低炭素社会戦略センター
CENTER FOR LOW CARBON SOCIETY STRATEGY

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Summaries of Proposal Paper for Policy Making and Governmental Action toward Low Carbon Societies

Japan Science and Technology Agency – JST
Center for Low Carbon Society Strategy – LCS

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Changes of Industrial Structure towards Zero Carbon Society: Application of Extended Input-output Table

By using an extended input-output table and a table of CO_2 emission factors by industry, a method has been developed to quantitatively analyze the impact on the economy and environment towards a zero-carbon (ZC) society such as the introduction of renewable energy and to present scenarios for the realization of ZC society.

- By using published input-output tables and CO_2 emissions data, an extended input-output table with renewable energy added and a table of CO_2 emission factors by industry were created.
- The results of the LCS evaluation of economic viability and material use were used to determine an input factor for renewable energy. Then the results of the ZC power system calculations and the changes shown in Table 1 were used to perform an input-output analysis.
- An example of calculation results of GDP and CO_2 emissions are shown in Table 2 as quantitative indicators of scenarios for a bright and prosperous ZC society.

Proposals for Policy Development

For a prosperous ZC society:

1) It is needed to quantify the impact of the introduction of ZC power systems on the society and environment through the input-output analysis and to present scenarios for the realization of ZC society.
2) Research and deregulation are needed to increase the potential of solar, wind and other renewable energy to realize ZC power generation.

Table 1: Examples of changes added to input-output analysis

Symbol	Item
a	ZC power system (electricity demand is the same as in 2013, zero CO_2 emissions from power generation sector)
b	Reductions in town gas through electrification
c	Reductions in kerosene and LP gas through electrification
d	100% penetration of electric vehicles (EVs) and 50% penetration of ride-sharing (RS)
e	Use of recycled materials reducing production of pig iron and converter crude steel by 50% and increasing production of electric furnace crude steel by 50%
f	Recycling reduces chemical production by 50%
g	Production of cement products decreases by 70% due to improvements in the properties of cement
h	Exports of general-purpose and industrial machinery double
i	Visitors to Japan create a 10 trillion yen increase in accommodation services, 6 trillion yen increase in food and beverage services, and 30 trillion yen increase in medical costs
j	20 trillion yen increase in production in the information services industry and 10 trillion yen increase in household demand for education

Table 2: Results of input-output analysis calculation

Case	Item refer to table 1 for symbols	GDP (trillions of yen)	Difference in GDP standards (trillions of yen)	CO_2 emissions ($Mt\text{-}CO_2$)	CO_2 reduction rate (%)	Demand for electric power (TWh)
0	2013 (Standard)	503	0	1,311	0	982
1	a ZC power	510	7	733	44	1,018
2	a+b Town gas	511	8	653	50	1,216
3	a+c Kerosene/LPG	511	8	688	48	1,149
4	a+d EVs, RS	513	10	482	63	1,295
5	a+e Steel	510	6	668	49	1,013
6	a+f Chemical products	510	7	720	45	997
7	a+g Cement	510	7	677	48	1,012
8	a+h Machinery	517	13	745	43	1,026
9	a+i Visitors to Japan	554	51	785	40	1,063
10	a+j Information	538	35	732	44	1,064
11	Combined (a to j)	595	92	242	82	1,752

https://www.jst.go.jp/lcs/pdf/fy2019-pp-14.pdf

Population Analysis for Industrial Structure Study in Future Low Carbon Society

A satisfying and fulfilling zero carbon (ZC) society of the future will see changes to the structures of energy supply, society and industry. Additionally, society will need to achieve economic growth in the midst of the significant changes of the employment structure due to a declining population. To clarify the key points necessary for the design of a future ZC society, basic data was compiled to perform an analysis and evaluation of a future industrial structure, taking into account the age range of the labor population.

- The labor population in 2050 will decline by 27% compared to 2018. Even with retirement age extended (from 60–65 to 65–70) and the employment rate increased (1.2 to 1.5 times), declines could only be reduced by around 21% to 24%.
- Without changes in labor productivity, future GDP estimated by multiplying the labor population by age group and industry, will decline by 30 % (Figure 1).
- The LCS scenario [1] proposes an 80% reduction in CO_2 emissions and a 5% annual increase in GDP. Realizing this will require an average productivity increase of 1.5 times (1% per year) across all industries. Such a change would involve a significant occupational shift (Figure 2).
- Incorporating expected future changes to industry and the necessary perspectives of education and welfare allow for more quantitative considerations using the LCS input-output table analysis [1]. This analysis clarifies factors and tactics toward ZC society, and a specific, clear future industrial structure.

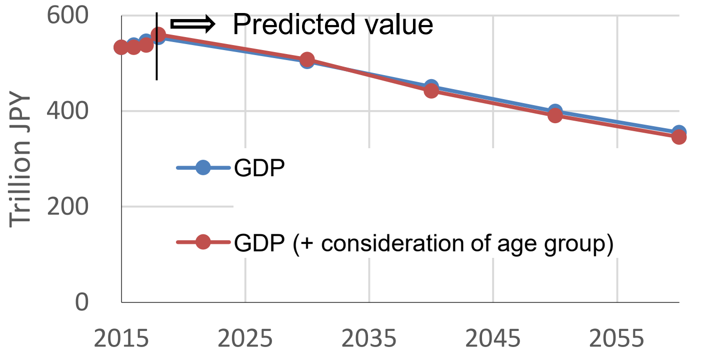


Figure 1: Future GDP values calculated by breakdown of value added

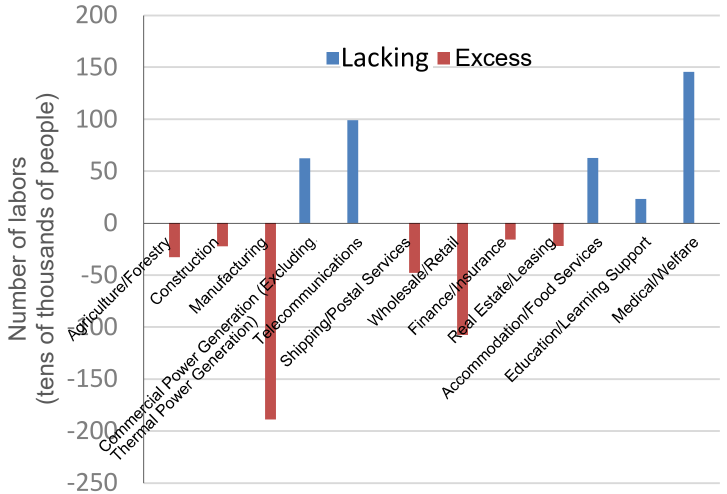


Figure 2: Number of labors lacking at the current labor population structure with assumption of 1.5 times productivity increase in each industry to obtain the GDP of the 80% CO_2 reduction scenario (only representative industries).

Proposals for Policy Development

In the face of a declining labor population, improvements in labor productivity are essential to achieve economic growth while realizing a ZC society.
Tactics that take into account age, as well as ability and knowledge, are essential in new - or rapidly changing - fields of industry. Challenges include providing vocational education for youth, while creating frameworks for elderly that help to provide vocational education for, maintain the health, and adapt areas of societal participation to their needs.

[1] LCS Proposal Paper for Innovation Policy Development: "Changes of Industrial Structure towards Zero Carbon Society: Application of Extended Input-Output Table" Mar. 2020.

https://www.jst.go.jp/lcs/pdf/fy2019-pp-16.pdf

An Empirical Study of Regional Carbon Emission Reduction Potentials by a Smart Integration of Buildings and Mobility Energy Systems

The conversion of buildings to zero energy (ZEH/ZEB), as well as integration with electric vehicles (EVs) and solar photovoltaic (PV) cells is expected to reduce emissions in the building and transportation sectors. These actions aim to realize the goal of a zero emission society. This study analyzed the shift in energy demand to electric power through the diffusion and expansion of these technologies and the impact this shift would have on the energy supply structure, e.g. power generation expansion planning.

- A quantitative analysis was performed on potential CO_2 emission reductions, along with regional differences, through the introduction of PVs and a shift to ZEH and EV interconnection in the household sector nationwide. This analysis was established based on the results of investigations by organizations such as the Tokyo University of Science and the Ministry of the Environment. Results revealed the feasibility of these changes in detached houses along with the challenges they face in collective housing.
- The regional energy model was applied to seven areas in Utsunomiya City, with an evaluation performed based on cost minimization through the effects of energy supply and demand interconnection among residences, offices, and stores, as well as the introduction of EVs. CO_2 emissions were reduced to 35% by insulating buildings, integrating EVs, and interconnecting consumers (Figure 1, 2).
- The large-scale introduction of EVs has the potential to increase load fluctuations in the grid power system. This suggests the need for the wide-area power charging management.
- Although there is high uncertainty regarding behavioral changes amongst consumers, existing smart city reports showed a shared reduction in energy consumption of about 30% through Demand-Response (DR).

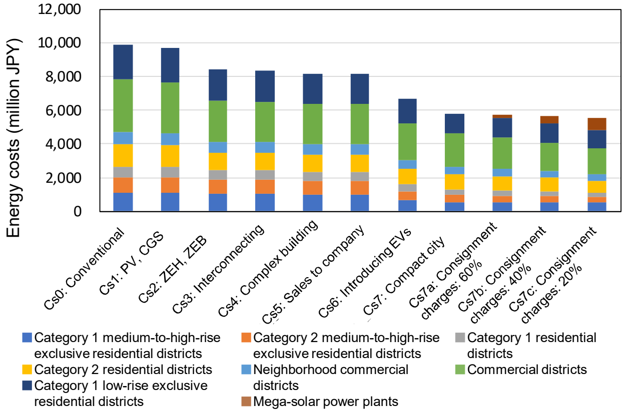


Figure 1: Comparison of annual energy costs between scenarios

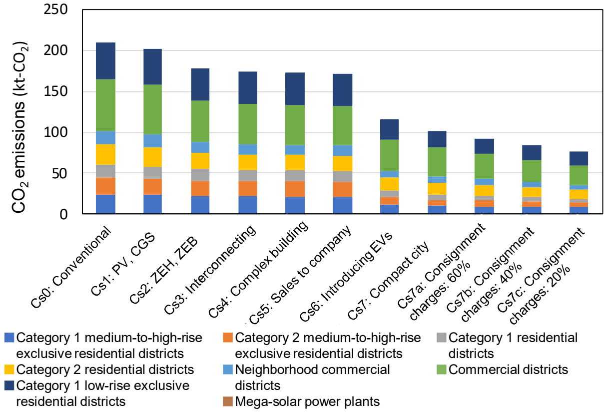


Figure 2: Comparison of changes in annual CO_2 emissions between scenarios

Proposals for Policy Development

The following policy agenda is proposed for achieving CO_2 reductions. This agenda realizes simultaneous reductions in local energy costs and CO_2 emissions by integrating energy demand among the consumer, household, and transportation sectors.

1) ZEB/ZEH have a large potential for emission reductions. Expansions in ZEB/ZEH introduction measures and certification of energy-creating equipment is required to promote these technologies.
2) EVs can replace gasoline vehicles in daily use, but the development of an efficient charging management system is essential.
3) Local consumer energy systems, transportation, and power supply structure models must be integrated to allow for a quantitative assessment of the potential for reductions in emissions by switching to ZEB/ZEH-M and EVs.

An Assessment of the Economic and Carbon Emission Reduction Effects of the Distributed Energy Systems Including New Energy Conversion/Storage Technologies and Unutilized Heat Sources

An analysis using an urban core model that incorporates large buildings revealed the possibility of a simultaneous reduction in costs and CO_2 emissions when compared to conventional systems. This reduction would be enabled by utilizing unused heat energy sources and the introduction of energy interchange among consumers. As part of a verification analysis for suburban residential areas, a highly reproducible model for a power interchange system was developed that utilizes solar cells and secondary batteries.

- In the urban core energy system, using unutilized energy sources and introducing energy interchange systems among consumers allowed for a reduction in total annual costs of 22% (Figure 1, Case-C-0deg) as well as a simultaneous reduction in CO_2 emissions of 26%. These results show that simultaneous reductions can be achieved even when summer temperatures are higher than average.
- The model developed for a power interchange system for suburban residential areas is based around the idea that mutual power interchange among consumers will increase the consumption of solar cell electricity amongst households. This increase will reduce the amount of electricity purchased by 1.4%

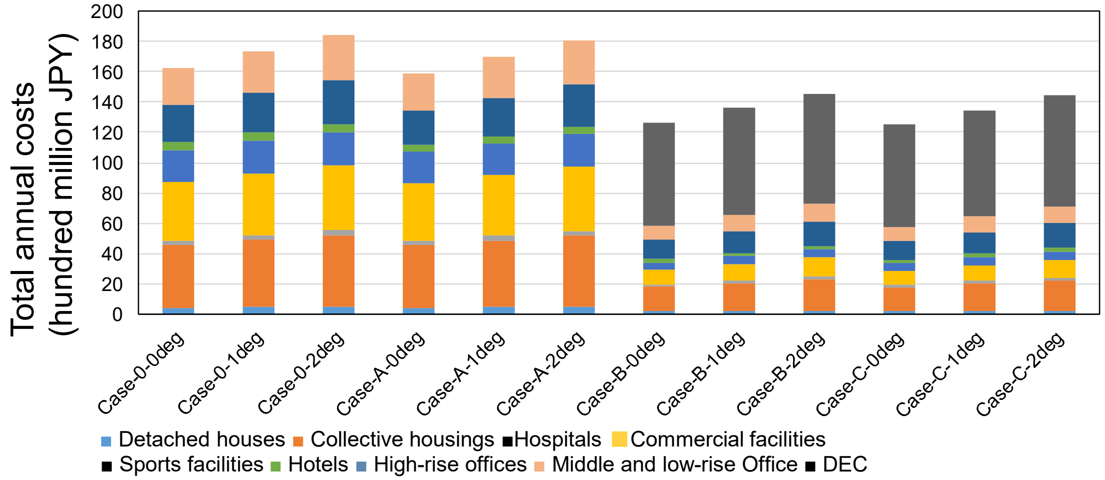


Figure 1: Change in total annual costs by case and type of temperature increase

(Case-0: Conventional equipment, Case-A: CGS/PV/Secondary battery, Case-B: Residual heat utilization + Interchange, Case-C: Inter-regional Interchange, CGS: Cogeneration System, PV: Solar cell (DEC: District Energy Control Center)

Proposals for Policy Development

The following proposals aim to increase utilization of unused heat sources and realize a power interchange system among consumers:

1) There are large regional differences in amounts of energy stored and potential availability. A database of unutilized energy sources must therefore be developed.
2) A refrigerant and control system that can maintain heat pump performance in cold regions must also be developed.
3) The development of a region-wide management system is needed to expand mutual energy exchange which includes Demand-Response (DR) of consumers and linkage with electric vehicles.
4) Consideration of a financial support system for issues such as power wheeling fees, which result from power interchange being performed in existing city blocks. This support is required to realize a reliable city block power interchange system that also contribute to the stabilization of power transmissions across a broader area.

Economic and Technological Evaluation for Zero Carbon Electric Power System Considering System Stability (Vol.1):

Technological Development Issues for Reliable and Affordable Zero Carbon Power Supply

A multifaceted evaluation of zero carbon (ZC) electric power systems to provide direction for the technological development necessary to realize Japan's ZC power system by 2050 was performed. Analyzed systems had a demand for electric power of 800 to 3,000 TWh a year, with the analysis being based on LCS quantitative technological scenarios. Under the assumptions of potential expansions in solar power generation, introductions of offshore wind power including floating wind turbines, and enhancements to the power grid, estimations were made regarding the economic impact of introducing new pumped-storage power [1] and hot dry rock geothermal power (HDR). For these estimations, the power generation ratio of synchronous generators (hereafter called “inertia constraint”) was set at 50%, 25%, and 10% to act as a system stability index.

- The introduction of new pumped-storage and HDR power enabled ZC power system under the annual demands of 2,000 TWh and 2,600 TWh, with inertia constraints of 50% and 25%, respectively.
- Affordable ZC power system will be realized with the expanded potential of renewable energy as well as cost reductions in renewable energy technologies and energy storage systems, and enhancements to the power grid (Figure 1).
- Cost reductions in renewable energy systems and technology developments of potential expansions would lead to reductions in power generation cost of 1 to 10 trillion JPY per year. Improvements in system stability technologies would produce reductions in power generation cost of 1 to 20 trillion JPY per year.

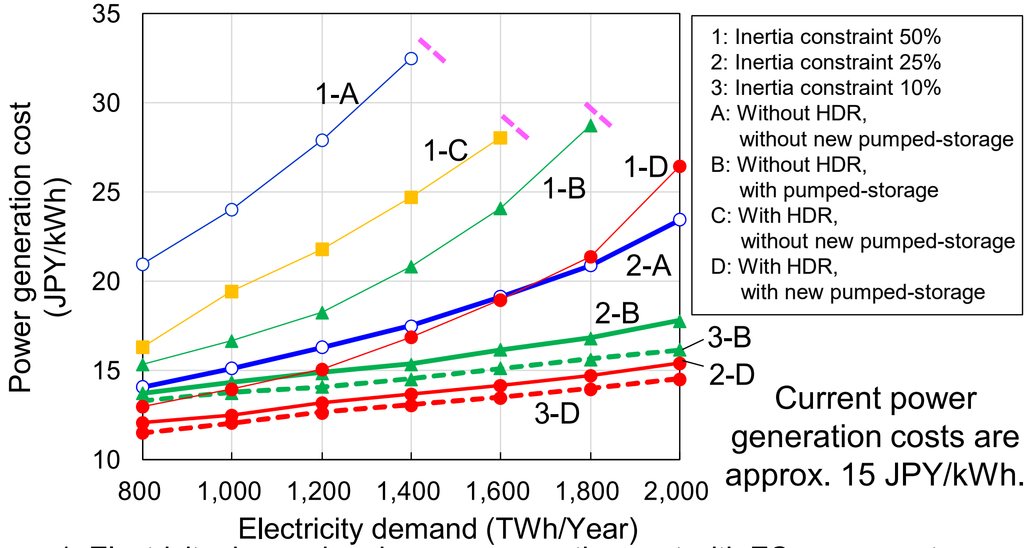


Figure 1: Electricity demand and power generation cost with ZC power systems

Proposals for Policy Development

1) Promote the development of system stabilization technologies which enable ZC power system with low rate of inertia constraints.
2) Support the development and introduction of new pumped-storage and HDR power as low carbon power supply systems that contribute to inertial force supplies.
3) Improve the efficiency of solar power generation, foster the solar power industry, and promote technologies to reduce the costs of offshore wind power.
4) Provide large scale transmission planning for ZC power systems and long-term technical and economic assessments of the grid system.

[1] LCS Proposal Paper for Innovation Policy Development "Potential Capacity and Cost of Pumped-Storage Power in Japan (Vol. 2)", Feb. 2020.

https://www.jst.go.jp/lcs/pdf/fy2019-pp-21.pdf

PV Power Systems (Vol. 6):
A Future Vision of the PV Power System Industry as a Major Power Source for 2050

The prospects of the photovoltaic (PV) power system industry were discussed based on preceding LCS's research results. The extended future PV potential in Japan was estimated considering technology development. Strategies were also presented to expand the photovoltaic (PV) system industry, enabling it to become one of major power sources.

- After summarizing the current industry and market trends, the future PV installed capacity, employees, and market size of PV industry in Japan and the world towards a zero-carbon society were estimated. 400 to 1,400 GW of PV installations were forecasted; however, Japan's share of the global market is shrinking (Table 1). Therefore, it is required to establish strategies of PV technology development that can lead global expansion and measures to improve labor productivity.
- Expanding PV power system resource potentials are estimated in the range from 652 to 1,437 GW with improved module conversion efficiency, use of abandoned agricultural land, and improved utilization of installed areas.

Table 1: Estimates of PV installed capacity, employees, and market size of PV industry in Japan and the world towards a Zero-Carbon (ZC) society

		2010 (Actual)	2018 (Actual)	2030	2050	
					A: 80% reduction	B: ZC power
World	Installed capacity [GW]	70	480	2,000	10,000	20,000
	Annual module production [GW]	17	100	140	500	1,000
	Market size [trillion JPY/year]	7	14	14	25	50
	Employees [thousands] (Note 2)	510	3,400	3,000	5,000	5,000
Japan	Installed capacity [GW]	3	60	170	500	1,400
	Annual module production [GW]	1	5 (10 (Note 1))	11	30	70
	88888	0.4	3	1	1.5	3.5
	Employees [thousands] (Note 2)	90	300	220	300	350

Note 1: Current annual installed capacity in Japan
Note 2: The ratio of Employees in the PV industry is
(Module manufacturing : Installation : Sales and management = 20% : 30% : 50%)

Proposals for Policy Development

The following industry strategies are proposed based on the results; the future vision of the PV power system industry as one of major power sources, with the aim to establish a zero-carbon power system.

1) It is important to establish a quantitative and long-term strategy to achieve high penetration of PV power systems, along with timely assessment results that contribute to technological and industrial development.
2) R&D that contributes to higher efficiency to cope with cost reduction requirements and land limitations must be evolved into technological developments that aim at to the global market. Progress must also be made with an industrial strategy that accounts for transitions amongst the energy industry.
3) Proposed PV deployment plans must take into consideration regional characteristics, for example, power systems designed for long-term and long-distance electric power transmission.

Strategy for Hole-Transport-Material-Free Perovskite Solar Cells Using Carbon-Based Electrodes (Vol. 2)

Perovskite solar cells, which can be produced using a simple low-temperature process, are expected to be the next generation of high efficiency solar cells. The results of this assessment, which used carbon nanotubes in place of hole-transport-layer/Au electrodes, revealed that introducing functional groups into the tubes improved the reproducibility and stability of battery characteristics. Enhancing the reciprocal action in the bonded interface between the perovskite crystals and the nanotube electrodes is the key for the improvement.

- Although perovskite solar cells have been reported to have a power generation efficiency of more than 25%, reproducibility and stability have become issues due to degradation of the perovskite layers and hole-transport-layer/Au electrodes. There have also been challenges surrounding the small dimensions of the cells.
- Carbon-based electrodes have been examined for improving stability and reducing cost of perovskite solar cells. This assessment reveals that carbon nanotubes with functional groups have a strong reciprocal action with perovskite crystals, which contributes to improved performance and subsequent stability of battery properties over time (Figure 1: right) [1].
- The surface bonded not by mere intermolecular forces but by hydrogen bonds between the functional group of the nanotubes and the crystal has strong adhesive force. This property leads to interfacial reconstruction at room temperature through ion diffusion, which is believed to enhance the stability and reproducibility of the new interface (Figure 1: left).

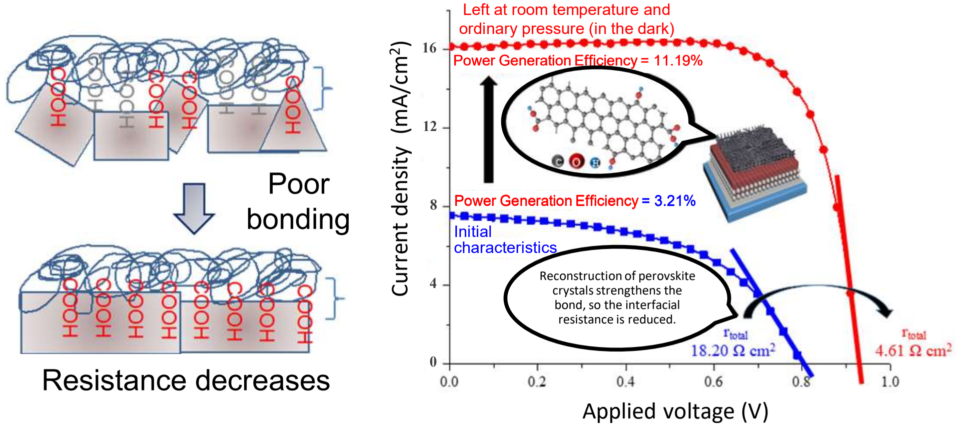


Figure 1: Schematic of efficiency improvements through interfacial reconstruction and solidification

Proposals for Policy Development

The assessment reveals that the strength of the bond at the interface between the perovskite crystal layer and the carbon nanotube electrodes is a key influencer of cell durability. Basic research on the following issues must be performed to allow for the manufacture of large dimension, high-efficiency solar cells for practical use.

1) Investigations into a fabrication process to optimize the bonding of perovskite and carbon materials.
2) Improvement of hole collection efficiency by controlling the electron structure (work function) of carbon electrodes.
3) A quantitative investigation of the degradation mechanism of carbon electrode batteries through clarifying reversible/irreversible reactions.

[1] Jie Chen et al., MAPbI3 Self-Recrystallization Induced Performance Improvement for Oxygen-Containing Functional Groups Decorated Carbon Nanotube-Based Perovskite Solar Cells, Sol. RRL, 3, 2019. https://doi.org/10.1002/solr.201970121.

Wind Power Generation Systems (Vol. 2):

Economic Evaluation for Future Wind Power Generation Systems Which Are Adapted to Japan Considering Large Scale Installation and Related Technological Development Issues

After summarizing technological issues relating to Japan's unique topography and meteorological conditions, offshore wind turbines with high capacity factor suitable for Japan were evaluated. Using these results, economics of several types of large-scale installed wind power systems in Japan were analyzed.

- To expand the introduction of wind power generation in Japan, wind power generation systems with high capacity factors - even in regions with low wind speed - must be developed. Reducing the cost of power generation also requires the large-scale installation of offshore wind power.
- The economics of wind power system were evaluated, considering a large-scale installation, including offshore wind turbines with a high facility utilization rate of 50% (Table 1), with lower specific power and large rotor diameter.
- For the standard case, the construction cost of a high capacity factor offshore wind turbine is double, but the power generation cost is 12 JPY/kWh (bottom-fixed) or 13.6 JPY/kWh (floating) (Figure 1). Lower transmission costs due to improved capacity factors lead to overall reductions in grid costs. Therefore, it would be worthwhile to adopt this model when constructing a zero-carbon power system.

Table 1: Wind power system specifications in each case

Wind turbine type		(1) Onshore	(2) Offshore bottom-fixed	(3) Offshore bottom-fixed with high capacity factor	(4) Offshore floating	(5) Offshore floating with high capacity factor
Rated power	MW	3	5	2.5	10	7
Rotor diameter	m	82	126	126	150	150
Capacity factor	%	25%	30%	50%	35%	50%
Assumed average wind speed	m/s	6.4	7	7	7.6	7.6
Estimated number of WTs in a WF	WT	20	100	100	200	200
Estimated WF scale	MW	60	500	500	2,000	1,400
Water depth	m	-	30	30	120	120

Proposals for Policy Development

The following considerations are required for Japan-specific technological development and industrial strategies related to the large-scale domestic introduction of wind power.

1) Development of materials / structure / device design technologies needed for high capacity factor wind turbines suitable for Japanese weather conditions.
2) Development of wind turbine / operation technologies suitable for Japan's complex terrain, typhoons, and winter lightning, and consideration of strategies for launching to the global market.
3) Overall system designs and economic assessments for offshore wind power, including cost reductions and connections to the grid.

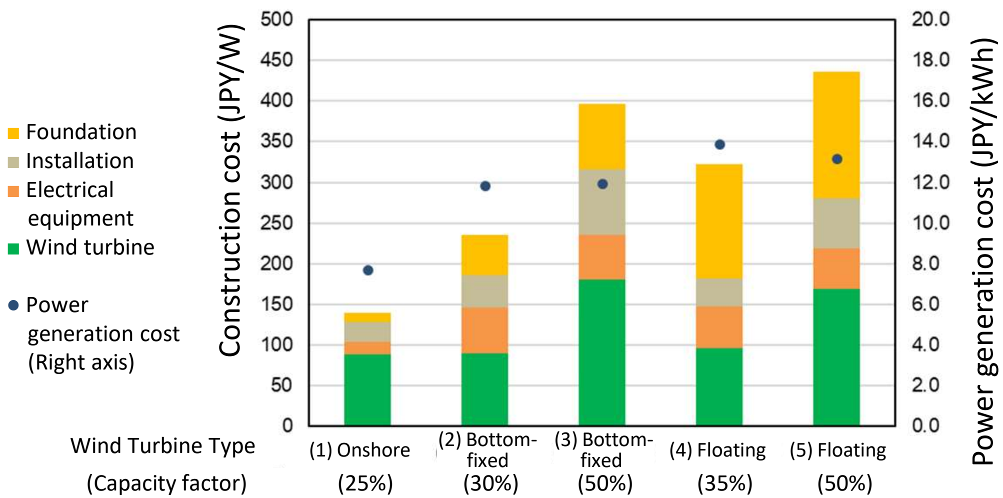


Figure 1: Generation costs for a future wind power system, assuming a large-scale installation

https://www.jst.go.jp/lcs/pdf/fy2019-pp-20.pdf

Secondary Battery System (Vol.7):
Evaluation of the Economics of Power Storage Systems; Efficiency, Costs and Future Challenges

Power storage systems that respond to fluctuations in output due to weather conditions are essential when adopting natural energy as a method to reduce carbon dioxide emissions. A cost model for a power storage system that utilizes batteries was developed, assuming that the batteries would be charged and discharged to their rated capacity at their rated output once a day for 330 days a year. This allowed for calculations of efficiency and cost of various battery types.

- In contrast to our former study of battery cost only, the system operator is assumed, and the calculation is performed by considering the facility cost, operating cost, and battery life (Table 1).
- The NAS battery system had the lowest cost per capacity and per cycle at 24 JPY/kWh/cycle. It is still expensive to store the surplus power from natural energy.

Table 1: Storage costs of power storage systems for various battery types [1 - 4]

			LCS assumed system	Tehachapi project	Minami-Soma secondary battery substation report	Nishi-Sendai secondary battery substation report	LCS assumed system	Buzen secondary battery substation operations report	LCS assumed System	Minami-Hayakita secondary battery substation report
	Secondary battery type		LIB (ternary system)	LIB (ternary system (LG))	LIB (SCiB)	LIB (SCiB)	NAS	NAS	Redox flow	Redox flow
	System rating	MW/MWh	10/40	8/32	40/40	20/20	10/40	50/300	10/40	15/60
Total costs (costs + conversion loss)		JPY/kWh/cycle	43	68	90 - 95	95 - 162	24 - 33	30	24 - 38	67, 89 - 106
Costs (fixed costs + variable costs)		JPY/kWh/cycle	41	65	88 - 90	92 - 151	19 - 29	25	21 - 35	61, 84 - 98
Conversion loss		JPY/kWh/cycle	2	3	2 - 6	3 - 11	5	5	3	5
	Capacity reduction rate	% per year	2.5	3.9	1.0	1.0	1.0	1.0	0.4	0.4
	Number of dischargeable cycles	Cycles	2,640	1,980	6,600	6,600	5,000 - 6,600	6,600	5,000 - 13,200	6,600 - 13,200
	Service life	Years	8	6	20	20	15 - 20	20	15 - 20	20
	System price	Million JPY	2,900	2,827	12,312	9,936	2,000 - 2,800	22,680	4,320	17,300

Proposals for Policy Development

Improvements to the efficiency of peripheral devices and battery management systems as well as the efficiency of batteries themselves are necessary for the cost reduction of the system.

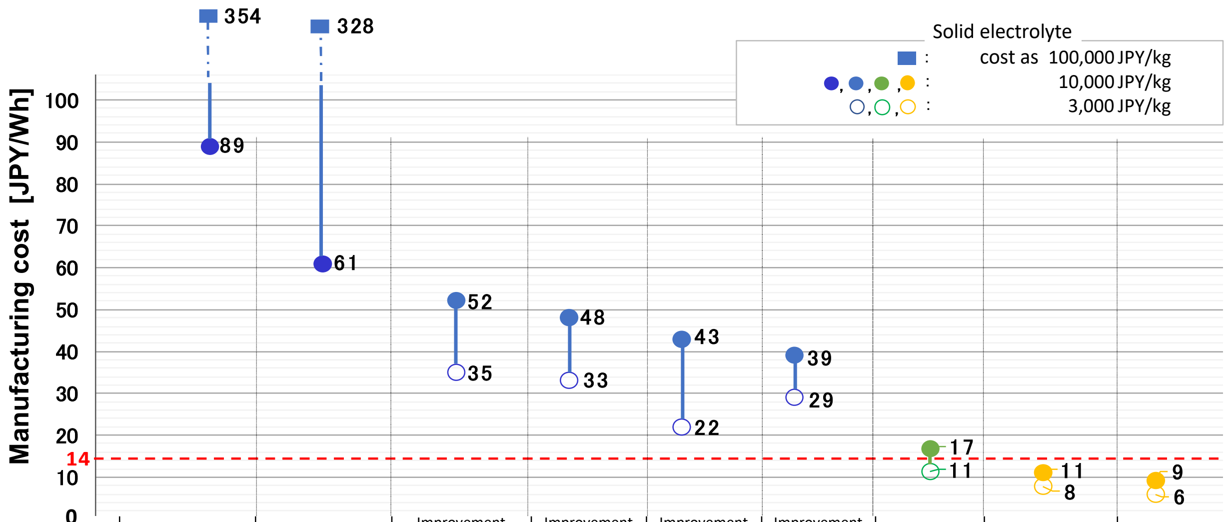
1) The LIB (ternary system) needs to be improved cycle characteristics, while the LIB (SCiB) needs reductions in battery cost. It is also important to improve efficiencies of the pack/module through utilizing new electrode materials and enlarging the unit cell size.
2) It is desirable to widen the operating conditions of charging and discharging for the NAS system. A lower cost will be possible for the redox flow system by improving the charge/discharge efficiency and the circulation system. However, few researchers and companies are working in these fields. Policies such as promoting open innovations are necessary to leverage the potentials in these systems.

[1] Southern California Edison, "Tehachapi Wind Energy Storage Project: Technology Performance Report #1, #2, #3", DE-OE 0000201 (Dec. 2014, Feb. 2016, Dec. 2016).
[2] New Energy Promotion Council, FY 2016 Accomplishment Report, " Demonstration project for a large scale power storage system to improve supply and demand balance: Demonstration project for a secondary battery system to improve supply and demand balance at Minami-Soma Substation ", Tohoku Electric Power Company, Feb. 2017, and "at Buzen Secondary Battery Substation", Kyushu Electric Power Company, Feb. 2017.
[3] Ibid, FY 2017 Accomplishment Report, "Emergent demonstration project for in a large scale power storage system: Demonstration project for a power storage system as a countermeasure for frequency fluctuations at Nishi-Sendai Substation", Tohoku Electric Power Company, Jan. 2018.
[4] Ibid, Accomplishment Report, "Emergent demonstration project for a large scale power storage system: Demonstration project for a large scale power storage system at the Minami-Hayakita Substation", Hokkaido Electric Power Company and Sumitomo Electric Industries, Jan. 2019.

Secondary Battery System (Vol.8): Cost Evaluation and Technological Challenges of an All-solid-state Lithium-ion Battery

As the energy density of lithium-ion batteries (LIBs) has increased and the demand for safety has increased, attempts to use inorganic solid electrolytes have gained attention. In this proposal, a laminated all-solid-state LIB cell using a sulfide-based solid electrolyte was designed and the manufacturing cost was calculated. In addition, technological obstacles to reducing the manufacturing cost were discussed.

- The manufacturing cost of the all-solid-state LIB using solid electrolyte $75Li_2S\text{-}25P_2S_5$ was as follows : the cost of Current Model 2 was 61 to 328 JPY/Wh, the costs of Future Models 1 to 3 were 6 to 17 JPY/Wh (Figure 1). On the other hand, the cost of conventional LIBs (same battery size as Current Model 2) was 14 JPY/Wh.
- The assessment revealed that the manufacturing cost of the all-solid-state LIB is heavily influenced by (1) the price of the solid electrolyte, (2) the amount of solid electrolyte used, and (3) the manufacturing process needed to use sulfide-based solid electrolytes (high-pressure press, atmosphere control in the presence of solid electrolytes).



			Current model 1	Current model 2	Improvement proposal 1	Improvement proposal 2	Improvement proposal 3	Improvement proposal 4	Future model 1	Future model 2	Future model 3
Battery composition	Electrode active materials	Material (positive/negative)	NCA / C_6	NCA / C_6	NCA / C_6				NCA / C_6	$Li_{1.2}Ti_{0.4}Mn_{0.4}O_2$ / Si	S-C/Li
		Capacity (positive/negative electrode) [mAh/g]	196 / 353	196 / 353	196 / 353				196 / 353	300 / 1,007	1,508 / 2,895
	Composition ratio of positive electrode compound (active material/solid electrolyte/other) [vol.%]		46/48/6	46/48/6	46/48/6	46/48/6	46/48/6	63/28/9	63/28/9	64/28/8	50/28/22
	Composition ratio of negative electrode compound (active material/solid electrolyte/other) [vol.%]		53/41/6	53/41/6	53/41/6	53/41/6	53/41/6	66/27/7	66/27/7	59/27/14	100/0/0
Battery performance	Energy Density by Weight [Wh/kg]		189	194	219	194	194	252	278	441	788
	Energy Density by Volume [Wh/L]		419	452	495	452	452	631	676	1,027	979
Manufacturing conditions	Cumulative yield of positive electrode active material standard [%].		64	64	64	88	64	64	88	88	88
	Price of solid electrolyte [JPY/kg].		10,000 - 100,000	10,000 - 100,000	3,000 - 10,000				3,000 - 10,000	3,000 - 10,000	3,000 - 10,000
Note	Differences from current model 2 (except for price of solid electrolyte) Note: NCA is an abbreviation for $Li(Ni_{0.85}Co_{0.12}Al_{0.03})O_2$		Battery size: small	—	Thickening of the electrode compound layer	Increased manufacturing yield	Increased manufacturing efficiency + easing of atmosphere controls	Reduction of content containing solid electrolytes	Combined with improvement proposal 1 to 4	Combination of substituting with high-capacity electrode material +improvement proposal 1 to 4	Combination of substituting with high-capacity electrode material + improvement proposal 1 to 4

Figure 1: Comparison of manufacturing costs for the all-solid-state LIBs used in the assessment

Future Challenges

In order to reduce manufacturing cost and increase the performance of all-solid-state LIBs to the level of the future model, it is important to find a solid electrolyte with the following features: (1) desirable physical properties (good lithium ion conductivity, chemical and electrochemical stability, and softness to form a good interface with low pressure pressing) (2) low-cost raw materials, (3) manufacturing process suitable for mass production.

Potential Capacity and Cost of Pumped-Storage Power in Japan (Vol. 2)

An assessment was performed of costs and facility capacities that can be developed throughout Japan for the construction of a new pumped-storage power system. The system uses a multi-purpose dam as a lower reservoir, pumping a portion of this water into the upper reservoir to be stored. The assessment model assumes that 30% of the effective water storage capacity of the lower reservoir is pumped into the upper reservoir for five hours a day x 300 days (a facility utilization rate of 17.1%).

- Changing from a conventional reversible system with a single water wheel and pump, to a tandem system, in which they are separated, provides total efficiency improvements of 70% to 85%.
- Furthermore, increasing the amount of water used from 20% to 30% of the effective water storage capacity decreases facility costs. This also reduces power generation costs by 15% to 19.4 JPY/kWh (Figure 1).
- The total storage capacity that can be developed throughout Japan also increases to 2,170 GWh/time (5h)/day if large dams of more than 100 million m^3 of the effective water storage capacity are also used.
- The assessment revealed that different sizes of power storage systems are required, depending on if they will be run once a day for peak shifting, or multiple times a day for balancing.

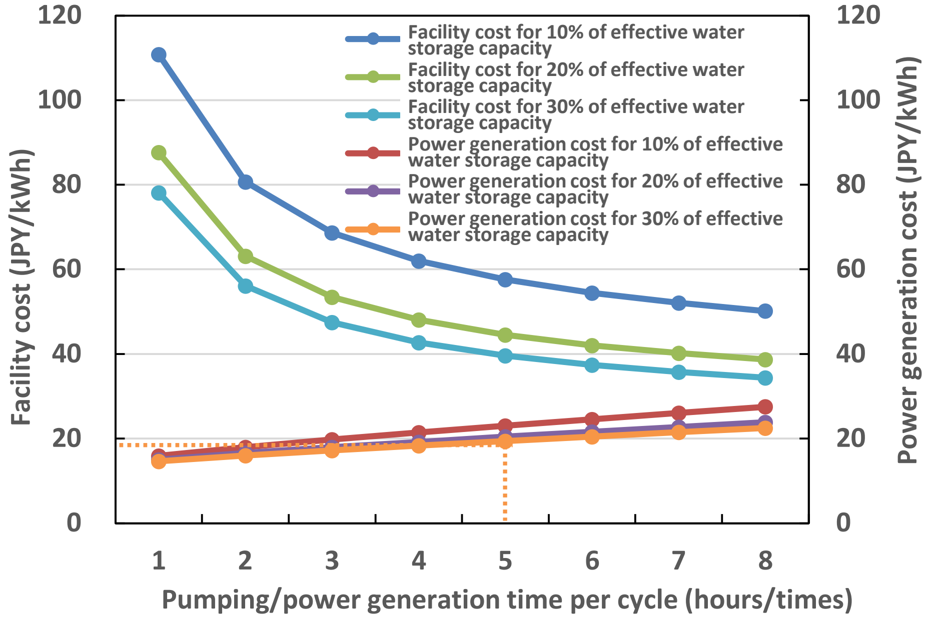


Figure 1: Equipment and power generation costs when pumping/generating at 17.1% of facility utilization.

(The water storage capacity in the upper reservoir is the same but the output of the water wheel / generator differs. There are also differences in the number of times it is operated a day. The larger the capacity of the facility and the greater the number of times it is operated per day, the lower the costs are.)

Proposals for Policy Development

This new pumped-storage power system is promising. The system is expected to have enough capacity to exceed the 510 GWh/day [1] required in 2050 by 900–2,200 GWh/time (5h)/day and for power generation costs to be reduced to 19.4 JPY/kWh.

1) Facility design and operational planning for the system must be tailored to match its rollout and to regional characteristics.
2) Planning in conjunction with nearby wind, small hydro and biomass power plants is necessary to hold down construction costs.

[1] LCS Proposal Paper for Innovation Policy Development "Economic Evaluation for Low Carbon Electric Power System Considering System Stability (Vol. 2)" Mar. 2018.

SOFC Systems (Vol. 7): Technology and Cost Assessments of High-Temperature Steam Electrolysis

High-temperature steam electrolysis using solid oxide electrolysis cells (SOEC) is believed to be a highly efficient way of producing hydrogen. Reversible power generation and electrolysis systems that use SOEC as a solid oxide fuel cell (SOFC) for hydrogen power generation are hoped to have a role in power conditioning and storage systems linked to renewable energy. A comparison of energy storage costs between lithium ion batteries (LIBs) and SOECs revealed that SOECs have advantages, but still face challenges.

- The cost of SOEC steam electrolysis systems can be significantly reduced by replacing hydrogen storage tanks with low-pressure spherical tanks.
- In a comparison of charging and discharging costs with LIBs, the longer the discharge times and the cheaper the power usage costs are, the more advantageous SOECs/SOFCs will be. It's believed this will create differentiation with LIBs for long-term storage needs.
- The assessment revealed that hydrogen production costs of 30 JPY/Nm^3-H_2 can be achieved in the future. This can be achieved with a 50% operation rate and an electricity price of 5 JPY/kWh, with steam electrolysis performed for 15 hours (Figure 1).

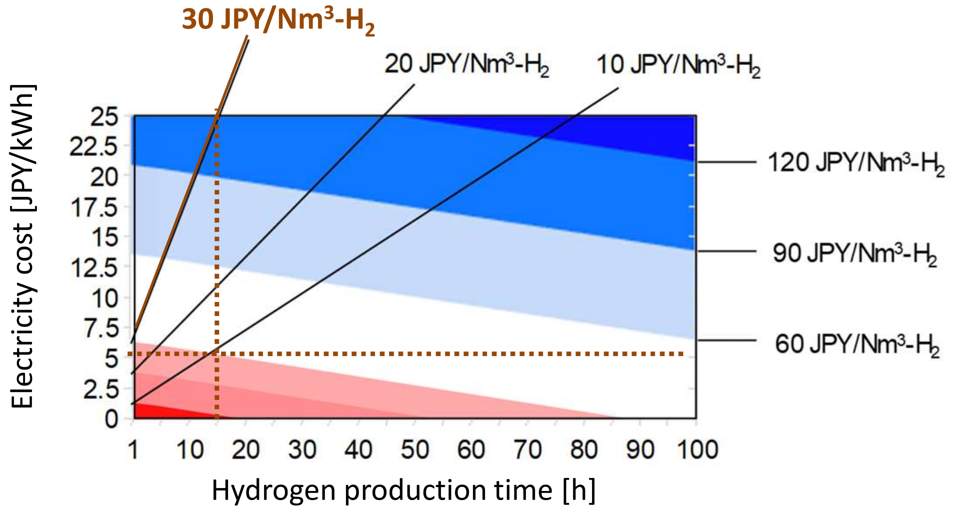


Figure 1: The interdependence between hydrogen costs and storage times using SOECs. Future case: Steam electrolysis operation rate of 50%

Proposals for Policy Development

For SOFC/SOEC systems to have a role in controlling output fluctuation and storing power from renewable energy sources, technological revolutions will be required in cell design and materials, along with improvements to manufacturing processes and the development of technologies to improve lifetime.

1) Expanding the use of SOEC systems will require cost reductions of comprehensive systems, which combine auxiliaries such as compressor, hydrogen storage tanks and heat exchangers, along with longer lifetimes and decreased sizes of SOEC modules.
2) Developments of SOEC systems assuming actual usage cases will also be required. These cases, in which SOEC systems are beneficial, include hydrogen storage system corresponds to time constants of fluctuations of renewable energies as well as small to medium sized SOEC systems for hydrogen stations.

Technological Issues and Future Prospects of GaN and Related Semiconductor Devices (Vol.4):Manufacturing Cost of GaN Power Device

Gallium nitride (GaN) is expected to have significant energy-saving benefits in power devices due to its high electron mobility and wide bandgap. An evaluation of competitiveness of GaN device with other devices was performed through estimation of the manufacturing costs about vertical MOSFETs assuming the manufacturing process, the device structure and the substrate costs.

- Manufacturing costs of GaN MOSFETs (Figure 1) were estimated to be 20,000 JPY per chip for 10 mm planer-type chips with 4 inch GaN substrates (costing 400,000 JPY per piece). The cost for trench-type chips were estimated to be 16,000 JPY per chip due to the shorter manufacturing process.
- Reductions in substrate costs are the most important as they account for nearly 60% of total manufacturing costs. If problems relating to crystal growth are resolved, prices can be reduced to 10,000 JPY per substrate [1] and 5,000 JPY per chip will be possible.
- Epitaxial growth equipment accounts for 50% of total facility costs. It is expected to reduce the cost to 11,000 JPY per chip simply by using 6 inch substrates instead of 4 inch.
- To compete with Si or SiC devices, it is necessary to reduce the manufacturing cost by realizing large-diameter substrates, multiple wafer processing, reduced production time, and a high overall yield. Development of trench-structures and/or ion implantation technology for p-layer formation will improve the competitiveness of the GaN device.

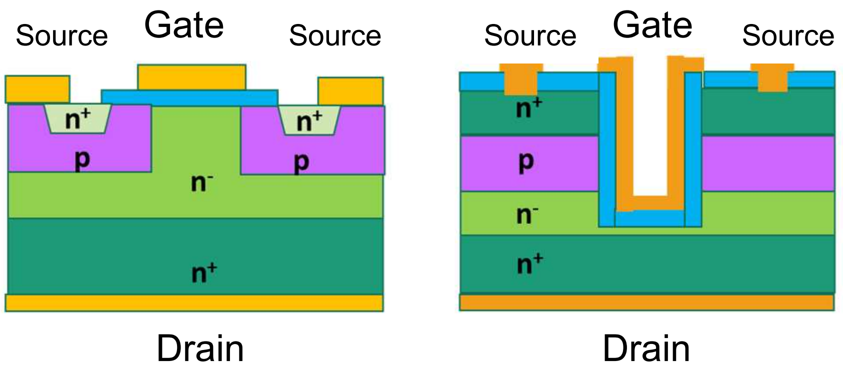


Figure 1: Vertical GaN MOSFETs
(Left: Planar-type, Right: Trench-type)

Proposals for Policy Development

Supplying high quality and low-cost substrates and improving the efficiency of the manufacturing process are essential for reducing the production cost of GaN devices. Towards these ends, following researches are needed.
1) Research on both GaN single crystal growth and SiC substrate utilization to reduce substrate cost.
2) Research on using large diameter substrates and reducing process time for improving efficiency of epitaxial process and research on new device structure which leads to reduction steps of epitaxial growth process. Furthermore, future basic researches on new film forming process and new device structures.

[1] LCS Proposal Paper for Innovation Policy Development "Technological Issues and Future Prospects of GaN and Related Semiconductor Devices (vol. 2): Manufacturing Costs of GaN Crystals and Substrates" Feb. 2018.

Survey of Technological Issues in Device Fabrications Processes for Gallium Oxide as a Next-Generation Widegap Semiconductor

Gallium oxide (Ga_2O_3), which has a wide bandgap and allows for melting growth of bulk crystals, is expected to contribute to a low carbon society through reducing power conversion losses when it is used in low-cost, highly efficient next-generation power devices. To accelerate the development of technologies for practical applications, the impacts of elemental processes in device manufacturing and the selection of gate dielectric materials on both Ga_2O_3 crystal surfaces and its device characteristics were investigated. This led to the identification of issues in development of Ga_2O_3 power devices production process.

- Cleaning, heat treatment, and dielectric film formation were investigated as elemental processes.
  - Cleaning: Observation of the crystal surface using atomic force microscopy led us to choose two successive cleaning processes: (1) A mixture of hot concentrated sulfuric acid and hydrogen peroxide to remove contaminated layers, and (2) A diluted hydrofluoric acid (5%) aqueous solution for surface flattening.
  - Heat treatment: As formation of gallium suboxides through reducing the surface and their volatilization damages the surface, employing the ambient with sufficient partial pressure of oxygen was effective to maintain the surface flatness.
  - Dielectric material: SiO_2 was selected as the material for the gate dielectric due to its sufficient conduction band offset and lack of tendencies of forming complex oxides at the interface. SiO_2 is also beneficial since it allows for high temperature heat treatment.
- The capacitance-voltage characteristics of the MOS (metal / insulator / semiconductor) capacitors fabricated with the combination of each selected elemental process were close to the ideal curve, showing no hysteresis or frequency dispersion (Figure 1).

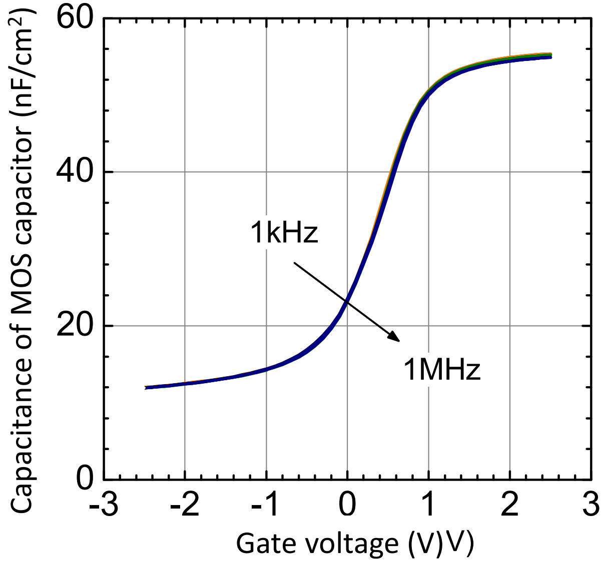


Figure 1: Demonstration of the good C-V characteristics of a MOS capacitor created via a SiO_2 gate dielectric, formed on a β-Ga_2O_3 wafer through a 1,000°C process [1].

Proposals for Policy Development

The limitations in processes such as wafer cleaning and annealing were revealed for the use of Ga_2O_3 as a next-generation widegap semiconductors. Research is required in the following two areas to accelerate commercialization:

1) Further clarification of the physical properties and reactivity of Ga_2O_3, especially the electronic structure of Ga_2O_3 and the correlation between the electronic properties and crystal defects in Ga_2O_3.
2) Clarification of reactions that occur on the Ga_2O_3 surface and near its interface with dielectric materials.

[1] K. Kita, E. Suzuki, and Q. Mao, ECS Transactions, 92 (1) 59-63, 2019.

An Analysis on Utilizing SOFC to Provide Reserve Capability for Power Systems

There are concerns that the mass introduction of renewable energy sources may reduce the ability to regulate power systems which are currently powered primarily by thermal power. For this reason, the possibility of utilizing solid oxide fuel cells (SOFC) with a relatively slow tertiary reserve capability was analyzed. Kyushu was used as an example for estimating the reserve capability price via a stochastic unit commitment planning model that included all power generation plants, taking errors in projecting photovoltaic outputs into account. Using the reserve capacity price, an energy cost minimization model for residential SOFCs showed that rewards for providing reserve capacity change operational patterns of residential SOFCs. This result reveals the high possibility of these SOFCs providing an upward reserve capability.

- The grid-wide stochastic unit commitment planning model was based around a typical electric utility company. The model was used to estimate the upward reserve capability price by determining the unit cost of electricity generation for the entire year in the Kyushu region, the amount of solar power curtailment, and the amount of reserve capability procured from the market.
- Figure 1 shows that there are seasons and times of year when the price of upward reserve capability exceeds the cost of providing upward reserve by typical SOFC-using households especially in summer weekday. This confirmed the economic rationale for providing reserve capability from home mounted SOFCs.
- When the resulting upward reserve capability power price estimates were entered into the SOFC energy cost minimization model, it became clear that the rewards for providing reserve capability cause changes to SOFC oparational patterns on summer weekdays in particular (Figure 2) revealing the high possibility that a scheme such as this could provide upwards reserve capability.

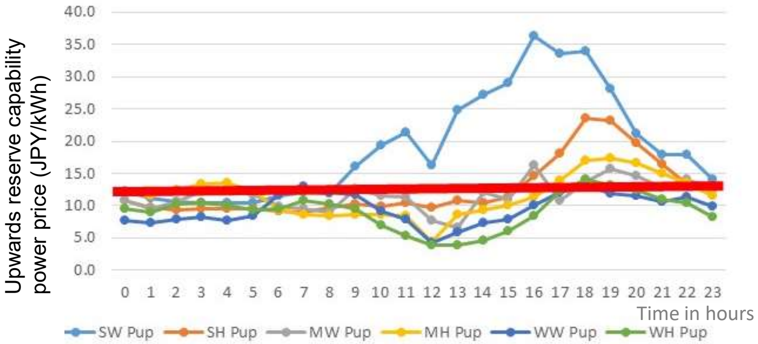


Figure 1: Estimation of the price of upward reserve capability through a stochastic unit commitment planning mode.

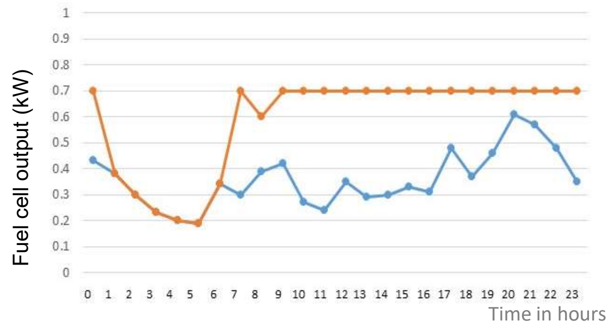


Figure 2: Difference in fuel cell outputs with and without rewards for providing upwards reserve capability (summer weekdays).

Proposals for Policy Development

1) Household SOFC-based reserve capability provision systems that allow for remote network control by power retail companies have future promise and are likely to become a reality. Further proof through a demonstration experiment is likely to further expand and energize this concept.
2) A business model for a system that compensates for forecasting errors in photovoltaic power generation through SOFCs should be verified through a government-led initiative that combines actual regional meteorological data, actual measurement data, and remotely controllable SOFCs.

Turbine System Driven by Direct Combustion of Rich Ammonia (Vol. 2)

Ammonia, which does not emit CO_2 as flue gas, is attracting attention as a fuel for large gas turbines for power generation. To evaluate output and efficiency of turbines, more accurate improved evaluation method was developed based on chemical equilibrium calculations to minimize the total free energy of the working fluid, instead of conventional simple method assuming working fluid as air. Applying the newly developed method, an ammonia-fueled turbine system was evaluated in terms of combustion efficiency and reduction of NO emission under excess ammonia condition. The performance of the turbine system was also compared with a hydrogen-fueled turbine system.

- An ammonia-only combined cycle under excess fuel condition is shown feasible even by the newly developed more accurate evaluation method. The estimated output was higher than that by the previous estimation [1].
- At an inlet temperature of 2,000K and a pressure ratio of 25, under normal lean NH_3 fuel condition, the thermal efficiency of the turbine was 0.63 and the NO concentration of the exhaust was 4,300ppm, whereas under excess NH_3 fuel condition, the thermal efficiency dropped to 0.63 but NO concentration showed double-digit improvement to 13ppm.
- The new method also showed that excess H_2 fueled combined cycle is feasible for the first time. The thermal efficiency of the cycle was 0.50 and NO concentration was 49 ppm.
- Not only with lower thermal efficiency and higher NO concentration, but also with the need for a larger amount of exhaust gas recirculation (larger EGR rate) than the NH_3 fueled combined cycle, H_2 fueled combined cycle has no advantage over NH_3 fueled cycle.

Table 1: Power and thermal efficiency with turbine inlet at 2,000 K

Fuel	Pressure Ratio	Equivalent Ratio	EGR Rate	Output[b] (MW)	Thermal Efficiency	NO (ppm)
NH_3	25	0.61	0	318	0.63	4,324
NH_3	25	1.52	0.2	504	0.53	41
NH_3	25	1.31	0.4	417	0.56	9.6
NH_3	25	1.08	0.6	340	0.60	13
NH_3	20	0.641	0	324	0.61	4,135
NH_3	20	1.67	0	581	0.50	109
NH_3	20	1.45	0.2	482	0.53	38
NH_3	20	1.22	0.4	395	0.56	7.6
H_2	25	0.47	0	296	0.61	5,314
H_2	25	1.74	0.8[a]	506	0.50	48.8
H_2	25	1.46	0.9[a]	434	0.53	52.4
H_2	20	0.49	0	303	0.60	5,189
H_2	20	1.79	0.7[a]	530	0.49	80
H_2	20	1.51	0.8[a]	457	0.51	29.1

a) EGR gas composition: N_2/H_2=0.75/0.25, b) Upper cycle flow rate 300 kg/s

Proposals for Policy Development

The ammonia rich combined turbine system could be a major breakthrough as a CO_2-free high-powered power generation system. To realize the system, a new combustor design is necessary, which will require large amounts of time and money.

1) A design and feasibility study of the turbine combustor need to be conducted by a team of experts. This would take around one year.
2) A national project needs to be implemented involving multiple companies with a proven track record with turbine systems.

[1] LCS Proposal Paper for Innovation Policy Development "Turbine System Driven by Direct Combustion of Rich Ammonia" Dec. 2018.

Cost Evaluation of Direct Air Capture (DAC) Process of Carbon Dioxide

Direct Air Capture (DAC) technologies, which capture low-concentration CO_2 directly from the atmosphere, are vital for the realization of a future zero-carbon society. The technologies used in Carbon Eng'g's KOH-$CaCO_3$-based DAC method [1] were evaluated and CO_2 capture costs were calculated.

- The case of 60,000 m^3/s and 900,000 t/year for the amount of air treated and CO_2 captured was evaluated. CO_2 capture costs were 35.4 JPY/kg-CO_2 (20.6 JPY fixed cost and 14.7 JPY variable cost). Air Contactor, a CO_2 absorption facility, accounted for 50% of the fixed costs, with natural gas, the energy source, accounting for 90% of variable costs.
- Reducing the cost of DAC requires the performance of Air Contactor, a low concentration CO_2 absorption facility that uses a KOH solution, be demonstrated at less than 400ppm. The cost of Air Contactor itself also needs to be reduced.
- The combination of an amine absorption method and DAC can be used to achieve zero-emission boiler exhaust gas, with significantly reduced costs for total CO_2 capture and storage (zero emission CCS) (Table 1). For example, if 98% of CO_2 is captured by the amine absorption process and the rest is captured by DAC, the cost would be 7.0 JPY/kg-CO_2.

Table 1: Cost of CO_2 zero emission measures for coal-fired power plants

Conditions: 958 MW of coal-fired power, 127 Mmol/h of combustion gas, 13.7% of CO_2, 766 t/h of emissions

Amine absorption process collection rate (%)	90	94	98	99	99.5
Exit CO_2 concentration	1.56%	0.94%	0.32%	0.16%	790 ppm
Amine absorption collection amount (%)	689.4	720.0	750.7	758.3	762.2
DAC collection rate (t/h)	76.6	46	15.3	7.66	3.83
Amine absorption and capture cost + storage cost (JPY/kg-CO_2)	5.4	5.8	6.4	7.0	8.1
DAC collection cost + storage cost (JPY/kg-CO_2)	36.7	36.7	36.7	36.7	36.7
Zero emission CCS cost (JPY/kg-CO_2)	**8.5**	**7.7**	**7.0**	**7.3**	**8.2**

Proposals for Policy Development

1) DAC technology is essential for the realization of a future zero carbon society.
2) DAC can be implemented anywhere, but overseas locations where natural gas is cheap and CO_2 reservoirs are nearby have an advantage. However, even if the CO_2 storage areas are abroad, given the size of these future implementations and the importance of these projects, it is vital for Japan to develop new DAC technologies.
3) It would be desirable to develop DAC-related technologies though national projects.

[1] D.W. Keith et al. "A Process for Capturing CO_2 from the Atmosphere", Joule 2, 1573-1594, 2018.

Methane Production from Biomass Wastes by Anaerobic Fermentation (Vol. 4): Rationalization of Multi-Stage Fermentation and High Temperature Fermentation & Examination of Hydrogen Fermentation

Methane fermentation technologies for biomass waste have been used around the world for many years. However, there has been a lack of quantitative studies into fermentation mechanisms. The International Water Association's model for methane fermentation "Anaerobic Design Model No.1" (ADM1) [1] was applied to two-stage continuous and high temperature processes of methane fermentation and to hydrogen fermentation process, which has potential to increase energy production. The improvements in yield of methane fermentation and the mechanisms of hydrogen fermentation were investigated.

- To improve methane fermentation process, a combination of a higher fermentation temperature of 55°C and a two-stage continuous fermenter was investigated. In the case of sewage sludge, the COD decomposition rate increased by 33% at high temperatures, with biogas production costs reduced from 3.3 JPY/MJ to 2.3 JPY/MJ. In the two-stage fermentation, the COD decomposition rate increases by 6–8%.
- Hydrogen is produced when the pH of the fermenter is between 4 and 5. The examination involved a combination of two tanks. The first tank, used for hydrogen production, is kept at at 55°C with a pH of about 5, and the second tank, for methane fermentation, is kept at 35°C with a pH of about 8. After a total residence time of 20 days, the amount of energy generated by both sewage sludge and garbage was 11% more than that of methane fermentation only (Table 1).

Proposals for Policy Development

ADM1 can be used to predict hydrogen and methane fermentation. As a next step, it will be necessary to optimize the model and fermentation conditions by confirming consistency with experiments.

1) Quantitative analysis and optimization of the fermentation mechanisms and systems are required, So that the COD decomposition rate would be increased to more than 80%.
2) For hydrogen fermentation, conditions need to be considered for optimal fermentation that inhibits methane-producing fermentation bacteria and activates hydrogen-producing fermentation bacteria.

[1] D.J. Batstone et al., "Anaerobic Digestion Model No.1", Scientific and Technical Report No.13, International Water Association, 2002.

Table 1: Hydrogen fermentation and energy production

Raw materials: supply of 5m^3/d, concentration of 58.6 kg-COD/m^3

Raw material	Sewage sludge	Sewage sludge	Raw garbage	Raw garbage
Hydrogen fermentation tank	**Yes**	**No**	**Yes**	**No**
Temperature (°C)	55		55	
pH	4.83		4.79	
Residence time (d)	**1**	**-**	**1**	**-**
Amount of CO_2 produced (m^3/d)	11.9		9.13	
Amount of H_2 produced (m^3/d)	4.31		4.21	
Amount of CH_4 produced (m^3/d)	1.85		1.36	
Amount of energy produced (MJ/d)	113		94	
Methane fermenter				
Temperature (°C)	35	35	35	35
pH	8.19	7.87	8.14	7.81
Residence time (d)	**19**	**20**	**19**	**20**
Amount of CO_2 produced (m^3/d)	55.3	55.5	82.8	81
Amount of H_2 produced (m^3/d)	0.0251	0.0016	0.004	0.0026
Amount of CH_4 produced (m^3/d)	69.1	65	94.5	87.5
Amount of energy produced (MJ/d)	2474	2327	3383	3133
Total amount of energy produced (MJ/d)	**2587**	**2327**	**3477**	**3133**
Comparison with methane fermentation only	**1.11**	**1**	**1.11**	**1**
Total COD decomposition rate (digestion rate)	**0.520**	**0.479**	**0.719**	**0.657**

https://www.jst.go.jp/lcs/pdf/fy2019-pp-10.pdf

Fuel Oil from Algal Biomass: Evaluation on CO_2 Emission and Economy

The production of fuel oil from algal biomass through photosynthesis has been attracting attention as a fuel for aircrafts that are difficult to electrify, and the attempts for commercial scale production have begun. By clarifying the production cost and CO_2 emission with the results of our process design based on the basic data of three cases, 1) University of Tsukuba Group, 2) US Department Of Energy (DOE), and 3) New Zealand's National Institute of Water and Atmospheric Sciences Research (NIWA), the challenges for realizing the low carbon fuel oil are shown.

- University of Tsukuba G: Fuel oil Production by *Botryococcus braunii* [Case 1].
- U.S. Department Of Energy (DOE): Combining a large culture pond with a fuel oil production process [Case 2].
- New Zealand NIWA: Use sewage treatment plant effluent as raw materials [Case 3].
- The production costs of case 1 and 3 are much higher than the current cost of fuel oil (50 JPY/kg) and case 2 is about three times higher. Factors such as the structure of the culture pond, the CO_2 concentration in the CO_2 resource, the production scale, and residence time make these differences.
- Even for CO_2 emissions, cases 1 and 2 are greater than the 70 g-CO_2/MJ of current gasoline fuel. For case 3, it's about 0.6 times because of feeding the carbon neutral CO_2. Even if renewable energy is used for power, each case produces 134, 108 and 20 g-CO_2/MJ respectively. This means it is impossible to produce the carbon free fuel oil from algal biomass through above study.

Conclusion

It is obvious that low carbon fuel oil from algal biomass can not be realized with feeding CO_2 derived from fossil fuel as the carbon source. In order to realize carbon free fuel in the future, further studies on using the non fossil resources or combination with Direct Air Capture (DAC) will be needed.

Table 1: Comparisons of fuel oils from algae

	Case 1 University of Tsukuba G	Case 2 DOE	Case 3 NIWA
Algae	***Botryococcus***	***Scenedesmus***	**Algae colony**
Productivity (g/m^2/day)	20	25	20
Days cultured	20	5	9
Size of culture ponds (ha)	1	4	1.25
CO_2 source	**Exhaust gas from thermal power plant: CO_2 concentration of 5%, recycling of unreacted CO_2**	**Exhaust gas collected from thermal power plant: CO_2 concentration of 100%**	**Exhaust gas from sewage treatment digestion of gas-based power plant: concentration of 5%**
Annual production per-module (t/y)	66	3,300	82.5
Number of modules	1	50	1
Fuel oil production (t/y)	33	79,900	33
(TJ/y)	1.38	3,040	1.38
Annual variable cost (million JPY)	**1.9**	**5,400**	**1.2**
Annual facility cost (million JPY)	41.4	7,150	12.2
Annual labor cost (million JPY)	5	540	5
Annual fixed cost (million JPY)	**46.4**	**7,690**	**17.2**
Total annual cost (million JPY)	**48.3**	**13,090**	**18.4**
Fuel oil cost (JPY/kg)	**1,462**	**164**	**558**

	CO_2 emission (g/MJ)		
Feedstock origin	**88**	**82**	**0**
Sub-feedstock origin	**0**	**24**	**0**
Power origin (400g-CO_2/kWh)	**36**	**9**	**25**
Construction material origin	**46**	**2**	**20**
Total	**170**	**117**	**45**

[1] JST Strategic Basic Research Programs CREST, "Oil-producing green algae (Research Completion Report: Sophisticated Utilization of Alkaliphilic Strains of Oil-producing Green Alga, *Botryococcus*", 2012)
[2] R. Davis et al., "Process Design and Economics for the production of Algal Biomass", NREL/TP-5100-64772, 2016.
[3] M.A.Borowitzka et.al., "Algae for Biofuels and Energy", Springer, 2013.

Regional Distribution of Energy Potential of Woody Biomass (Vol. 3):
Reduction of Total Production Cost of Woody Biomass

Woody biomass is widely distributed throughout Japan and is a widely available energy source. This evaluation revealed that operating costs calculated from forest management plans, forest registers and geographic information, as well as ones calculated under the uniform conditions in planted forests [1], are equivalent. Transportation costs were also calculated based on distance and means of transportation and an assessment of total forestry production costs was performed.

- The operating costs in each area were calculated based on forest management plans and other data. Compared to the previous report [1], in which conditions were uniform in planted forests, the yield was lower because restricted forests were excluded, but the timber volume (volume of wood per area) was comparable, so operating costs remained the same. Intensive forestry management that ensured scale, along with the introduction of multi-trailer trucks, made it possible to reduce transportation costs from current levels.
- Cost of woody biomass production in fifteen prefectures were at or below 5,000 JPY/m^3, which is comparable to those in Western forestry countries and is internationally competitive in terms of price (Figure 1).
- Another option for further development cost reduction is sharing infrastructures including roads with other renewable energy facilities such as small and medium hydro and wind power.

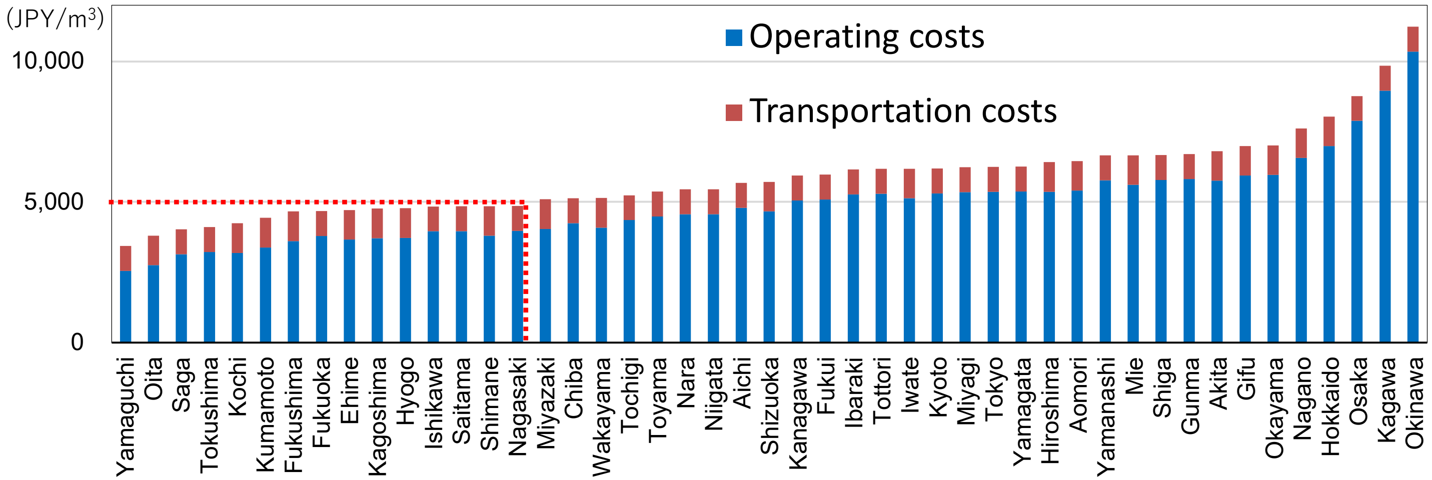


Figure 1: Cost of woody biomass production in each prefecture (JPY/m^3)

Proposals for Policy Development

1) To reduce forestry production costs, it is important to introduce high-performance forestry machine and maintain high labor productivity in sufficiently large planted forests. Multiple municipalities need to work together to support intensive forestry.
2) It is necessary to train and make active use of a forest manager who can supervise and instruct management plans and operations.
3) The development of road networks is essential for improving forestry productivity. Aiming at the completion of the road network within several decades, continuing the development with a small amount of support each year will lead to forestry development. The development of multi-trailer trucks, as well as maintenance of travel routes for these trucks, is also required.

[1] LCS Proposal Paper for Innovation Policy Development "Cost Reduction of Woody Biomass Fuels (vol.2): Total Production Cost and Cost Reduction Scenario of Woody Biomass", Mar. 2017.

Innovative Energy Technology Research & Development and ARPA-E

The Advanced Research Projects Agency–Energy (ARPA-E), which began operations in 2009, is an organization under the U.S. Department of Energy. The agency aims to create innovation in the energy sector through high risk, high impact results. Its operational characteristics include high levels of authority being delegated to its program director, with reviews of interim results and decisions to continue projects made rapidly. Based on the investigations into the trends of ARPA-E, noteworthy features of the program are proposed.

- ARPA-E focuses on supporting the development of budding technologies, even if their cost and performance are inferior at the present time. The agency is based around a philosophy of creating success by retaining technologies that can bring about future, disruptive change (Figure. 1).
- ARPA-E provides three kinds of funding opportunities: call for proposal in non-specific technical area (open), in specific technology area, and for small /medium business. The technical goals of the funding programs are presented after public workshops. Project proposals are evaluated for their scientific and technical merits, as well as for innovativeness.
- The agency has a budget of $350 million (2019). Its programs are categorized by technology fields of generation-transmission-distribution, energy and resource efficiencies, and transportation, but they may span multiple fields.

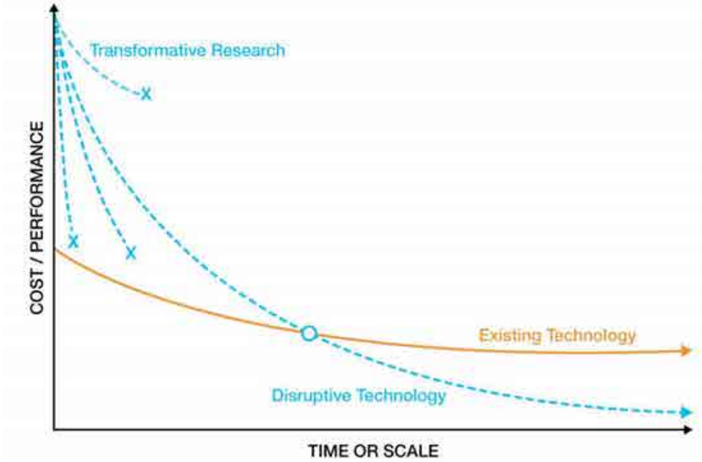


Figure 1: The potential for disruptive creation through selecting a diverse group of technologies [1].

Proposals for Policy Development

The keys to realizing a low carbon society include innovation based on technological seeds that lead to reductions in greenhouse gases, as well as management that expands these efforts and disseminates them to society at large.

1) ARPA-E covers a wide variety of technological seeds and aims for high impact results. The program directors are uniquely provided a great deal of discretion and responsibility when running the programs.
2) The Defense Advanced Research Projects Agency (DARPA), which is comparable to ARPA-E and operates under the Department of Defense, has had a large impact on the civilian sector through technologies such as the internet and GPS. ARPA-E has a lot of project-based failures over the past 10 years and cancels projects that lack prospects. Identifying successful projects requires a long-term perspective.

[1] ARPA-E Website https://arpa-e.energy.gov/.(accessed Dec. 20, 2019).

Investigation of Degradation Behavior of Lithium-Ion Battery

The degradation behavior of lithium-ion batteries was organized by parameter and electrode material. Trends of and factors relating to degradation were analyzed. Parameters included temperature, state of charge (SOC), depth of discharge (DOD), and charge/discharge rate (C rate). The electrodes which were made of $Li(Ni_xMn_yCo_{1-x-y})O_2$ (NMC) and lithium iron phosphate (LFP) were used as positive electrode materials. Graphite and lithium titanite (LTO) were used as negative electrode materials.

- The test results from various literature were organized, arranged by combination of positive and negative electrodes for each parameter, then, degradation trends and factors were analyzed (Table 1).

Table 1: Summary of degradation studies (excerpt)

Test method	Parameter	Positive electrode	Negative electrode	Effect
Calendar aging tests	SOC	NMC	Graphite	The lower the SOC, the less likely it is to degrade. Takes 220 days to degrade to 90% of capacity at 50% of SOC.
		LFP	Graphite	Similarly, lower SOC leads to slower degradation than NMC (>600 days under equivalent conditions).
	Temperature	LFP	Graphite	The higher the temperature (20°C to 60°C), the faster the degradation is. Film formation on the surface of the negative electrode is presumed to be a factor.
Cycling aging tests	SOC	NMC	Graphite	Tends to degrade easily in SOC regions that are high or low. Presumed to be electrode erosion at the sudden point of change where dV/dQ passes through.
		LFP	Graphite	Smaller dependence on SOC for degradation and less degradation than NMC.
	DOD	NMC	Graphite	The wider the DOD, the easier it degrades, with the capacity lowering to 80% after 500 cycles. Presumed to be erosion at the sudden point of change for dV/dQ.
		LFP	Graphite	Degradation is slower than that of NMC, and it takes about 3,000 cycles to reach 80% of capacity.
	Electrode materials	—	—	Positive NMC and negative LTO has the slowest rate of degradation; it takes about 3,000 cycles to reach 90% of capacity.
	Temperature	NMC	Graphite	34→46°C leads to capacity degrading to 80% in 1,200→500 cycles. Presumably an effect of preservation.
		LFP	Graphite	35→45°C leads to capacity degrading to 90% in >3,000 → <2,000 cycles. Presumably an effect of calendar aging.
	C-rate	NMC	Graphite	A C-rate of 6.5 degrades faster than one of 2 or less. 80% of capacity reached in 1,000 or less cycles.
		LFP	Graphite	If the c-rate is 8, takes 1,700 cycles or less to reach 80% of capacity. 2,000 cycles or more for <4C.

https://www.jst.go.jp/lcs/pdf/fy2019-sr-01.pdf