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Reweave the World

Energy Systems Convergence leads to global resilience and sustainability in energy, food, and water

White paper - January 2023

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Abstract

Humankind's global effort to become carbon neutral by 2050 is driving towards a major tipping point, transforming nearly every social activity and industry. Factors such as geopolitical uncertainty, resource availability and climate change are calling for a global restructuring of the energy system to create new opportunities for the future.

Indeed, the decarbonization trend and review of energy schemes are accelerating discussions about switching from oil and natural gas to renewable energies, yet this is a complex issue that cannot be resolved by simple substitutions.

In 2012, Yokogawa predicted in its "Future Sense 2025" white paper that the world will inevitably face the Triple Nexus, which is defined by the interlocking issues of energy, food, and water security. For example, solving energy security or climate change by substituting with alternative sources will have compounding financial and availability effects to food production and/or water cooling, and vice versa. It is then crucial to see the interdependence of human needs and the environment through a larger lens rather than in independent silos.

Yokogawa calls this holistic approach to resolving the Triple Nexus "Human Behavior Innovation." On top of technology innovation and energy transition, human behavior innovation features collaboration based on circular economy, sharing economy and trust between regional industries, as well as more sustainable consumption by choosing cleaner, greener, or fair-trade products. By combining energy exchange (such as electricity, steam, and hot water), material exchange (such as CO_2, hydrogen, methane, and oxygen) and information exchange (such as weather, supply and demand plans, production plans, and market forecasts), we can overcome barriers in resource availability and industrial optimization. By sharing resource surpluses, reducing buffers,

and making full use of peak shaving and leveling across regions, we can likewise draw a clearer path to carbon neutrality.

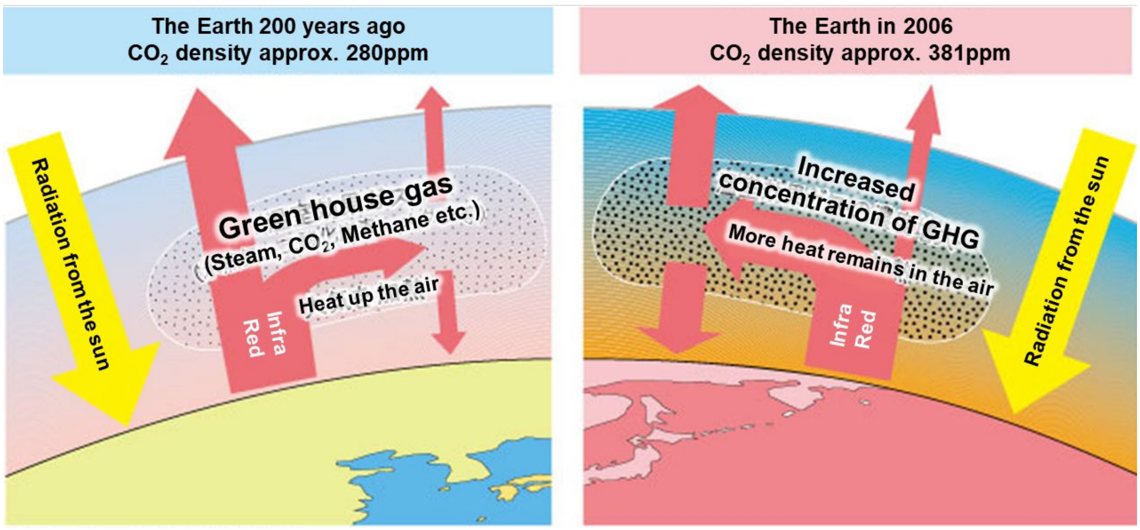
As 2030 is a transit point for the energy system to converge on a combination of production methods and energy sources while maintaining balance, we will take a bird's eye view of the overall structure of the energy system and explore various opportunities for inter-industry collaboration. To realize this, we need to develop active discussions with our neighbors (industrial, commercial, and social communities) today.

The earth seen from the space

Where does energy come from, and where does it go? The source of energy (input) is the thermal energy of magma, the energy that sleeps in the substance itself and its physical laws, and the electromagnetic energy due to radiation from the sun (both oil and natural gas can be regarded as the accumulated one of past electromagnetic energy). The only output is electromagnetic radiation from the Earth to space. The Earth realizes a miraculous environment in which this input and output are balanced, resulting in a temperature range in which life can survive.

Figure 1. Mechanism of Global Warming

Source: Ministry of Agriculture, Forestry and Fisheries
“2007 White Paper on Food, Agriculture and Rural Areas”, YOKOGAWA modified

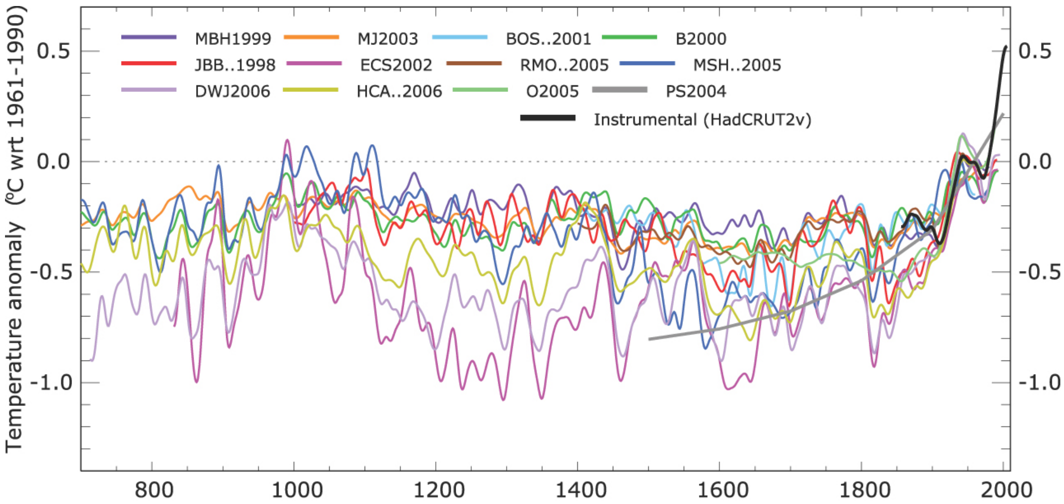


This balance has remained stable for more than 1000 years until the beginning of

1900, but since the First Industrial Revolution, human activities have accelerated the release of stored energy and CO_2, resulting in an increase in input and the decrease in output that led to global warming.

Figure 2. Northern Hemisphere Mean Temperature Variation

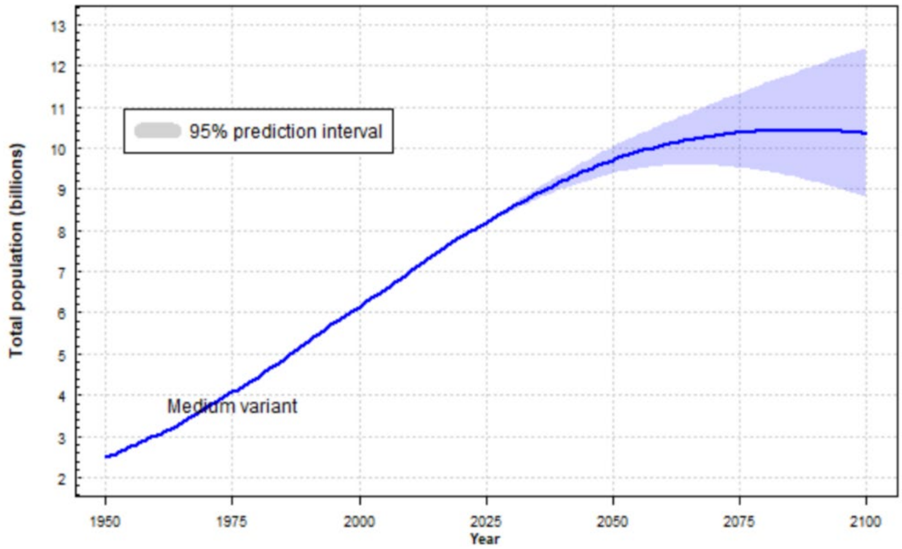
Source: IPCC Fourth Annual Report, Working Group I, Figure 6.10. Paleoclimate. In: Climate Change 2007: The Physical Science Basis.



Global warming has a great impact on humanity and the global environment, and the movement toward decarbonization is accelerating. From this holistic perspective, decarbonization is not only transitioning power sources to greenhouse gas-free energy, but it is also about redesigning the energy system so that so that the economic activity of 11 billion people stays within the Earth's energy balance.

Figure 3. Total Population

Source: United Nations, Department of Economic and Social Affairs, Population Division (2022). World Population Prospects 2022, Online Data. https://population.un.org/wpp/



Triple Nexus: Energy's Impact on Food and Water

From a human perspective, access to energy has a deeper context as it impacts our fundamental needs and sustainability, making it challenging to introduce significant changes to existing energy schemes. From a climate change perspective, energy usage, availability, and affordability correlate to higher GDP and standard of living, making it even more challenging to change dependencies on fossil fuels.

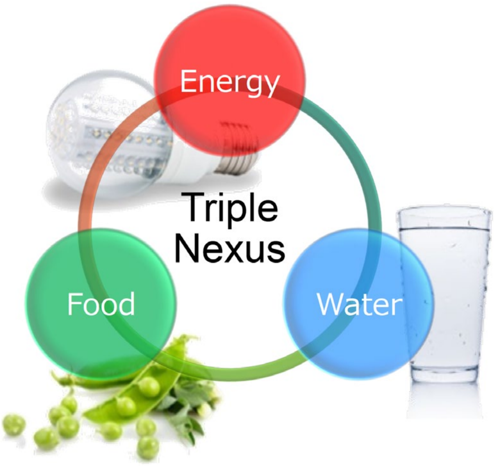
In the "Future Sense 2025" white paper published in 2012, Yokogawa stated, "Energy challenges are closely linked to food and water challenges, and by 2025 humanity will face depletion due to the competing demand for these resources." Triple Nexus, which is defined by the interlocking issues of energy, food, and water security, have rapidly evolving and complex demands from geo-political, socio-ecological, and economical aspects. Attempting to solve energy security or climate change by substituting with alternative sources will have compounding pricing and availability effects to food production and/or drinking water, and vice versa. Thus, introducing solutions to each issue will have limited outcomes, making it even more crucial to see the interdependence of human needs and the environment through a larger lens.

This holistic approach to resolving the Triple Nexus is called "Human Behavior

Innovation." On top of technology innovation and energy transition, human behavior innovation features collaboration based on circular economy, sharing economy and trust between regional industries, as well as more sustainable consumption by choosing cleaner, greener, or fair-trade products. That is, our mindsets must be transformed to see the interdependencies, and that we must strive to develop new behavior patterns to sustainably support humanity and the environment.

Figure 4. Triple Nexus: Interlocking Issues of Energy, Food and Water Security

Source: YOKOGAWA "Future Sense 2025" (2012), YOKOGAWA modified



Today, the decarbonization trend is actively shaping discussions about switching the energy source from oil and natural gas in favor of renewable energies, but this is a complex issue that cannot be fundamentally resolved by simply changing sources and technologies from A to B. The key to achieving a sustainable and forward-looking energy system lies in human behavior innovation. For human beings, energy is not simply a source of economic activity, but also an extremely important agenda for life support and well-being. The success or failure of human behavior innovation will determine our future.

Four Future Scenarios: Where to Aim?

Governed by the Paris Agreement, the world ultimately aims to achieve net-zero emissions. In the white paper entitled "Future Scenario 2035: A Journey Through Time," Yokogawa introduces four different yet possible scenarios based on the most influential mega trends such as socioeconomic risk, digital transformation, biotech R&D, capital markets, and so on, which significantly impact the industrial ecosystem and Triple Nexus.

By recognizing each of these scenarios as a world to enconter by 2035, we can prepare, strategize in advance, and act today.

1. Productive Harmony

Humanity recognizes its reliance on the environment, and nations, recognizing their own radical interdependence, prioritize global-scale social advancements and ecological balance over self-interest.

Enabled by technology innovations, humanity prioritizes global socio-ecological advances, and cooperate on ensuring human needs are met, while wellbeing, equality and environmental stewardship indices become the major standards by which economic health is measured. User experience and relationship interactions form the basis for cooperative sharing economy and service-led business models. In addition, unified and seamless virtual worlds enable significantly less resource-intensive consumption and global connectivity. Synthetic biology supports adequate access to vital resources globally while respecting biodiversity. In order to meet growing global energy demand, renewables are highly integrated and distributed. Advances in other related energy & carbon capture technology advances lead humanity towards a net-zero economy and nature-positive economy.

2. Green Digital Fortresses

Governments push toward addressing the existential threat of climate change, while the private sector must act on and manage business risks associated with natural disasters and broad resource scarcity. At the same time, restricted data flows create silos of innovation.

As governments and private sectors strive toward addressing climate change and global risks, sustainability focused technology advances occur. However, data sharing model limitations result in incremental progress and few breakthroughs innovation, while data flow limitations slow progress and creates gap in global social uplift. In addition, industries dominated by closed systems over rely on vendor lock-in to secure customer loyalty, and remaining reliance on legacy systems hinders overall efficiency. Various virtual ecosystems also compete through a vendor lock-in approach, both improving and limiting connectivity among consumers and businesses. Biotechnological advances seek to resolve broad environmental concerns, while renewables form a large, growing portion of the energy mix. Yet, national energy needs still require the use of fossil fuels and nuclear options, pushing back net-zero emissions goals.

3. Missed Opportunities

The global community continually misses opportunities to address large existential threats fully and adequately to humanity and the environment, leaving this responsibility to future generations.

As multiple competing technology infrastructures and standards take hold, overall socio-ecological progress slows down as national interests and short term corporate objectives are prioritized. Fragmented public and private global power structures divide global governance, diverting efforts towards addressing global threats to humanity. The responsibility falls on future generations as humanity fails to adequately respond, and many individuals still do not have their basic needs met. While technological advancements do occur, wealthy economies reap benefits in advance of poorer nations. In parallel, virtual worlds are fast-growing with disparities from the physical world mirrored into the digital ecosystem. Uncontrolled artificialization spurred by biotechnological advancements also threaten global biodiversity, while most developing nations remain carbon emissions-intensive, exceeding environmental limits.

4. Distracted Innovation

Innovation lowers the cost of technology and goods, encouraging progress toward individual self-actualization and individual force, but this progress remains vulnerable to rising threats from the climate crisis and resource insecurity.

Open systems and greater data flow enable global innovation to proliferate, often targeting mass consumption which further strains the natural resources balance and shifts the socio-ecological focus away from sustainability initiatives. virtual worlds are become borderless and infinite, primarily used by consumers for escapism from the physical world. Corporations are driven by ESG expectations to disperse sustainable and technologies benefiting society, yet lack the weight of governments or international organizations. Biotechnology enabled significant progress in medicine, but fails to reach all nations equally. Controversial experimentation also gains momentum. Regarding the global energy mix, despite advances in renewables, fossil fuel use remains significant. While exceeding environmental limits is a concern, competing national interests often takes priority.

With mega trends and global uncertainties continuously changing and re-shaping the industrial ecosystem, these four scenarios may still change. At the same time, depending on the location, infrastructure, resources, readiness and so on, adoption of multiple scenarios are likely to occur, resulting in various outcomes in relation to the Triple Nexus (resource availability) and climate change (net-zero emissions).

Yet, out of the four scenarios, Yokogawa aims towards "Productive Harmony," we believe it an ideal world that enables prosperous communities and fuels its interdependence. By using this scenario as a framework, global networks can evolve and closely cooperate on a shared focus for sustainability, creating resilience, optimization and innovation for humanity and the environment. Taking this scenario closer to reality, we can take concrete steps and a clearer path towards “Productive Harmony” by redesigning the current energy system.

Figure 5. The World in 2035: Four Scenarios

Source: YOKOGAWA “Future Scenario 2035: A Journey Through Time” (2022), YOKOGAWA modified

Today's Challenges

Navigating Energy Security and Decarbonization

As of 2023, the supply of natural gas has become imbalanced due to International relations factors, and energy availability and soaring prices have become pressing issues. All countries around the world put a lot of effort to procure energy, secure stable supply routes, and develop new security schemes. This results in a chain reaction where competition for energy in various parts of the world exists, causing a rise in energy prices that later leads to a rise in food and water prices. With this, some countries faced a situation need to consider balancing heating and food in winter. This news reminded us once again of the importance of building a well-balanced procurement portfolio for energy security. Over time, as domain knowledge, technology and infrastructure mature, renewable energy will become more affordable, while fossil fuels energy prices may be forced to rise because it will need to incorporate efficiency improvements and CO_2 capture measures. When energy prices are stabilized and competitive, building a well-balanced energy portfolio becomes easier as governments and private companies can choose the most appropriate and practical mix of renewable energy sources and fossil fuels based on their own use cases.

Similar issues exist from the perspective of decarbonization, which has been accelerated by the Paris Agreement. Countries have an obligation to make structural changes in energy production and use, as well as take ambitious steps to put the brakes on climate change. In addition to setting long-term national targets, countries aree required that, preferential policies such as incentives, tax cuts and subsidies, as well as technological advances such as carbon capture technology will be used to reduce CO_2 emissions, recover exhaust gas that can be reused in other applications, and prevent further emissions by increasing the production of renewable energy (electricity) and utilization of energy conversion through energy carriers (Power-to-X).

Again, building an energy portfolio is a challenge, as it is not as simple as replacing everything with renewable energy saying like energy transformation. Renewable energy is primarily electricity, but building a grid to electrify everything, including industrial use, is not realistic in terms of equipment cost and physical power capacity. While energy will be converted into some kind of energy carriers and supplied (Power-to-X), this is not the only all-purpose option. For example, hydrogen is known to be clean because it turns into water even if it is burned. It is challenging to apply hydrogen to all use cases due to its low energy density(calory per unit volume and unit weight), huge energy is required to liquefy by freezing down to -253℃, high speed of combustion cause NOx emission, and when stored in a tank, gaseous hydrogen leaks, and liquid hydrogen has a large boil-off loss. Therefore, other options such as ammonia, methane, MCH (methylcyclohexane), methanol, ethanol, batteries, potential energy, and so on, should be combined according to the characteristics of the use case to create a robust portfolio.

Limits of Individual Optimization

In the industrial world, factories and companies have made great efforts to reduce CO_2 emissions and increase renewable energy production based on government guidelines and their own policies. These efforts include various aspects such as installing solar panels, procuring renewable energy from power providers, adopting alternative fuels that emit less (or no) CO_2 emissions, making lighting and equipment more energy efficient, turning off power frequently, and providing better heat insulating wall materials for buildings. While these are undoubtedly contributing to the improvement of the environment, these are gradually approaching their limits, much like wringing out a dry rag.

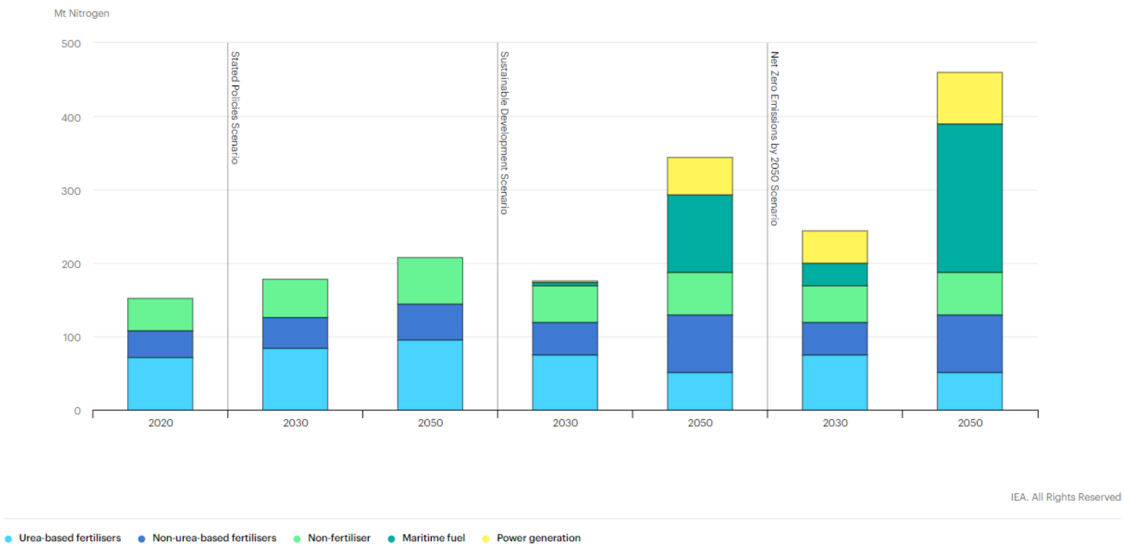
Such individual initiatives that have been carried out reflect a closed paradigm of a company that exists as a part of a single supply chain. Typically expressed as upstream and downstream – raw materials are procured from specific suppliers, waste is treated at a cost, waste heat is then released to the atmosphere, captured CO_2 is treated by own system, and grid power contract is designed by subtracting self-generated power from the company's peak power demand, and boilers have a buffer for load fluctuations. Under such an assumption the road to carbon neutrality will already be very tough.

Let's think about it from a broader perspective. Ammonia, for example, has been industrially produced for about 100 years by a revolutionary chemical reaction process invented by Dr. Haber and Dr. Bosch. The manufacturing process uses a large amount of energy and hydrogen from methane gas at high temperature, high pressure, with a global scale centralized production, and has been emitted a lot of CO_2. Approximately 80% of ammonia is used as a raw material for fertilizer. The increase in the world population, which is expected to reach 11 billion in 2100, coupled with the improvement in living standards, will increase the demand for food. This results in a chain reaction of an increase in demand for fertilizer, an increase in demand for ammonia, an increase in CO_2 emissions, which later becomes a massive problem for all humankind.

In recent years, technological breakthroughs such as special catalysts, renewable energy, and water electrolyzers have made it possible to produce ammonia at low temperatures and pressures, independent from oil and gas, in small scales and distributed around the world. That is, green ammonia which is made from water and renewable energy. This essentially is a good news for producing food for the world's 11 billion people.

Figure 6. Nitrogen Demand by End Use and Scenario, 2020-2050

Source: IEA, Nitrogen demand by end use and scenario, 2020-2050, IEA, Paris https://www.iea.org/data-and-statistics/charts/nitrogen-demand-by-end-use-and-scenario-2020-2050, IEA. License: CC BY 4.0



When viewed as a fuel and energy source, ammonia has been attracting attention in recent years as a carrier for renewable energy (Power-to-X), due to the fact that the technology for long-term storage has been established, does not generate CO_2 when combusted, has an energy density per volume that is approximately two-thirds that of LNG and approximately twice that of hydrogen, and is capable of long-distance transportation. Mixed combustion with coal combustion and gas combustion, or simple combustion (replacement) in the steel industry and electric power industry are also being considered. Combining the unevenly distributed and fluctuating renewable energy with the optimal placement of power plants across the globe, it is certain that ammonia will be incorporated as part of the energy supply route in the near future. It is also a promising and profitable use case.

Now, ammonia which has been used almost exclusively for fertilizer applications, suddenly has the possibility and potential demand as an alternative fuel, and therefore there is an increasing danger of competition for resource shares on the Triple Nexus (energy, water, and food security) through green ammonia. Restricting the optimization perspective to a single company or industry limits its effectiveness and may produce undesirable side effects for the Triple Nexus. If we expand the use of green ammonia as an energy source, a large amount of water will be used, and ammonia, which was used as a raw material for fertilizer, will be turned into fuel. A serious conflict arises for humanity, where the optimization of energy and the optimization of food and water are at odds with each other. If left unattended, prices will not stop rising and will subsequently collapse. Even if we aim to double or triple the production volume of ammonia, it will not be possible to achieve it immediately due to the large scale of demand for energy. Each company and industry are required to cooperate with each other and find an appropriate balance.

Energy Systems Convergence

The idea of energy systems convergence is to seek and find a balanced approach for global-scale carbon neutrality, energy security, the energy-food-water Triple Nexus, while considering these individually optimized silos (supply chains that are independent of each other, or one-way supply chains) as an energy system, integrating them ("convergence") allows us to respond to individual issues. Companies, industries, regions, and nations will exchange, accommodate and share energy (electricity, steam, hot water, hydrogen, ammonia, methane, etc.), materials (CO_2, oxygen, other raw materials, and waste, etc.), and information (supply and demand plans, production schedules, market forecasts, weather data, etc.) to redesign desirable energy system structures for the entire region and the planet.

What is Energy Systems Convergence?

The speed and degree of change in energy systems brought by global decarbonization pressures, nations leaderships and technology advancements is not new, but oftentimes individualized and unexpected. This is because today's global energy system is designed as a supply mechanism to meet a series of demands represented by the word "supply chain". Disruptions on the supply side trickles down to the demand side, furthering issues related to energy security. The harsh reality is that there is no coordination between different supply chains, a lot of waste and scarcity can happen here and there, and prices tend to fluctuate for unexpected reasons.

The ideal energy system that will be needed in the future, even today, should consist of a balance between the structuring of networks, publicizing of various demands and the diversification of supply. It is necessary for the energy system to be redesigned and adjusted by starting from the community's point of view, optimizing the amount of energy and CO_2 emissions per unit according to use and purpose on a global scale while maintaining balance with food and water.

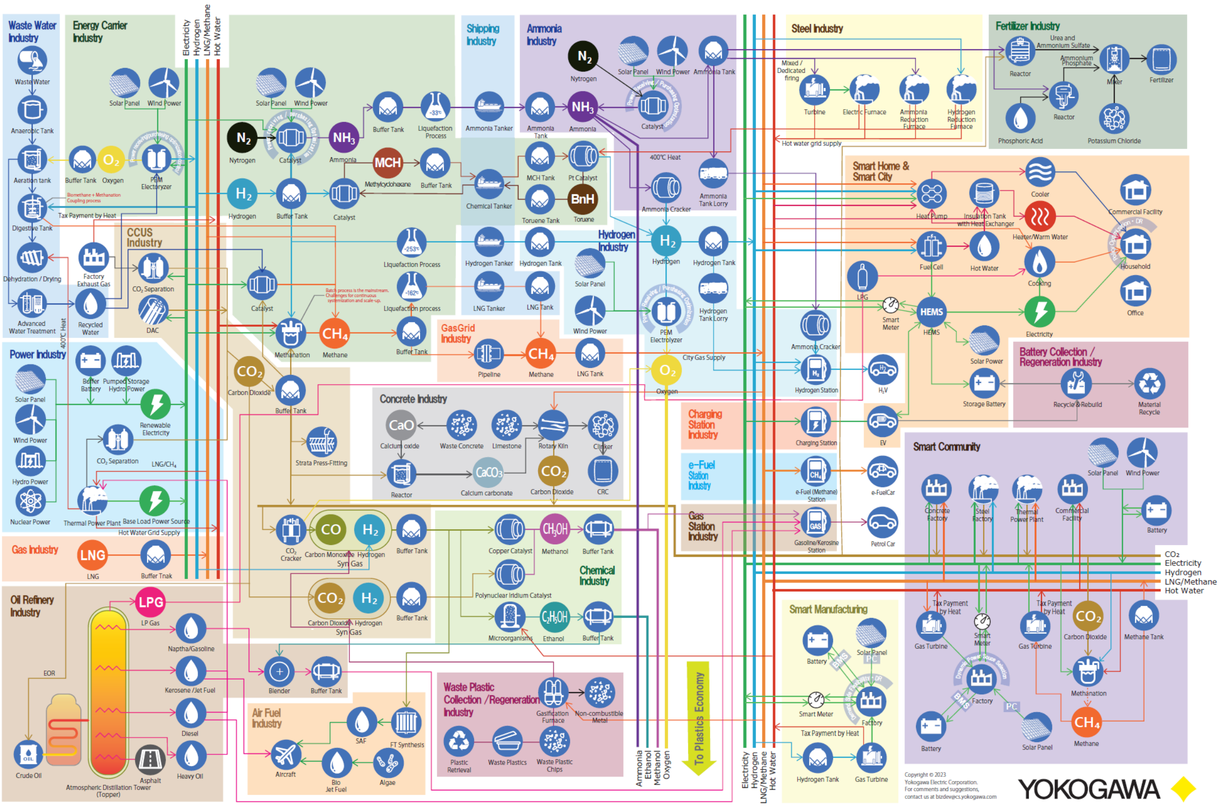
As energy systems convergence builds cross-industry ecosystems of energy, material, and information exchange, it leads to a merging of an environment driven by shared industries, solutions, economics, policies, which enable new strategies, business models and more importantly, foster new value chains and mindsets.

Let's take a bird's-eye view of society in 2030, focusing on the flow and exchange of energy and materials between industries. As shown in the "Energy Systems Convergence 2030"†, the flow of energy originating from renewable energy will be converted into various energy carriers, and energy usage options will be prepared according to use case and geographical constraints. Not only hydrogen which we see many initiatives in 2023 in relation to hydrogen as an energy source, yet towards 2030, companies and industries will be highly connected much like a web through many energy carriers including electricity, ammonia, methane, MCH, and steam.

† There is the Energy Systems Convergence 2030 CUD version also available to download. CUD version is designed to fit with the guideline by CUDO (Color Universal Design Organization).
Refer https://www2.cudo.jp/wp/?page_id=1936 for more information.

Figure 7. Energy Systems Convergence 2030

Source: YOKOGAWA (2023)



By looking at society as a whole, we can see that neighboring industries are indeed interconnected, and there are opportunities to exchange various energies and materials according to their use cases and goals. Evoking the potential for mutual cooperation across multiple industries and societies, we can find insights in terms of where to deploy solutions, how to promote digital transformation and smart manufacturing, and how to apply societal transformation through smart home and smart communities. And imagining the necessary technological developments to realize such energy system, will not only expand business, but will also contribute to decarbonization and energy, food, and water security. It is an important step leading to and supporting human behavior innovation to solve the Triple Nexus.

Three Modes of Behavior

As supply chains connect and expand, it becomes more important to ensure supply chain resilience. Indeed, implementing technology and optimization solutions are important to build resilience, but networks and behaviors between industries and regions complement and sustain it. Thus, the concept of energy systems convergence encompasses three modes of behavior: the circular economy, the sharing economy, and the trust economy.

1. Circular Economy

Energy systems convergence follows a production and consumption model that aims for zero waste by looping across the supply chain, connecting with adjacent supply chains, and reliably recycling and reusing resources. As everything in nature has value and can be used for different purposes, it is important to constantly explore the possibilities of using one company's waste as feedstock for another. By freely configuring multiple circular economies, we can see the road to zero waste and zero CO_2 emissions. As time passes, better combinations and more advanced utilization schemes will be created, and the balance between the growth of each company and the sustainability of society will be established at a high level.

2. Sharing Economy

The energy industry continues to face the challenge of producing clean energy at lower cost while securing enough supply to meet demand. One of the reasons why the total amount of energy that must be secured by the region surges is that each company and industry has designed its capacity according to its own peak demand and buffers in case of adversity or emergencies. By sharing the energy system, the power peaks of each company are minimized and leveled; for example, steam boilers are physically and virtually integrated and can be used mutually, resulting in benefits such as optimizing (minimizing) surpluses and buffers. It then becomes possible to minimize the amount of energy required for the entire region and the amount of CO_2 emissions.

In the sharing economy, it is required to build a system that appropriately and automatically rewards participants who contribute resources. It is equally important to assess how effective the operations of energy system integration are and measures to improve them. Furthermore, sharing data of best practices and lessons learned in the context of achieving common goals beyond industrial barriers, regional barriers, and national borders is also a very important behavior pattern.

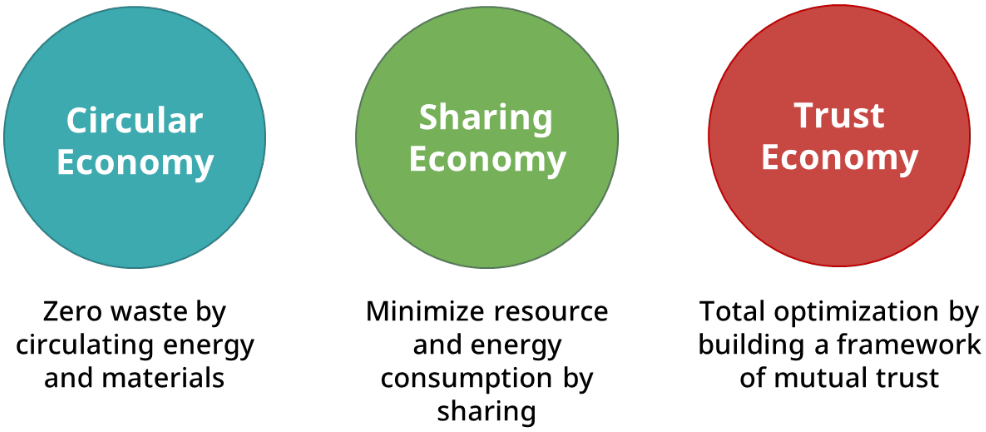
3. Trust Economy

As the energy system becomes even more highly connected, it requires flexibility and knowledge to effectively manage peaks in supply and demand. Thus, it is necessary to establish a data repository to optimize the entire region, in parallel to ensuring complex exchanges (transactions) remain autonomous and secure, and corporate competitive secrets protected.

With this, leaders in local communities and governments play a central role in building a framework of mutual trust. Through this framework, it is possible not only to build a one-to-one relationship of trust, but also between companies that had no direct relationship in the past, as well as between regions and between countries. It can also be used to extend credit between regions and between nations.

Figure 8. Converging Energy Systems:A Call for Human Behavior Innovation

Source: YOKOGAWA (2023)



Through the convergence, participating members can reduce waste and CO_2 emissions, balance and distribute resources where they are needed, and increase profits through optimization and addition of new services. More importantly, as this ecosystem becomes more autonomous and symbiotic over time, supply and demand of energy become self-sustaining, contributing to the prosperity and continuity of both industry and society.

6Cs of Energy Systems Convergence: Key Players

As the industrial ecosystem becomes an interconnected web of energy, material, and information exchange, close coordination and mutual trust among its stakeholders become increasingly necessary. There are six key players in the energy systems convergence, each one responsible for balancing the combined network structure, its operations, knowledge, and technology, as well as its supply, demand and environmental impacts to create an effective and scalable system.

1. **Controller** (such as governments, regulators) can accelerate the decarbonization agenda by implementing favorable policies and incentives that support companies and industries, and by providing platforms for partnering with other regions or countries.

2. **Consortium** (such as academia, research institutions, R&D) share knowledge and research findings in discovering breakthroughs in technology, special catalysts, and others that could lead to more cost-efficient, faster, safer, and cleaner operations.

3. **Cooperators** (such as investors and partners) optimize the business environment by providing funding, expanding market reach, maximizing business opportunities, and bringing together technologies and intellectual property to accelerate the speed of innovation. Through the growing partnerships, they can equally work and access various locations around the world.

4. **Competitors** (or Collaborators, such as companies in the Information Technology, Operational Technology, and Engineering Technology domains) develop new products, services and solutions based on their unique value proposition and competitive advantage. Likewise, companies are urged to develop necessary partnerships with competitors in their market/s in order to co-innovate and provide even more value to their shared customers.

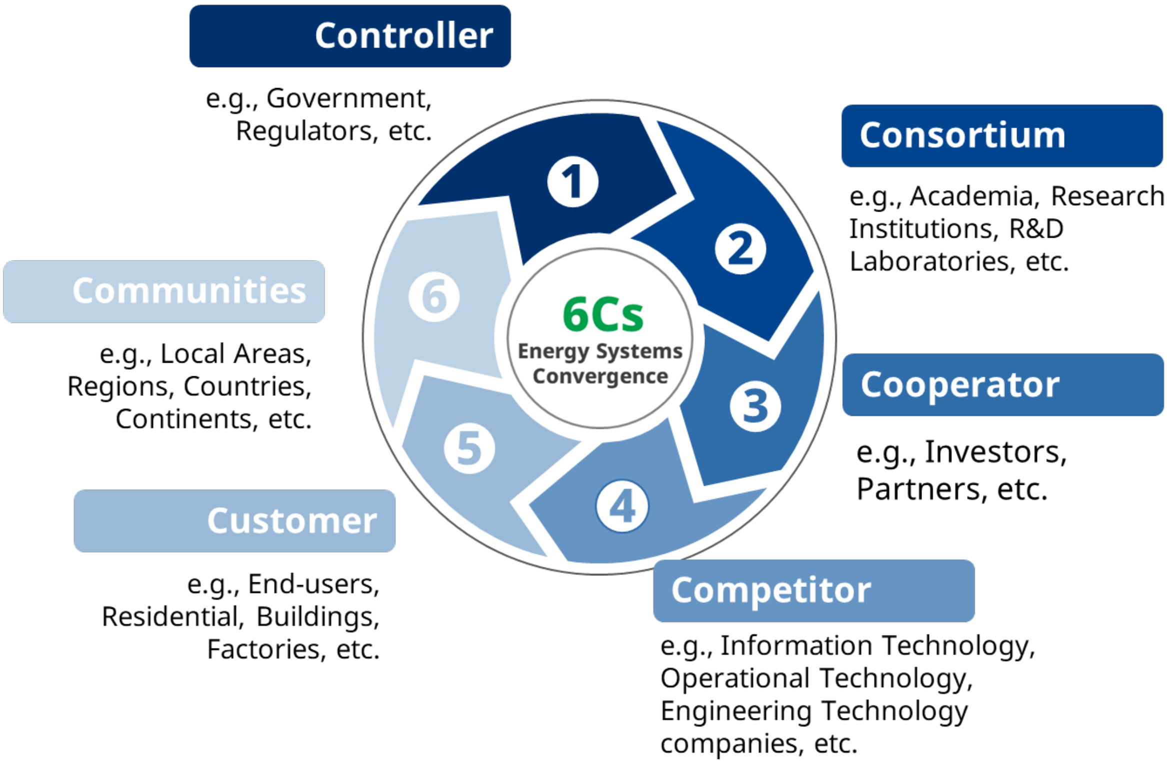
5. **Customers** (such as end-users, residential buildings and facilities) deepen their understanding of their counterpart's energy usage patterns, raw materials and waste through dialogue with neighboring businesses and government agencies. It is required to actively participate in co-creation activities that lead to cost reduction, energy efficiency improvement, and CO_2 emission reduction by

appropriately exchanging information while protecting competitive secrets automatically.

6. Communities (such as local areas, regions, countries) are encouraged to form small sub-communities around open regional energy system convergence. Over time, communities are urged to build friendships with other communities, integrating their small ecosystems into a much bigger web of ecosystems (CoC: Community of Communities).

Figure 9. 6C's of Energy Systems Convergence

Source: YOKOGAWA (2023)



Each stakeholder has their own role in making the energy systems convergence run smoothly, but they can share their ideas, best practices, lessons learned, findings and commitment with everyone in order to collectively improve, optimize, and sustain the ecosystem.

Case in Point: Cross-Industry Scenarios

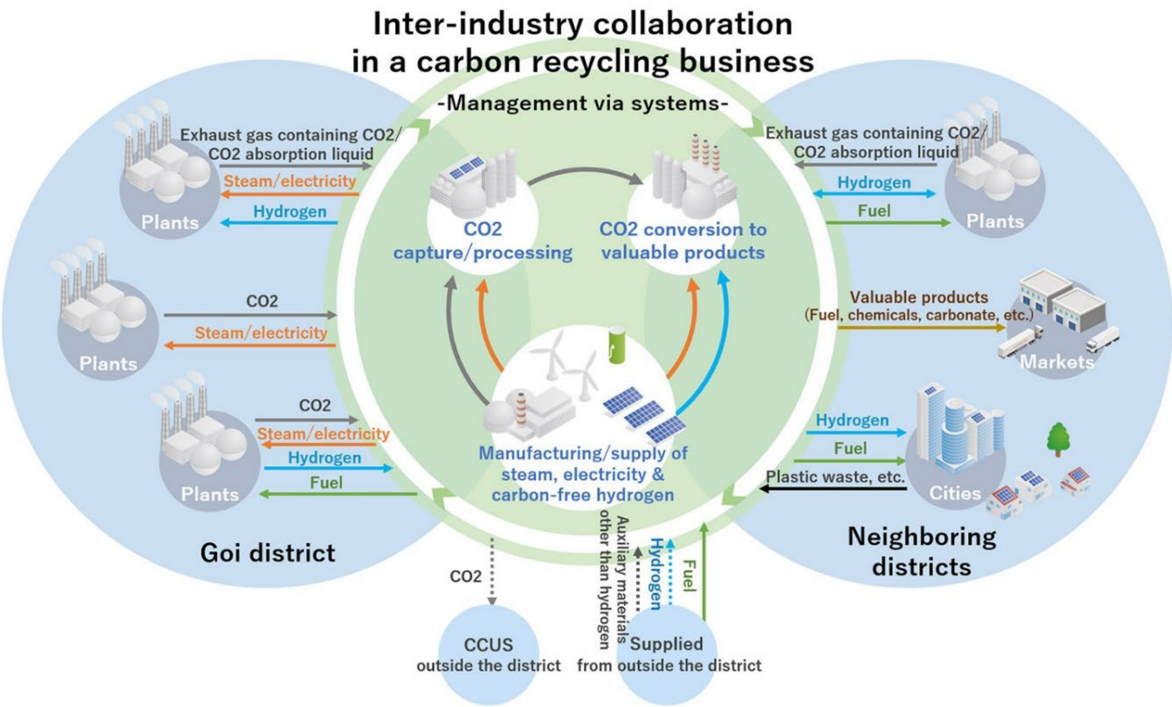
One example of energy systems convergence in action is Yokogawa's cross-industry research project at an industrial park located in the Goi area of Chiba Prefecture, Japan.

In 2021, after being commissioned by the New Energy and Industrial Technology Development Organization (NEDO), Yokogawa began work on investigating the feasibility and impact of exchanging energy and materials across multiple industries to achieve the goal of net-zero CO_2 emissions in the Goi community by 2050. In collaboration with companies that run plants with large CO_2 emissions in the area, Yokogawa conducted surveys to understand utility consumption and CO_2 emission predictions. Multiple scenarios were also simulated, where cross-industry interactions could reduce or eliminate CO_2 emissions through balancing between individual plants, and others where the by-products of one company (CO_2, hydrogen, etc.) could be captured and used in another. Through the study, Yokogawa has confirmed the possibility of combinations that could be valuable raw materials for another company.

For this project, Yokogawa draws on its domain knowledge and expertise in the manufacturing process in Japan and overseas, including process and energy efficiency improvements, control, simulation, and virtualization technology implementations, as well as systems and site integration. Participating companies share domain knowledge and expertise in their respective industries with the community and engage in cross-industry collaboration. Both CO_2 reduction and economic effects have been realized, and it is a successful case that can be reproduced in other regions and has the potential to further expand the range of companies and exchanged materials.

Figure 10. Goi Project: Inter-Industry Collaboration Study Project

Source: YOKOGAWA Press Release "Yokogawa Begins Work on Inter-Industry Collaboration Study Project for the Realization of a Carbon-Neutral Industrial Complex" (2021)



The Way Forward is Now

As 2030 is a tipping point towards realizing carbon neutrality in 2050, it is an extremely important year to realize the integration of energy systems through various energy carriers and production methods. To this end, it is important to engage in proactive dialogues within your own company and with your "neighbors" about potential opportunities for cross-industry collaboration. Yokogawa advocates three pillars as a corporate stance to promote the integration of energy systems and to continue to work with society as a whole.

Figure 11. Three Principles of Action

Source: YOKOGAWA (2023)

1. Policy and Investment: Commit to Advocacy

Today, many companies have started embracing "green," and it became a buzzword. It is very good that people are interested in new energy systems, including decarbonization. This is because if interest is gathered, policies will move, investment will be attracted, and active discussions will be triggered. However, in today's reality, "green" is often just a replacement of the signboard of existing initiatives, so it is from now on that the real change must begin.

To solve complex issues from many perspectives, such as energy security, decarbonization, and the Triple Nexus, we need the commitment of everyone (6Cs mentioned above). Envisioning what the future should be, continuous thinking and action are required at all levels and in all situations. Strategic (re)development, investment in research and development of new technologies, dialogue between governments, regulators, and industry, as well as initiatives that involve end-users on a close level are necessary.

2. Economy: Take practical steps to reach your goals

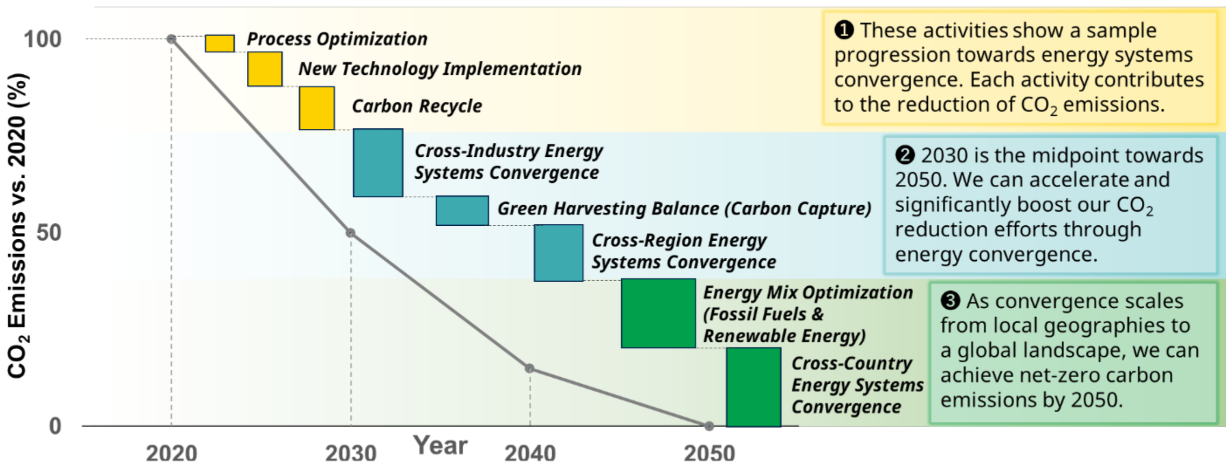
Looking at the overall worldview of what we are trying to achieve, embarking on the energy systems convergence appears to be a complex and expensive process, without guaranteed results. Companies need the right set of data, the right balance of domain knowledge and technical skills, and the right forward-thinking partners to make their energy systems convergence efforts meaningful. However, this combination is not always instantly available.

Therefore, it is important to break down the big picture into small actionable steps. First, we will start with the most familiar processes and process optimization (such as energy management), implement new technology (such as replacing equipment with more efficient equipment), and recover emitted CO_2 and search for supply destinations. Through this initiative, it is also important to collect basic data in a reusable manner, on key performance indicators such as the energy usage status of the company's processes, energy conversion efficiency of steam boilers, etc., CO_2 emissions, and production efficiency. Then, promote the creation of partnerships within the local community and define an economic model (that is, identifying initiatives that will bring the greatest impact and profits calculated based on the basic data above), a roadmap, and a concrete action plan.

Indeed, depending on the individual circumstances of the participating companies, such as when the stage is already advanced and some of the initiatives have already been implemented, it is possible to participate right away in the energy systems convergence.

Figure 12. Roadmap to a Decarbonized Society: Accelerated by energy systems convergence

Source: YOKOGAWA (2023)



3. Collaboration and Governance: Embracing a cross-industry environment

Over the past few years, there have been numerous discussions in the industry about committing to resolving energy security or decarbonization, yet only a few large players are delivering the necessary disruption at scale. There are several possible reasons for this.

First is the concept of corporate self-help efforts. It is an attitude that focuses on the company's activities and supply chain, optimizing them by improving efficiency and conducting continuous improvement reviews. Indeed, this is also important, but there is a limit to the size of the impact on society.

Second, there is a low awareness on the business processes other companies are doing, including what they can do today and plan to do in the future. In the past, it can be said that the activities of one industry had nothing to do with other industries, and even within the same industry, companies avoided communicating with their competitors to avoid altruistic information exchanges.

Third, even if companies had an idea, they probably did not know how to implement it, how to measure results, and how to judge the return on investment in terms of funding.

Even small implementations of energy exchange, material exchange, and information exchange are combined across multiple companies, the effects will expand gradually. Through energy systems convergence, participating members share a common language, a set of goals and a roadmap, and connect circular economies one after the other to build a resilient exchange pathway much like that of a web structure. Governed by mutual trust and fair exchange, participating members wil naturally be able to engage in concerted efforts for energy security, fair distribution and decarbonization, starting from small communities and extending to entire regions and global inter-regional coalitions, by sharing energy, materials, information, services and ideas to the community.

Empowering Communities for a Better Tomorrow

It is said that the present age is an era of change, an era of great uncertainty. The pace and volatility of recent uncertainties such as floods caused by climate change, changes in the regional situation, changes in financial markets, crop failures and droughts, pandemics, and many other phenomena, have taken us by surprise. However, that does not mean we have to accept it and we cannot do anything about it. We can confront these changes by rebuilding a more resilient and flexible system focused on sustaining humanity and the environment through energy systems convergence. In restructuring, Yokogawa presents significant aspects in this new paradigm.

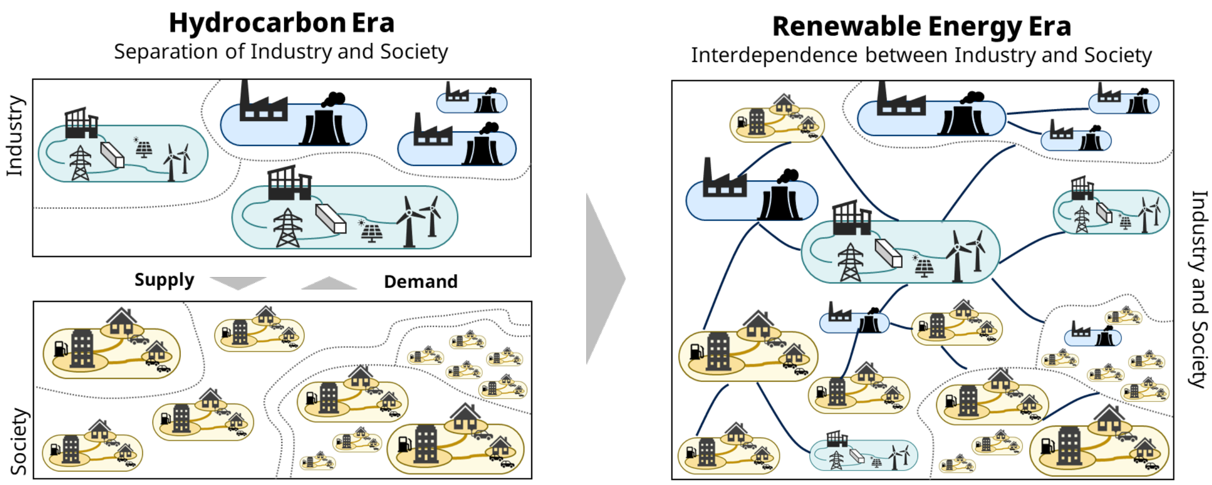
Symbiosis: Integration of Society and Industry

More than ever, everything is tightly connected and has influence over the other – be it people, businesses, countries, and even information. Yet, no single entity has all the answers to put together solutions to existing issues and identify synergies that could support thriving businesses or communities.

Energy systems convergence envisions a framework for coexistence. Industry coexists with society, and society coexists with industry. In other words, one cannot succeed without the other, and one cannot be designed without the other. Convergence of energy systems removes inter-industry barriers and strengthens deep-level symbiotic relationships. For example, companies will be able to identify areas where resources can be maximized while minimizing the industrial impact on the environment. Similarly, individuals and societies connected to this symbiotic community can enjoy a steady supply of electricity, heat, or steam, returning surplus energy generated from their own energy generation utilities back to the community.

Figure 13. A Borderless World

Source: YOKOGAWA (2023)



- No material or energy exchanges between similar or co-located industries
- Less investment on alternative clean energy
- Heavy dependence on fossil fuel sources
- Unstable energy supply

- Active material and/or energy exchanges between industries and regions
- Focus on alternative clean energy investments
- Appropriate and varied energy mix
- Stable energy supply

System of Systems: Sustainable Energy Clusters

The magnitude of energy systems convergence is determined by the scope and scale of its participating members.

Take for example: starting with a relatively small community of about 10 neighboring companies. In this community, participating companies will first aim to balance local energy demands through their own optimization activities and mutual exchanges, as well as virtualize and share operational infrastructure such as steam to reduce costs and minimize CO_2 emissions. As this small community grows into a larger community, it connects with the energy systems formed by other communities, reflecting the concept of System of Systems (a system that binds together multiple systems). Later, it becomes a vast, interconnected network of communities – large and small – meshed together to continuously create value and expand impact.

By combining and sharing local community successes with energy security and decarbonization mindsets, interconnected communities will ultimately become the optimal global renewable energy production base. This base serves as a platform for optimization efforts such as flexible supply networks, minimum energy / CO_2 route delivery, and so on.

Figure 14. Community of Communities

Source: YOKOGAWA (2023)

Supply Mesh: Market and Infrastructure Network

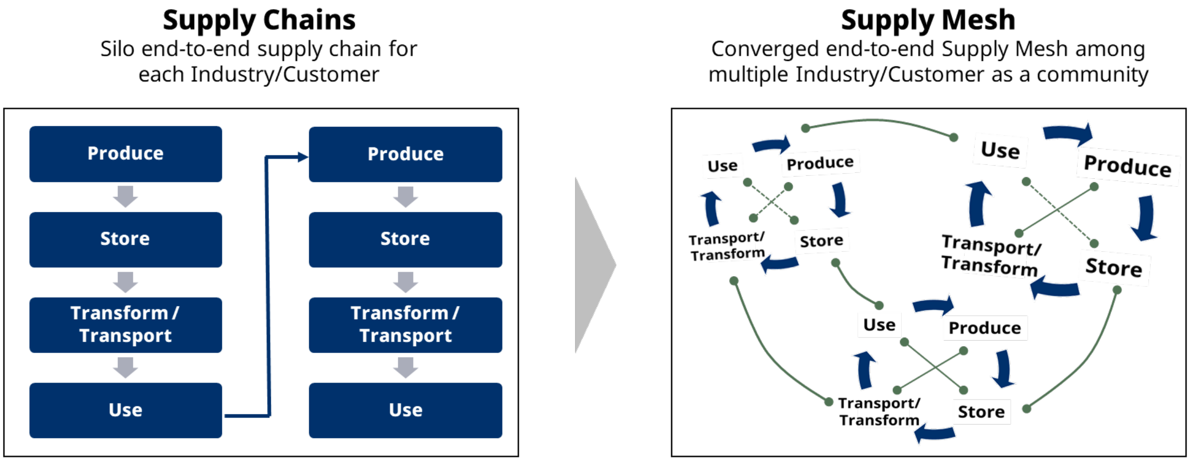
The view of the market will be changed significantly. One of the hallmarks of the energy systems convergence is the evolution of the one-way supply chain structure that flows from the supply side to the demand side, and the traditional focus on how companies and industries use it to optimize single-purpose services. Simply, energy systems convergence revolutionizes how we perceive supply chains.

Traditionally, the energy supply chain consists of four phases – "Production" of renewable energy, "Storage" for later use, "Conversion" for transportation or for other applications and "Usage" in households, buildings, and facilities. While creating concepts such as "just-in-time" from upstream to downstream, it can be said that we have already maximized the efficiency of the four phases of the chain. This in itself is a desirable initiative, but the relationship with other supply chains remains weak, and opportunities to think about the different results that can be produced through mutual co-creation have been limited.

With energy systems convergence, traditional supply chains will gradually become less of a 'chain' and more of a 'mesh' in which various elements of multiple chains are interconnected. Energy is exchanged between communities, regions and countries, waste becomes raw materials for other companies, and heat sources are shared. Leveraging the characteristics of the supply mesh, we mitigate risks for the enterprise and society, achieve energy, food, and water security, reduce CO_2 emissions, and optimize energy costs. We can help shape effective economic systems and policies that contribute to a better planet and make our future a reality.

Figure 15. Supply Mesh

Source: YOKOGAWA (2023)



- Linear flow of supply and demand
- Defined and fixed point/s of integration
- Fewer and smaller circular economies
- Waste at the end of use

- No broken "chains"
- Increased cross-collaboration opportunities at any point
- Various circular economies
- Waste as source material for others

Call to Humanity: Fair Trade in Energy

When the idea of humanity in energy trade permeates the world, the final result will be a global-scale cross-industry collaboration, where there is energy production in suitable locations and an available mix of multiple energy sources. Our world becomes a world where renewable energy is produced in places where it can be produced most efficiently and then distributed globally through multiple routes and transportation methods optimized for distance. Fundamentally, the world functions and harmonizes as a single community.

For example, when considering sunlight, renewable energy potential is concentrated near the equator. There are many developing countries in these regions, mainly in Africa and Brazil, that have a lot of hope in this natural resources, which have the potential to generate significant income to their region when effective and fair infrastructure is in place. Many people in other regions also profit from these resources by importing them in combination with an energy carrier. In that sense, it is possible to build an energy system that is mutually beneficial. On the other hand, if we switch to the lens of LCOE (Standardized Cost of Electricity), electricity prices remain at low levels, especially in Africa, which raises a similar concern.

Figure 16. Global Horizontal Irradiation (GHI): Long-term yearly average of daily and yearly totals

Source: Map obtained from the "Global Solar Atlas 2.0", a free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP).

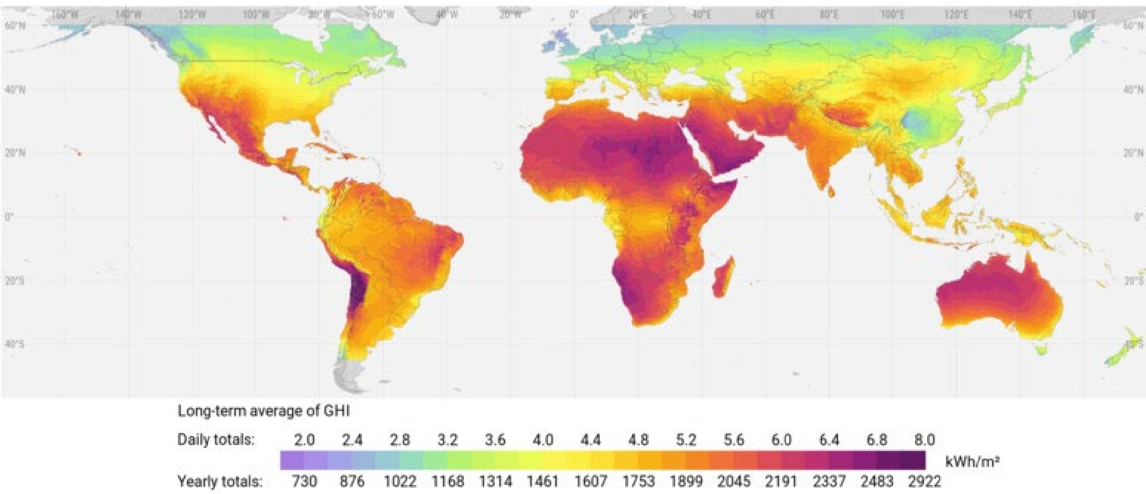
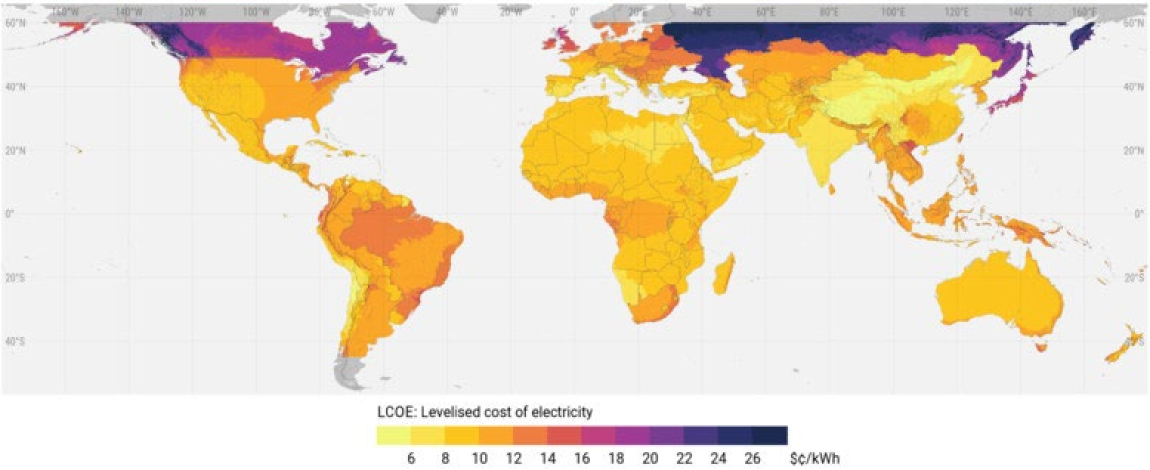


Figure 17. A Simplified LCOE Estimated for Large-Scale Ground-Mounted PV Power Plants with Expected Lifetime of 25 Years

Source: Map obtained from the "Global Solar Atlas 2.0, a free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP).



It is then necessary for the entire international community to pay close attention to the perspective of fair access to food and water, so that the pattern of exploitation that occurred with diamonds and chocolates, for example, will not occur in the future energy system. To that end, in building a new energy system based on renewable energy, we need to establish a mechanism for traceability of the energy system (where and by whom it was produced, how it was converted into a carrier, and transported), and to incorporate the concept of fair trade from the beginning. It is also necessary to discuss operational matters such as the fair distribution of incentives to create standards and mechanisms in preventing this risk and problem for everyone.

What We Can Do Together

Energy, food, and water security as well as climate change are life-or-death issues for all of us. The need for collective, transformative yet sustainable approaches to addressing these challenges has never been greater. Indeed, these crises – extreme weather, high food prices, and droughts – are making the world realize that it is time to start acting together now.

Yokogawa's passion and strength lie in its ability to measure, control, connect, and contribute to optimization through energy system integration, such as interconnecting customers with nearby businesses and industries. We support the entire local community to achieve a higher quality of life by stabilizing energy procurement, continuously reducing CO_2 emissions, and balancing the use of materials between industries. Leveraging our global network of carbon neutral expertise and innovation, we are exploring new opportunities for joint research and development of new modes of behavior, mechanisms, products, and services with our partners to support the society's transition to the energy systems convergence. We also aim to trigger active conversations around policy, economics, society, and innovation in order to design and realize future energy systems in harmony and symbiosis.

Figure 18. Invitation to the Energy Systems Convergence

Source: YOKOGAWA (2023)

We call on all customers, consortiums (academia), competitors, cooperators (partners), communities and controllers (governments) to come together to share your ideas and start this journey.

From today, our connections will serve as lifelines for our future.
Together, we can make a difference that lasts for generations to come.

If you are interested in joining the energy systems convergence, please contact us at bizdev@cs.jp.yokogawa.com.