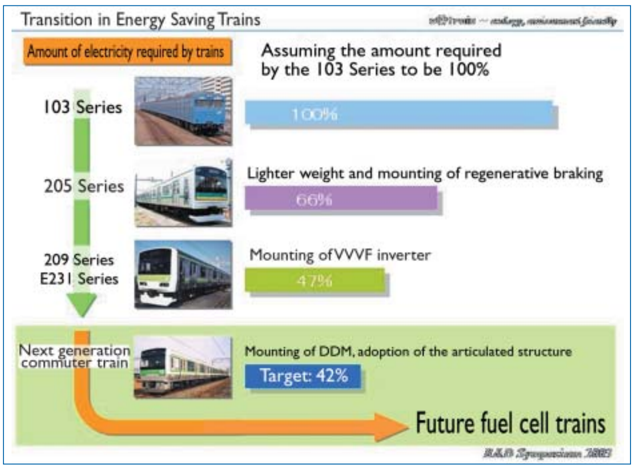

Fig.6: Transition in the Volume of Electricity Required by Trains

2.3 Future Image of Environment Friendly Trains

The final target for the NE train is to mount fuel cells in the place of the engine. It is thought that this will be possible in 10 to 15 years and one of the dreams we envision is to introduce fuel cell trains on the Yamanote line. Here I will explain the feasibility of this in terms of improvement in the fuel cell and the supply of hydrogen as well as the reduction of cost.

The image of a railway route plied by fuel cell trains is a simple one that requires no overhead line equipment (Figure 7). The hydrogen storage tank will, in principle, be mounted on the roof. A direct drive motor will be used and the fuel cell will be mounted below the floor. In the case of the Yamanote line, one complete loop is comprised of 29 stations, and acceleration and deceleration are constantly repeated between these stations so that the energy from deceleration may be stored in a secondary battery to raise energy efficiency. In a review undertaken several years ago, the conclusion was that the fuel cell would need to have considerably large capacity, but by combining it with the secondary battery, it has now become clear that a small capacity fuel cell will be sufficient. Here I will explain the specifications of the fuel cell required for adopting this to the 52 trains of the Yamanote line (Figure 8). Trains on the Yamanote line travel about 400 kilometers per day and the 52 trains as a whole consume approximately 450,000 kWh of electricity per day. The

Fig.7: Image of a Fuel Cell Train

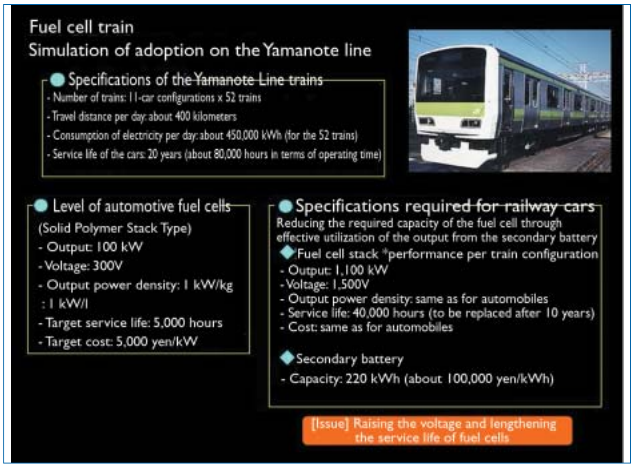

Fig.8: Fuel Cell Trains; Simulation of Adoption on the Yamanote Line

service life of a car is about 20 years, so the service life of the fuel cell will need to be approximately 80,000 hours. A fuel cell with a service life of 80,000 hours is quite a difficult hurdle and specifications are being considered assuming that the fuel cell will be exchanged every 10 years.

The fuel cells employed by automobiles are the solid polymer stack type that achieve output of 100 kW, voltage of 300V, output power density of 1 kW per kg or liter. The service life is 5,000 hours and the targeted cost per kW is reported to be about 5,000 yen. While details have not been disclosed on the cost of automotive fuel cells, in the case of Toyota Motors, as an example, the lease charge for a lease contract spanning 30 months is reported to be 1.2 million yen per month, but even this is seen to be below cost. Assuming the service life of an automobile to be six years, the lease cost will be 60 to 70 million yen. In the case of Honda, the lease charge is 800 thousand yen a month for a lease contract spanning 12 months or the annual amount of 10 million yen, amounting to 60 million yen over the service life of the automobile. When calculated based on these assumptions, since the cost of the automobile itself will not differ much from current automobiles, assuming that the propulsion device may be configured at a cost of several million yen, since the output of the fuel cell is about 100 kW for an automobile, if the above lease cost is appropriate, the cost per 1 kW will be between 500 and 600 thousand yen. In this sense, the targeted cost of the fuel cell for automobiles which is 5,000 yen per kW means that a cost reduction to one hundredth of the current cost level will be required. This would seem a difficult goal, but since the automotive industry is working towards this, we place great expectations on the success of this development effort.

If fuel cells are used on the 11-car trains of the Yamanote line, since the required output will be 1,100 kW, it would be sufficient to mount 11 units of 100 kW each. Since 1,500V are required, it will be necessary to raise the output voltage significantly. The output power density may be the same as that for automobiles. If a cost of 5,000 yen per kW is achieved, the system will be entirely feasible. Even if the cost were several tens of thousands of yen, practical use would be possible. While the targeted service life in the automotive industry is 5,000 hours, railways will require at least 40,000 hours, even assuming replacement after 10 years, and this remains a significant impediment.

With respect to the effect of the introduction of fuel cell trains, the total emission of CO2 gas by the Yamanote line per year is about 60,000 tons that accounts for about 5% of the total emission of JR East Railway Company, excluding emission from Shinkansen lines, and the elimination of this emission will contribute to reducing the overall CO2 emission. If this amount of gas were to be absorbed by forests, an area equivalent to three times the area enclosed within the Yamanote Line would be required, and therefore it can be said that the effect of the use of fuel cell trains will be significant. Another effect will be the fact that the overhead line equipment will no longer be required. Updating to a new overhead line device called the integrated type has just been completed but looking forward to the next update, it is hoped that overhead lines will be eliminated from the Yamanote line in 30 years to provide a rail route that is pleasing to the eyes.

In the case of applying fuel cells to diesel rail cars, there is the problem of the inadequacy of the amount of regenerated energy. In the case of trains that run on light-density lines where the distance between stations is long, there is very little regenerative electricity that can be stored in the secondary battery. In other words, a large capacity fuel cell will be required for each car. However, from the perspective of output, if the type targeted by the automotive industry is achieved, it would be possible to mount multiple cells of this type and there is the possibility that use on diesel rail cars will lead other applications.

The supply of hydrogen is another significant issue (Figure 9). Practical use of up to 350 atmospheres of high pressure hydrogen has become possible. With respect to liquid hydrogen, low temperature management is a problem, as is the fact that hydrogen absorbing alloy is extremely heavy. Pilot hydrogen stations for automobiles have been installed in 10 locations. For on-site types (a type of station whereby the hydrogen is produced at the station itself), the capacity for producing hydrogen is 700 Nm3 per day while for the off-site type whereby the hydrogen is transported using trailer cars, the volume per trailer is 1,000 Nm3. When this is considered from the perspective of providing hydrogen to trains, in the case of the Yamanote line, the requirements are 5,200 Nm3 or 450 kg per train (Figure 10). If high pressure hydrogen or liquid hydrogen were to be used, the volume that can be loaded is 11,000 liters or less per train when the configuration of the train is taken into consideration. For this reason, the volume density of the high pressure hydrogen and liquid hydrogen will need to be 0.5 Nm3 per liter. If hydrogen is to be supplied through a hydrogen absorbing substance, the weight that may be loaded will be 11 tons per 11-car train or 1 ton per car so that 4 wt% will be required as weight density of the hydrogen. Looking at the current technical level of suppliers, the 350 atmosphere level has already been achieved as mentioned earlier. The 700 atmosphere level is currently under development, but since the volume density at this level will still be 0.3 Nm3 per liter, even at this level, 0.5 Nm3 per liter will not be achieved. While the volume density is 0.4 Nm3 per liter in the case of liquid hydrogen, even this will not reach the 0.5 Nm3 per liter level. The system that offers the best hope is hydrogen absorbing substance into which the hydrogen will be absorbed. Since the weight density is 3 wt%, raising this by 1% will enable practical use. Daily transportation of 5,200 Nm^3 or 450 kg of hydrogen is an enormous task and since as a whole, the daily supply in volume terms must be 270 thousand Nm3 or more, a replaceable cassette type of a hydrogen absorbing substance would seem the most practicable method available. If the cost of the fuel falls to 17 yen or less per 1 Nm3, this would allow changing from the current overhead line device system (Figure 11).

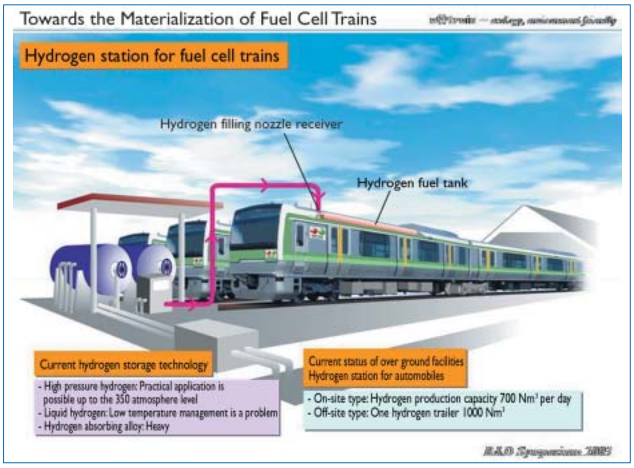

Fig.9: Hydrogen Station

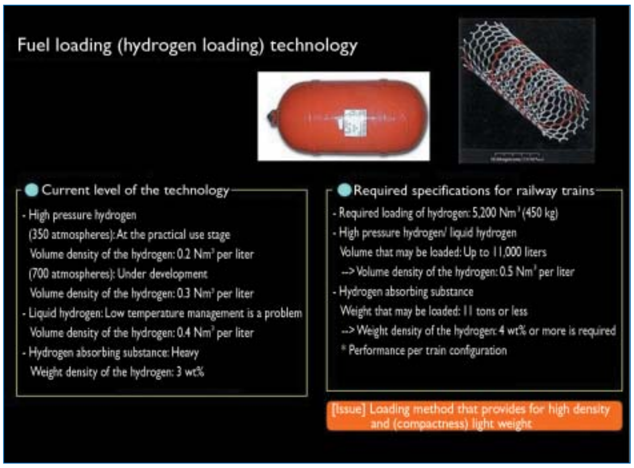

Fig.10: Hydrogen Storing Technology

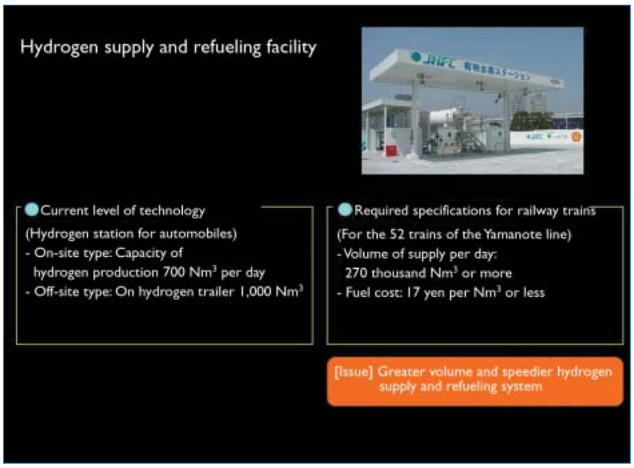

Fig.11: Hydrogen Supply Facility

There are representatives from manufacturers participating in this symposium today, and I would request that they provide information on this, if available, later on during this symposium.

3 Zero Emission

3.1 Zero Emission by Railway Trains

The rate of recycling of railway trains of the past was 94% but the AC Train is being developed with "zero emission" as a target and, for example materials that may be reused or recycled are used in FRP parts, floor framing, glass wool, and polyvinyl chloride. No consideration is given to thermal recycling (Figure 12).

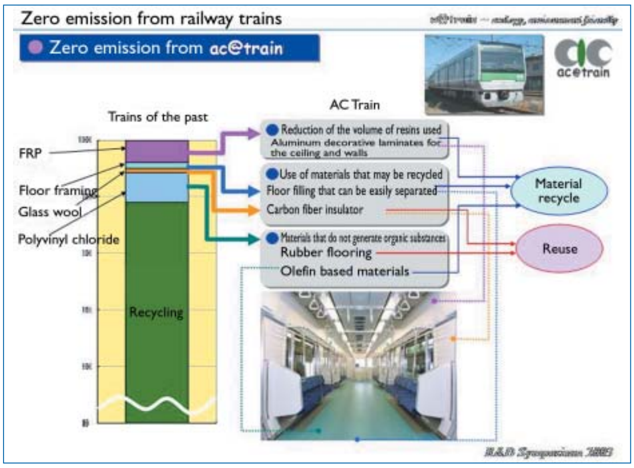

Fig.12: Zero Emission from AC Trains

With respect to FRP, after removing the FRP from a discarded vehicle, the material is separated into fiber, resin, and filler and the retrieved material is formed and recycled into vehicle material. In the case of recycling factory waste into resources, for example, brake lining is recycled as pad material and base material and the base material is recycled as iron. In the case of the carbon brush for the main motor, since the alternating current motor is primarily being used in recent years, the carbon brush itself will eventually go into disuse, but even so, there are old types of trains and technology for separation of this material is being developed.

3.2 Lengthening the Service Life of Railway Facilities

Maintenance free TC type energy saving tracks have been in use on the Yamanote line (Figure 13) since 1998. In the future, the intention is to introduce this system on tracks used by freight trains and in places where the tracks are relatively weak as reinforcing structure. The testing equipment at the research and development center is currently being used to develop this type of energy saving track.

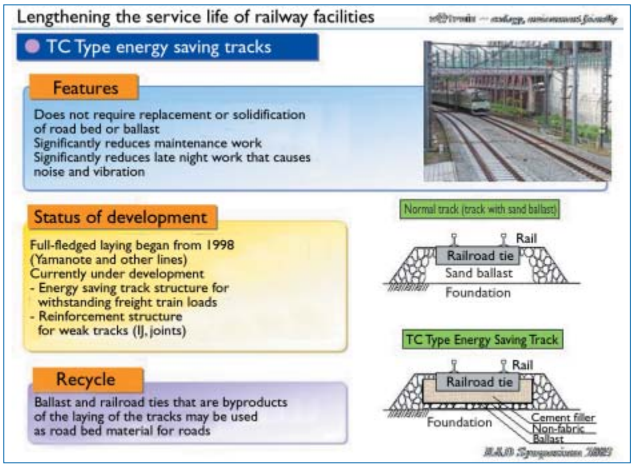

Fig.13: TC Type Energy Saving Tracks

Railroad ties and ballast generated as byproducts during the construction are reused as material for road-bed foundation.

With respect to the lengthening of the service life of the rails, the standard for replacement is 600 million tons or 800 million tons for normal gauge lines and 600 million tons for Shinkansen in terms of accumulated service tonnage of the rails and the intention is to lengthen this by about 200 million tons. Experiments are currently being conducted at the research and development center with respect to the fatigue durability of the rail joints through load and stress measurements (Figure 14). Moreover, research is being conducted on a method of lightly grinding the surface of a rail prior to the occurrence of shelling to prevent damage to the rail in order to ensure that rails may be used until the standard replacement time based on accumulated service tonnage without the need for earlier replacement.

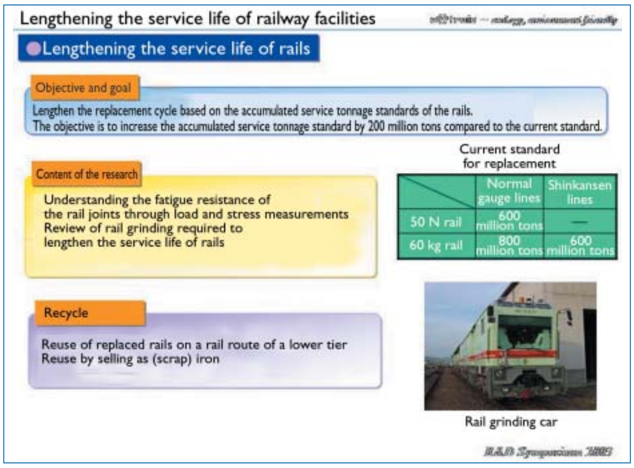

Fig.14: Lengthening the Service Life of Rails

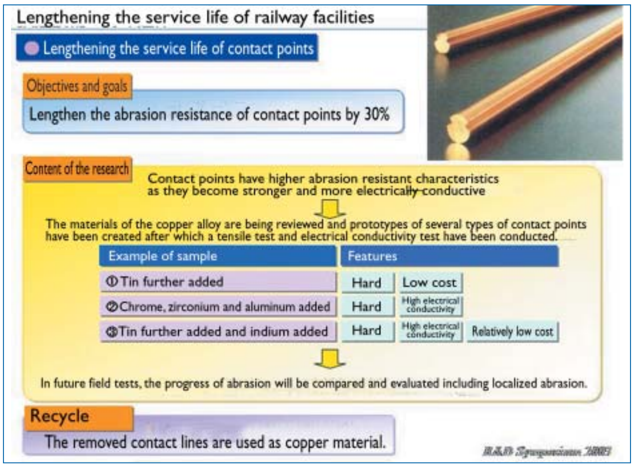

Fig.15: Lengthening the Service Life of Contact Points

With respect to contact lines, carbon contact slips have been introduced in a significant proportion of the routes and abrasion has been reduced to about 1/3 the level of the previous system. However, research is currently being conducted in order to increase the service life of the contact lines by another 30% through changing the material of the contact lines themselves (Figure 15). The intention is to use material that is stronger and with higher electric conductivity than the current material and fatigue durability experiments are being conducted at the research and development center on materials to which tin, chrome, zirconium, aluminum or indium has been added.

4 Supply of Energy

4.1 Self Generation of Electricity

JR East Railway supplies about 56% of its electricity needs through self-operated hydro and thermal power generation facilities (Figure 16). There is a target to reduce the emission of CO_2 gas per unit of power generation by 30% from the level in fiscal 1990, and the amount of 726 grams in fiscal 1990 has been reduced to 519 grams. With respect to a goal of achieving 508 grams by fiscal 2005, achievement is now close at hand.

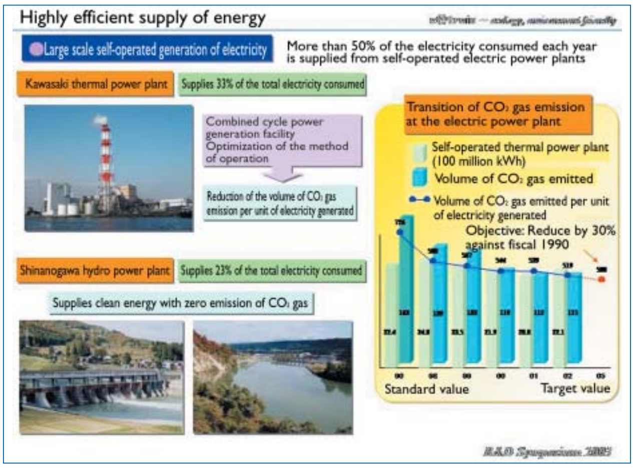

Fig.16: Self Generation of Electricity

4.2 Generation of Natural Energy

Solar cells constitute a method of natural generation of energy and experiments are being confirmed in a variety of locations (Figure 17). A 100 kW class solar generation system that is integrated into construction material has been installed on the roof of the Takasaki Station platform since 2001. Moreover, a pyramid shaped solar panel and a plate shaped panel are installed in the hall of the research and development center in order to confirm the electricity generating performance. For those with the panel installed on one side, the electricity generating capacity is about 130 W per square meter. There are also four solar panels units that are capable of receiving light from both directions that have been installed and are being tested in the research and development center and in this case, the average amount of electricity generated is 160 W per square meter, indicating that panels capable of receiving light from both directions provide just under 40% greater generating capacity. Research on the optimum installation of such panels will continue in the future.

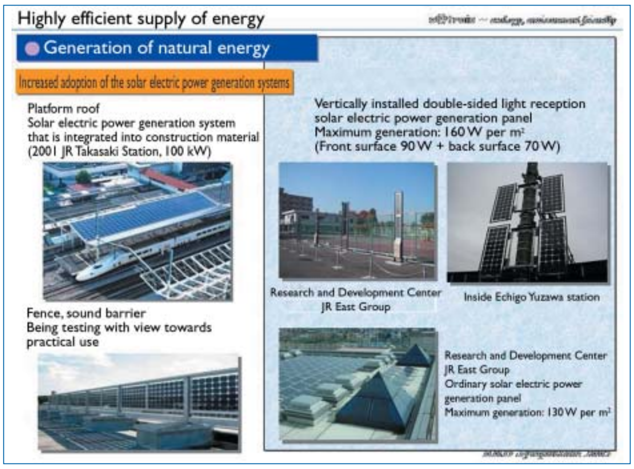

Fig.17: Solar Electricity Generating System

4.3 Electric Power Storage Technology

As technology for storing electric power, there is the Redox Flow Battery that utilizes the oxidation and reduction reaction of vanadium water solution of sulfuric acid and promises to be capable of practical applications in the future. Alternately, there is the battery called NaS Battery that stores electricity through solid electrolyte using sodium and sulfur (Figure 18). In the case of NaS batteries, this is a fixed type battery and output that is greater than the rated output cannot be expected, while in railway applications, there are cases when electric output that is slightly above the rated output becomes necessary. In this sense, the Redox Flow Battery is capable of providing twice the rated output even if only for a short time and this is more appropriate for practical applications. However, since this battery has a large footprint, it cannot be said to be ideal as an electric power storage tool at the present time. The electric double-layer capacitor stores an electric charge in an electrode but contrary to ordinary electrolytic condensers that can only be charged on the surface, the system uses activated carbon to allow charging the space as a whole (Figure 19). Compared to ordinary condensers, this system has the characteristic of allowing the storage of large electrical charges. Moreover, deterioration through repeated charging and discharging is small, the service life of the system is long, and rapid charging and discharging is possible. Therefore, research is being conducted for possible use to compensate for capacity inadequacies of substations and the effective use of regenerative electric power.

In order to use regenerative energy effectively, it is necessary for a regenerative vehicle and cruising vehicle to exist within the same section of a substation. If there is no counterpart that uses the regenerated energy, the regeneration effect will be forfeited (Figure 20). For example, on the Saikyo Line, while regenerative energy is being used with significant effect on the route from Shinjuku to Omiya, from Nisshin Station forward, regenerative electric power is not being fully utilized. In order to use this energy effectively, something like a compensation post will need to be installed in a substation section using an electric double-layer capacitor to charge the electric double-layer capacitor with the regenerative electric power even when there are no other trains and to provide electric power prioritizing the compensation post rather than the substation when the next cruising vehicle arrives (Figure 21). The technical issues are the control that prioritizes provision of electric power from the compensation post and the integration of the quality of the

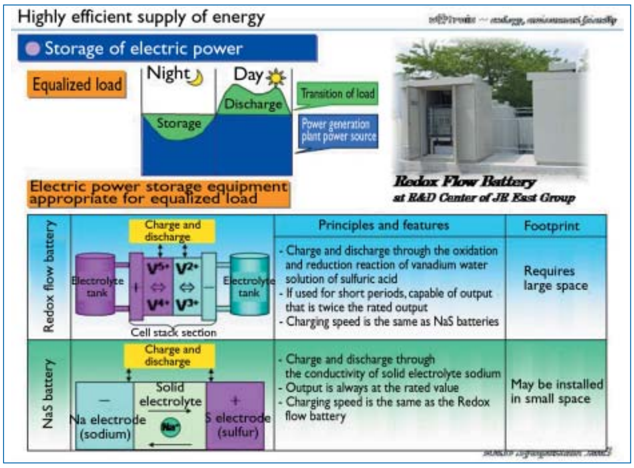

Fig.18: Redox Flow Battery and NaS Battery

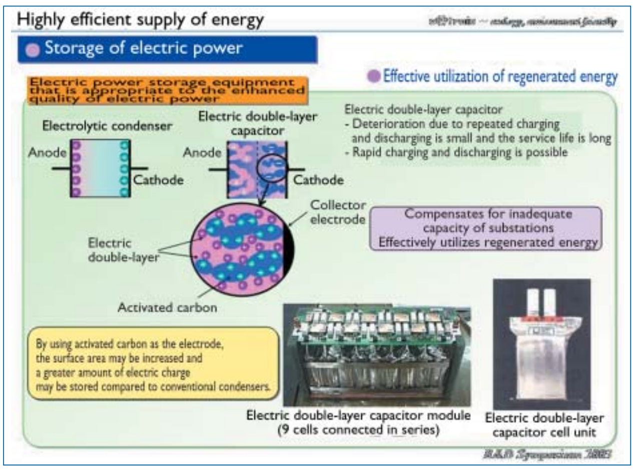

Fig.19: Electric Double-Layer Capacitor

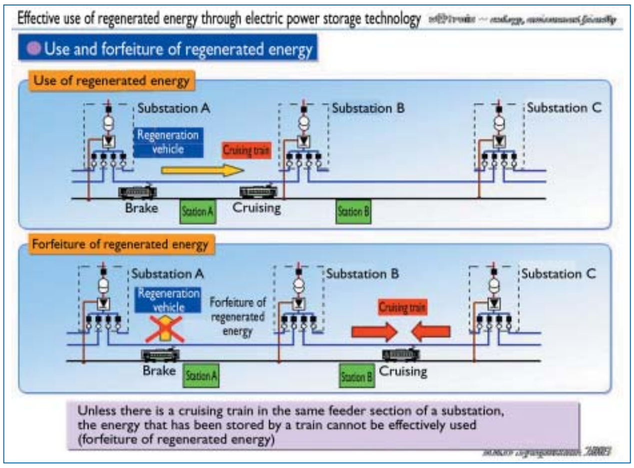

Fig.20: Use and Forfeiture of Regenerated Energy

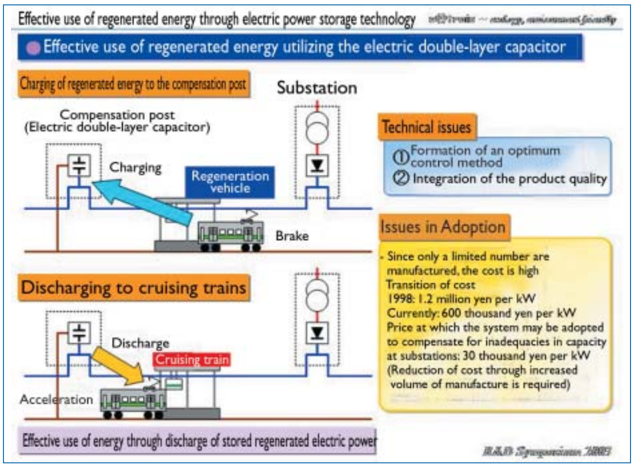

Fig.21: Effective Use of Regenerated Energy

electric double-layer capacitor itself. Today, as demand is small, production is on a small scale and status of manufacturing is not as an industrial product but rather as a hand-made product so that the price is extremely high. However, the cost has come down from the 1.2 million yen per kW in 1998 to 600 thousand yen per kW at the present time. As a result of trial calculation of the price at which this system can actually be adopted, the price per kW would need to be 30 thousand yen or 1/20 the current level. If demand increases and line manufacturing becomes possible, there is the possibility of significant cost reduction and we believe that the concept is not entirely without promise.

4.4 New Heat Exchangers

There is a device called a heat exchange element of a semiconductor (Figure 22). The heat exchange efficiency of this device is extremely high at 93%. Moreover, electric power consumption may be reduced by 30% or more and since the material is not self-igniting, the system ensures safety.

In the winter of 2003, this heater was affixed under the floor of the Shinkansen vehicle Komachi to test prevention of snow accumulation. When a voltage is applied to this semiconductor heat exchange element after snow has adhered, heat is generated. While a high temperature is reached almost instantaneously, since the calorific capacity is small, the applications are limited, but with certain types, the temperature may be raised to 1,000 degrees in several seconds. The effect of this heater melting the surface with which it is in contact and causing the lumps of snow to slip away has been confirmed and this effect has been named "skate effect."

Since this is a significantly effective method for freely dropping off the accumulated snow, the intention is to conduct a test by attaching this heat exchanger to a complete Komachi train in the winter of 2004. In addition, it also has possibilities for application to melting accumulated snow from switch points, depending on the properties of the snow, and tests are planned in this regard as well.

5 Eco-Station

The stations of the future will need to take into consideration such aspects as solar energy, collection of heat, passive control, generation of natural energy, and use of greenery from the perspective of energy savings (Figure 23). In terms of material, natural materials, materials

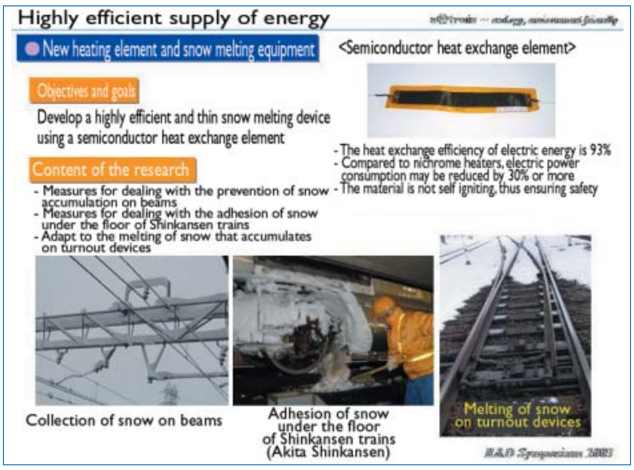

Fig.22: New Heating element (Semiconductor Heat Exchange Element)

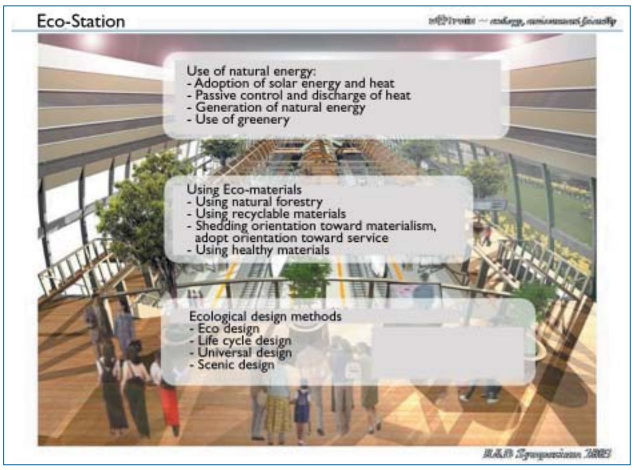

Fig.23: Eco-Station

that may be recycled, and materials that are healthy for humans will need to be used and the design will need to adopt eco-design and universal design. Stations that are people friendly and environment friendly have not been achieved as of yet but when building stations in the future, the intention is to adopt this concept.

6 Shinkansen, the World Leader

6.1 Overview of the Project

This project targets achieving the world's top level high-speed operation without increasing the burden on the environment (Figure 24). There is a plan for extending the Shinkansen network comprised of five routes by 2012. Moreover, when competition with airplanes is taken into consideration, it has become clear that required travel time of three hours is the crucial dividing line in obtaining market share. In Europe, whether or not this will eventually become possible, a maximum speed of 350 km/h is currently being planned and as the world leader. The Japanese Shinkansen has commenced research and development targeting maximum commercial speed of 360 km/h. Already in fiscal 2003, tune-ups of currently held vehicles have been carried out three times in order to implement high speed tests, and results of a certain level have been obtained.

Figure 24: Shinkansen Project -- the World Leader

6.2 Identification of Noise Sources

In order to identify the source of noise, a parallel array of microphones comprised of 114 microphone units and line sensor cameras were installed. Using the current E2 Series vehicle, operating at 360 km/h, the sources and frequencies of the sounds were measured (Figure 25, Figure 26). As a result, it was found that the noise is loudest at the nose, the door to the driver's cab, pantograph, and the awning between cars. Moreover, it was also found that reflective sound is emitted where the wheels touch the slab track. Accordingly, it will be necessary to take comprehensive measures with respect to these parts.

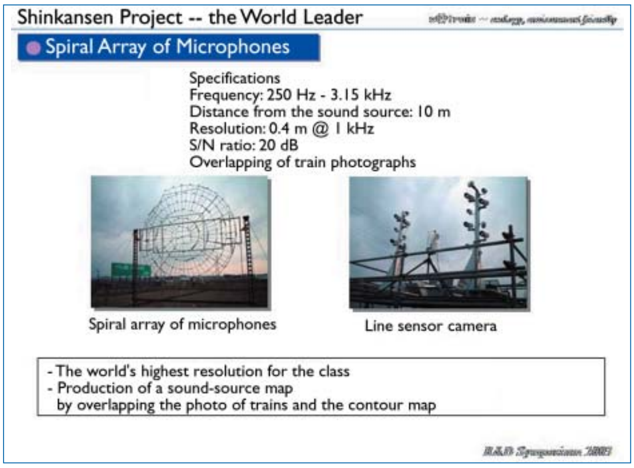

Fig.25: Spiral Array of Microphones

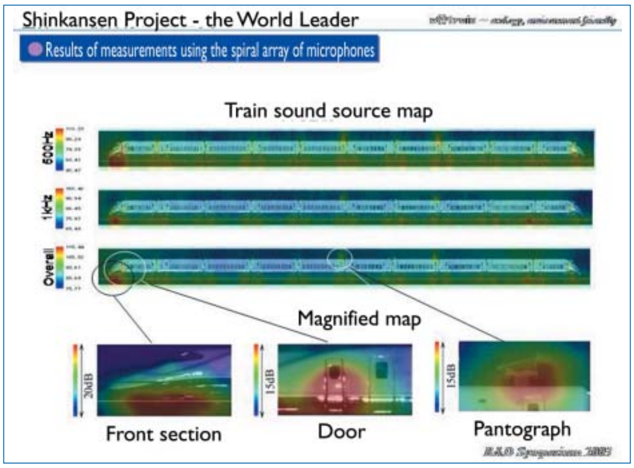

Fig.26: Identification of the Source of Noise

6.3 Control of Noise

In order to reduce the sound from the lower part of the vehicle, truck covers with sound absorbers installed on the inside were used. In order to reduce noise from the collection of electricity, low noise pantographs are mounted on the E2 Series Model 1000 group of trains. If the speed is to be further increased, it will be necessary to attach pantograph sound barriers similar to those used in the Nozomi vehicles. The form of the snow plow that is a feature of Shinkansen vehicles that operate in the north will also be changed. The gap between cars will be made smoother by using a spherical bearing type awning. The driver's cab will also be made smoother.

As measures on the ground, sound absorbers will be attached to the track foundation, sound absorbers will be affixed to the inside of sound barriers, and rather than merely making the sound barriers higher, experiments are being conducted based on analysis of the use of a Y-shaped sound barrier material.

6.4 Control of Statoscopic Pressure Waves

Control of statoscopic pressure waves is also a very important issue (Figure 27, Figure 28). While mitigation structures are currently being installed at tunnels, the pressure gradient of the compression wave that is generated upon a vehicle entering a tunnel will need to be further decreased. Alternately, since with ballast tracks it has been confirmed that pressure waves are attenuated causing a reduction in the statoscopic pressure waves, the use of sound absorbers in the tunnel and in order to reduce the pressure gradient in the course of propagation is conceivable.

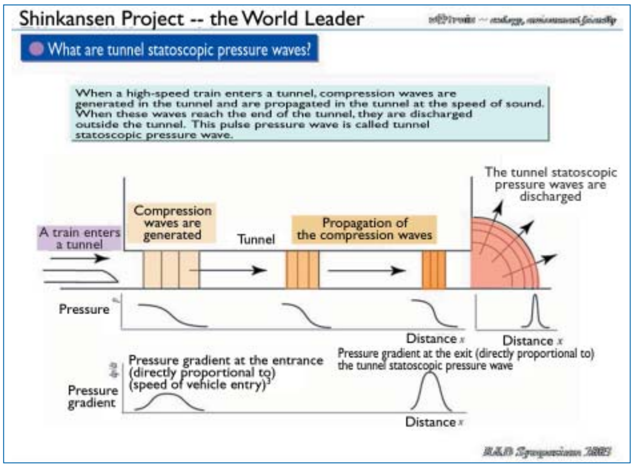

Fig.27: Tunnel Statoscopic Pressure Waves

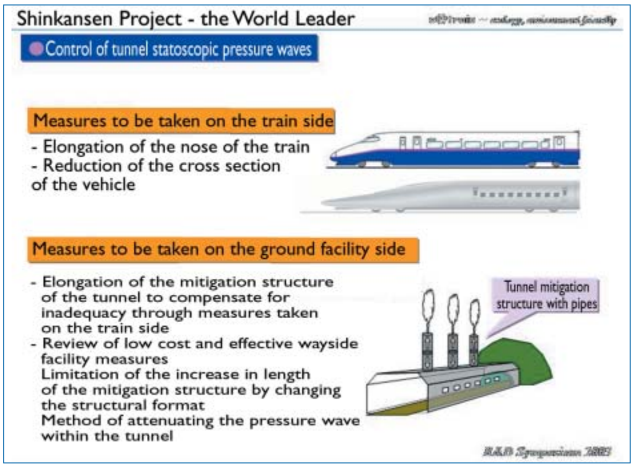

Fig.28: Control of Tunnel Statoscopic Pressure Waves

Optimizing the rate of change of the cross section of the lead car is an effective measure and for new Shinkansen vehicles that will be introduced in the future, that type of lead shape will need to be considered. With respect to measures on the wayside, rather than the current mitigating structure on the entry side that merely positions windows on the side, a scheme for temporarily incorporating the compression waves may be added in an effort to reduce the pressure gradient of the compression waves.

7 Conclusion

I have tried to explain the level of technology that is required for various measures in order to allow their use in a railway system. Advances in technology are rapid and this age is one of fierce technical innovation that makes it possible to accomplish within 5 to 10 years things that were thought to be beyond our capability just 5 years ago. We conduct our development efforts with the firm belief that things that may seem to be but a dream will become reality in the future. We sincerely hope to be able to exchange information and to cooperate with all interested parties.