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SMART GRID
RESEARCH**

IEEE GRID VISION 2050



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IEEE Grid Vision 2050

Georges Simard, Editor-in-Chief



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Dedication

IEEE Grid Vision 2050 is dedicated to all of the engineers to come—the people who will be expected to take this vision and make it work. Yours will be an exciting task that will require more true innovation than in any generation since Edison.

This document is also dedicated to the engineers who have brought the grid—the most complex, reliable machine ever created by humankind—to this point. The benchmark you set for the future is a challenge for all future generations. Thank you to every engineer who has, or ever will, work on this machine.

You are the light bringers!

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Overview

The IEEE Power and Energy Society (PES) Horizon 2050 team was given the task with writing the Grid Vision, including generation, transmission, distribution and end use. This document will provide guidelines and expectations related to power systems for planning and developing future standards. It will be a resource for the IEEE PES and the IEEE Standards Association (SA) as they plan their activities in the long-term horizon (2050). It will attempt to predict and anticipate where technology is heading and what needs to be developed in terms of guidelines and standards, allowing IEEE-SA to be a leader in charting future technology developments.

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The IEEE PES Horizon 2050 team reports to the IEEE PES and IEEE-SA.

Scope

This document describes the IEEE PES's vision of the power system infrastructure into the year 2050. This document sets the stage and includes future scenarios, electricity generation (*Make*), electricity transmission and distribution (*Move*), and electricity usage (*Use*). It also covers the related *Operations and Control* issues. The document uses scenarios from the International Energy Agency (IEA), which defines future energy availability, production and usage into the year 2050.¹

Purpose

This document is intended to provide guidelines and priorities related to standards development, especially for ongoing and future working groups in the areas of generation, transmission, distribution, and end use of electricity. In particular, this document will be a resource for the IEEE-SA in providing detailed information on the anticipated evolution of equipment and operating procedures in these areas.

¹ International Energy Agency. 2012. *Energy technology perspectives 2012: Pathways to a clean energy system*. Paris: IEA.

Foreword

Electrification is at the top of the list of the Greatest Engineering Achievements of the 20th Century,² compiled by the U.S. National Academy of Engineering. In *IEEE Spectrum* magazine's list of Engineering's Grand Challenges for the twenty-first century,³ various power and energy challenges appear near the top. These two lists emphasize the importance of power and energy systems throughout the modern world.

GREATEST ENGINEERING ACHIEVEMENTS OF THE 20TH CENTURY	ENGINEERING'S GRAND CHALLENGES
1. Electrification	Make solar energy economical.
2. Automobile	Provide energy from fusion.
3. Airplane	Develop carbon sequestration methods.
4. Water supply & distribution	Manage the nitrogen cycle.
5. Electronics	Provide access to clean water.
6. Radio & television	Restore & improve urban infrastructure.
7. Agricultural mechanization	Advance health informatics.
8. Computers	Engineer better medicines.
9. Telephone	Reverse engineer the brain.
10. Air-conditioning & refrigeration	Prevent nuclear terror.
11. Highways	Secure cyberspace.
12. Spacecraft	Enhance virtual reality.
13. Internet	Advance personalized learning.
14. Imaging	Engineer the tools of scientific discovery.
15. Household appliances	
16. Health technologies	
17. Petrochemical technologies	
18. Laser & fiber optics	
19. Nuclear technologies	
20. High-performance materials	

Source: *IEEE Spectrum* (2009)

For all countries and modern human societies, the power system is one of the most fundamental and important ingredients for ensuring economic and social development. In fact, many other evolved systems (e.g., telecommunications and computers) depend on electric power systems for their operation. To support the continuation and further development of electric power, engineers, technicians, and other workers maintain and enhance power systems all over the world in order to meet the present and future needs of customers who rely on it.

² See www.greatachievements.org.

³ See <http://spectrum.ieee.org/at-work/innovation/engineering-achievements-the-two-lists>.

In the late twentieth century, developments in transistors and microprocessors led to a technical revolution that brought several industries to improve their productivity levels significantly. Computers and microprocessor-based technologies allowed new ways to process data and increase the speed and precision of several types of processes. Some qualified these improvements as “smart” technologies, and the early twenty-first century saw a proliferation of new products with names such as *smart phones*, *smart TVs*, and *smart cameras*.

The power systems industry was also targeted by this naming trend, and around the year 2000, the term *Smart Grid* was given to future electrical power systems that would combine the existing power grid with telecommunications and computer infrastructures. Today, the definition of *Smart Grid* varies widely, and is used generically by countries, companies, and technical associations to describe their interpretation of the next generation of power systems, including their communications and control.

Despite differences in nomenclature, everyone agrees that integrating power, telecommunications, and computer infrastructures is no easy task. In addition to this challenge, existing power grids are very often qualified as aging systems that have not changed much since their original early-twentieth-century designs.

Many organizations, agencies, associations, and utilities around the world are now attempting to forecast the development of the Smart Grid. By looking at the historical development of the power industry, and analyzing the trends, technologies, and needs of modern societies, we might be able to develop roadmaps of the next generation power grid into at least the middle of our current century.

The IEEE Power and Energy Society wishes to contribute its own forecast of the future grid by publishing this long-term grid vision of the power system.

Acronyms and Abbreviations

2DS	International Energy Agency's (IEA) 2 Degrees scenario, which is a vision of a sustainable energy system of reduced greenhouse gas and CO ₂ emissions to limit the earth's temperature rise to 2 degrees Celsius.
4DS	International Energy Agency's (IEA) 4 Degrees scenario, which reflects pledges by countries to cut emissions and boost energy efficiency to limit the earth's temperature rise to 4 degrees Celsius.
6DS	International Energy Agency's (IEA) 6 Degrees scenario, which is where the earth is now heading if no change is made, corresponding to a temperature rise of 6 degrees Celsius.
ANSI	American National Standards Institute
AWEA	American Wind Energy Association
CENELEC	European Committee for Electrotechnical Standardization (Comité Européen de Normalisation en Électronique et en Électrotechnique)
CIGRÉ	International Council on Large Electric Systems (Conseil International des Grands Réseaux Électriques)
DER	Distributed energy resources
EHV	Extra high voltage
EPRI	Electric Power Research Institute
EWEA	European Wind Energy Association
FACTS	Flexible alternative current transmission
HV	High voltage
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
LEED	Leadership in Energy and Environmental Design
OECD	Organisation for Economic Co-operation and Development. The OECD member countries are: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States. The European Commission takes part in the work of the OECD.
MAGLEV	MAGnetically LEVitated transportation
Non-OECD	All countries that are not members of OECD

PES	IEEE Power and Energy Society
UHV	Ultra high voltage
UL	Underwriters Laboratory

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1.1 Introduction

This chapter explains why the power grid has to change, and what the drivers are for that change. Additionally, this chapter looks at the magnitude of the changes involved and the assumptions made in developing this vision.

1.2 Why 2050?

To create a grid vision for the future, the IEEE PES Horizon 2050 team first needed to limit its definition of “the future” to a manageable and quantifiable length of time. In the power industry, most hard assets have a useful life of approximately 40 years, commonly referred to as an *asset cycle*. Any program started in 2010 would reach 100 percent completion in 2050, if assets were retired in a normal fashion during the course of the program. By basing its future vision on a typical asset cycle (backdated a couple of years), the PES felt comfortable choosing 2050 as a target year for its vision.

There were several more compelling reasons to choose 2050 as a target:

1. When the project began, no other publicly available vision documents reached out to 2050; they all take a much shorter view of the future. With the publication of the European Commission’s *Energy Roadmap 2050*, this short-range view has recently changed.
2. Looking out to 2050 means that all of the existing assets in the power grid will be fully depreciated by then, and that a program started today could reach completion without implementing special financial measures (stranded costs and other regulatory relief) in order to achieve it. The Horizon 2050 team is pragmatic enough to realize that technology is always in evolution and that grid implementations follow this evolution; so a product selected today for installation might not be the product installed 20 years from now. From a pure financial point of view, an asset installed in 2010 will be fully depreciated by 2050 for almost every class of assets that the industry uses.
3. The year 2050 offers a complete turnover of personnel. By that year, almost everyone working in the industry today will have reached retirement age.
4. Freedom to dream. Because the grid will have to be fully changed by 2050, the authors could take a clean sheet look at how the future grid could be organized and designed. This

out-of-the-box dreaming allowed the team to think about things that would normally be difficult because of the sunk costs of the existing grid. If the technology is in the laboratory today, then these technologies can be applied to the 2050 vision. Dreaming—and dreaming big—as part of a vision is important to stimulate innovation. The IEEE PES Emerging Technology Coordinating Committee provided several input documents on what might be possible; most of these possible technologies have been included in this vision.

The Horizon 2050 team realized that even in 2050, stranded costs and infrastructure will have to be incorporated into new programs. These are facts of life, but for the purpose of much of this vision, the team started from the idea that they could do things in the best way possible for 2050.

1.3 It is a vision—so why should I care?

A vision is not a roadmap, it is not a set of guidelines that have to be followed, nor is it regulation or statutory requirements. So why should anyone care about it?

Every invention starts with an idea or vision. History often retains the good visions, although the time between the vision and its realization might be years, decades, or even centuries. The first helicopter drawing is generally attributed to Leonardo Da Vinci in the fifteenth century, but the first operable helicopter was designed and built in the early twentieth century.

Jules Verne's *From the Earth to the Moon* was written in 1865, and John F. Kennedy added to Verne's vision in 1962 by challenging his country to put a man on the moon by the end of the decade. In 1969, an Apollo 11 module landed safely on the lunar surface, which resulted not only in the successful realization of putting a man on the moon, but to a large extent the commercialization of microchips and personal computers.

On the other hand, some visions might not be completely accomplished. The space station envisioned in Arthur C. Clarke and Stanley Kubrick's *2001: A Space Odyssey* is not yet orbiting the earth. However, the International Space Station is a significant achievement approaching this original vision.

In the twentieth century, many expected cars to fly in the twenty-first century. In 2012, we do not yet fly our cars, but the vehicles we drive change every decade or so, and their evolution will continue.

Good visions cause changes, cause innovation, and create tension in industry. That tension is healthy, creating debates on the results of the vision, the benefits and concerns about elements of the vision, and what the good and bad impacts of the vision would be on society. When Guglielmo Marconi created the radio, it is doubtful that he envisioned almost every adult carrying a radio with him or her in the form of a mobile phone. Over the last 100 years, the impact of Marconi's invention has driven many aspects of society, and a number of visions have centered on spinoffs of his basic invention of the radio. Many traditional telephone companies in the late 1980s ignored a number of vision documents related to the mobile phone industry, but today none of them do. Several of those vision documents circulated and ultimately created the environment entered into by the mass-market mobile phone. Different visions in North America and Europe resulted in very different regulatory environments in the two regions.

The primary goal of this vision is to spur debate—to make you think, to start the discussion about how the future environment will develop from today’s existing infrastructure, and what has to happen to the grid between now and the year 2050. Will society be driving all-electric vehicles? Will all of the field operations be automated? Will hackers be so capable that use of any remote controls is impossible? Should there be standards to support parts of the vision? The authors of this vision document wish to stimulate these and other types of questions. The Horizon 2050 team hopes you will think long and hard about this vision, and welcomes debate on every aspect herein.

1.4 Flipping the dimes

This document examines a very different industry than the authors experienced while growing up. Over the last 100 years, electric utilities optimized the current paradigm—that of a load-following industry. (“If you flip a switch, we will make more power.”) However, the days of large-scale investment in generation, and the ability to make energy at any time to meet any demand, run counter to the idea that the industry will use more renewables and do away with base load generation over time, as suggested in 2010 by Dr. Mark Diesendorf of Australia [1] and commented on by FERC Chairman Jon Wellinghoff in his New York City presentation shortly after taking office [4]. This position has been mirrored by a number of other officials in other parts of the world and expanded on in *The Oxford Handbook of Climate Change and Society* [3].

If this discussion is correct, the industry needs to evolve into a supply-following industry. (“If someone makes power, we will find a way to use it.”)

In countries or areas of countries where there is little or no electrical infrastructure, a different industry will probably evolve—one that is focused on harvesting available energy from all sources and storing it locally in some form until it is needed. In some cases, the energy storage will occur in batteries or other storage media that can return electricity to the grid; in other cases, the storage will take form of water, hot rocks, or even ice, which cannot return electricity to the grid. The overall infrastructure design that has successfully served Europe, Asia, and much of the developed world might not be repeated in the developing world; instead, those areas might focus on local energy generation and consumption. Canada has proven this model viable in a number of remote locations, where connecting those communities to the main grid is too costly and inefficient.

Large cities will still need a shared infrastructure, because the density of energy consumption will exceed the ability of the local area to generate enough electricity on an individual level. Therefore, approximately 90% of the people who have access to electricity will be served by some form of shared infrastructure.

To this end, *IEEE Grid Vision 2050* focuses on four main areas of the industry:

1. **Make (Chapter 2).** Creating from any source, at any location, electricity that can be delivered to a customer.
2. **Move (Chapter 3).** The ability to move the created electricity to any location that wants to use it. *Move* will become more complex over time, because *Make* and *Use* will not always occur in their traditional locations, and electricity could actually flow in the opposite direction than the grid design originally intended it flow.
3. **Use (Chapter 4).** Taking electrical energy and converting it to something else, including chemicals, transportation, clean water, light, kinetic energy, cold, and heat. In some cases,

it will be necessary to shift the time that the energy will be used (e.g., making ice at night to cool a house during the day, or charging a vehicle at night in order to drive to work in the morning). *Use* is going to become much more complex in the future, by the very nature of the variety of ways that we will convert electricity to something else.

4. **Operations and Control (Chapter 5).** As the overall system becomes more complex and offers more options to control it both financially and physically, *Operations and Control* will become much more important. Today, traditional generation and high voltage transmission are operated and controlled by remote commands, while the rest of the grid is manually operated and maintained. By 2050, we expect that all parts of the grid will have significant options, and that control and operations will occur throughout the entire system. Three models are being debated: 1) a centralized control, 2) a layered control system that distributes significant responsibility to individual devices, and 3) an autonomous model in which each device makes its own decisions based on parameters provided.

This vision document is meant to provide a focus point for future research and standards, and is not intended to provide the “one vision” of the future. Each chapter contains a discussion of research that is required and standards that will need to be written to support the vision. This document also includes a section on conclusions and recommendations that, unlike many vision documents, were written from the work submitted by the chapter authors themselves.

1.5 Assumptions

While developing this vision, the IEEE PES Horizon 2050 team acknowledged that every vision has a certain bias. While ours is no exception, we did choose to freely discuss a number of assumptions that should help explain our particular bias. Because these assumptions are the foundation of many decisions in this document, the team felt it important to include them in the opening of the vision.

In addition to these assumptions, the team felt it important to look at the impact of them on our vision, as well as the impacts on our vision if the assumptions were not true. In Table 1.1 and Table 1.2, we discuss each assumption, its impact on the vision, and its impact on the vision if it turns out false. The vision editorial team attempted to keep the number of assumptions to a minimum. Table 1.1 summarizes what the team acknowledged as generally accepted assumptions. These assumptions are basic, and some are obvious, but the team felt the need to mention them nevertheless.

Table 1.1 – Generally accepted assumptions

Assumption	Impact on the vision	Impact if it turns out to be false
People will always use energy to do work for them.	With the continued use of energy comes the need for electricity and other “fuels” to provide the energy to light homes and businesses, and perform work and other tasks.	If no energy is consumed, then the electric industry can fall by the wayside unused.

Assumption	Impact on the vision	Impact if it turns out to be false
Global population will continue to grow.	In the last 12 years, the world has added 1 billion people. Regardless of the speed of growth, each person puts additional demand on the world for food, water, and shelter, and that puts demands on the energy industry for additional energy, including electricity.	If the global population stagnates or drops significantly, the demand for energy might also decrease, taking much of the pressure off the industry to provide more efficiency and more energy overall.
The fundamental laws of physics will always exist.	Perpetual motion, antigravity, faster-than-light travel, and repeal of <i>force = (mass x acceleration)</i> will not happen, and so the way we create and move electricity will have to follow the fundamental laws of physics.	If the fundamental laws of physics change, the technologies discussed in this paper could be irrelevant. For instance, if low energy antigravity were developed, the result would be (potentially) no need for poles, towers, and other structures to hold up lines, and no need for roads and railroad tracks to move people and freight.
Assets, when installed, will be run for their normal life cycle.	The vast majority of assets will be deployed and live out their planned life cycle. Equipment will not face wholesale changes in the grid in very short time frames, and engineering will have to continue to work with long asset replacement cycles compared to telecommunications and other industries.	If the industry adopts a rapid replacement standard, then equipment design, tariffs, and many other economic and engineering processes will have to change to match these changes.
Pressure to keep the price of energy low in all forms will continue.	With pressure on prices, regulators and others will be unlikely to provide unlimited funds for upgrading infrastructure, and any upgrades will have to be justified.	If there is no pricing pressure, then prices might rise and consumption might fall. If prices do rise, more capital could flow into the market for investment in the industry, including on infrastructure.
The global economy will continue to grow.	A growing economy demands additional energy, even with energy efficiency, which drives additional investment in infrastructure.	If the economy collapses, the investment in infrastructure also collapses, and the likelihood that the industry will reach this vision dims.
Economic prosperity increases the demand for energy.	Even though equipment efficiency and business productivity will increase over time, economic prosperity will mean higher incomes. Consequently, people	Should the improvement in economic circumstances result in no additional energy consumption (from any source), then the need to improve <i>Make</i> and <i>Move</i> to

Assumption	Impact on the vision	Impact if it turns out to be false
	will consume more energy by using more energy-consuming devices. Industry will continue to expand the way people can use energy, through new types of devices, such as tablets and phones.	support additional <i>Use</i> will fall away.

Table 1.2 summarizes the assumptions on which the vision team came to a consensus.

Table 1.2 – Consensus assumptions

Assumption	Impact on the vision	Impact if it turns out to be false
Environmental pressure will remain.	Environmental concerns within society will continue to rise, with higher levels of pressure added on a regular basis. The consumers will be asked to do more with less, waste less, recycle more, and emit less. This push on industry will cause industry to move in a green direction, incorporating more and more environmentally friendly processes, equipment, and curtailment plans. Environmental concerns will not be limited to climate change, but will span the entire environmental value chain.	If environmental pressure lessens or disappears completely, changes such as electric vehicles, photovoltaic distributed generation, and other green technologies will have to find a different business case for existence.
Fusion will not be commercially available.	Although fusion might be perfected in the laboratory, the chances that it will be commercially deployed by 2050 are relatively small, given the pace of testing, licensing, costs, and other non-technical details. So both centralized and distributed generation in a wide range of fuels, like wind and natural gas, and sizes will be required to provide enough electricity load.	If fusion becomes available either on a large scale or in a commercial version, then the way electricity is generated could change drastically. If fusion is widely accepted by the public and widely deployed, then it is likely that most of the distributed generation options discussed in this document will be relegated to history.
No major space-	No large-scale resource recovery,	Major space-based industries can

Assumption	Impact on the vision	Impact if it turns out to be false
based industry will exist.	refining or manufacturing industries will exist in outer space by 2050. For example, visionary space-based energy concepts, such as solar power satellites beaming power to Earth-based antennas, will not occur by 2050. The world will be restricted to the resources and manufacturing capabilities on Earth.	result in massive additional resources available in commodities (e.g., metals, solar power, and manufactured goods). This change would cause a dislocation in commodity prices and potentially put most of the generation sources in space, beaming power back down to the surface.
Regulation will remain for the monopoly parts of the industry.	Globally, transmission and distribution will remain heavily regulated. Decisions will not be made by utilities alone for new infrastructure, market design, pricing, or other items.	Should the industry be entirely deregulated, a number of changes are possible, including but not limited to these items: 1) Change in generation mix and carbon production 2) Prices for the end consumer 3) Reliability of the system 4) Investment in infrastructure 5) Universal service to customers
Customer expectations will continue to grow.	As with any industry, the electric industry always strives to improve customers' satisfaction. Increased electric energy dependence, and increased performance levels expected by customers, can lead to more decentralized systems to achieve these goals. However, coordination with existing centralized systems will be required so as not to jeopardize actual performance levels.	If customer expectations do not increase, the pressure to improve the power system will be reduced. However, because the actual levels of customer expectations should not decline, the actual performance levels should be maintained.

1.6 Energy scenarios

In the International Energy Agency's (IEA) 2012 report, *Energy technology perspectives 2012: Pathways to a clean energy system*, three featured scenarios are proposed [2]:

- **The 2 Degree scenario (2DS).** A vision of a sustainable energy system of reduced greenhouse gas and CO₂ emissions to limit the earth's temperature rise to 2 degrees Celsius.
- **The 4 Degree scenario (4DS).** Reflecting pledges by countries to cut emissions and boost energy efficiency to limit the earth's temperature rise to 4 degrees Celsius.

- **The 6 Degree scenario (6DS).** Where the world is now heading if no change is made, corresponding to a temperature rise of 6 degrees Celsius.

The IEEE PES Horizon 2050 team decided to use the IEA's 2 Degree scenario (2DS), in order to challenge the IEEE PES to face the most optimistic future of energy systems.

1.6.1 World use of energy in 2012

In Figure 1.1, the IEA illustrates world energy flow as it is in 2012. On the left side are the world energy sources, and on the right side are the global uses of this energy. The electrical generation, transmission and distribution energy contribution is identified by the blue stream.

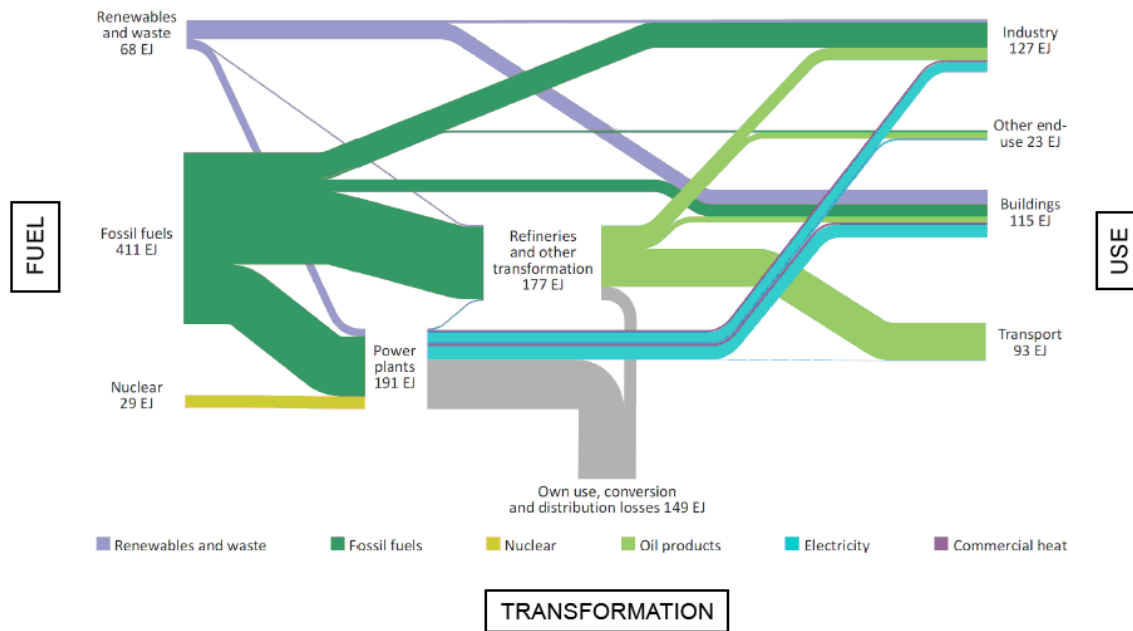


Figure 1.1 – World energy flow in 2012 [2]

1.6.2 World use of energy in 2050

In Figure 1.2, the IEA illustrates world energy flow in 2050 according to their 2DS scenario. The figure clearly indicates (in blue) an increase of electricity use compared to 2012 (see Figure 1.1). Some sources of electricity (Nuclear and Renewables/Waste) have been added, while fossil fuels' contribution to electricity generation has been reduced. As for electricity usage, it increases significantly in all major *Use* categories (Industry, Buildings, and Transport). This information confirms our assumptions made in the previous section. Note that electricity consumption almost doubles from 2012 to 2050.

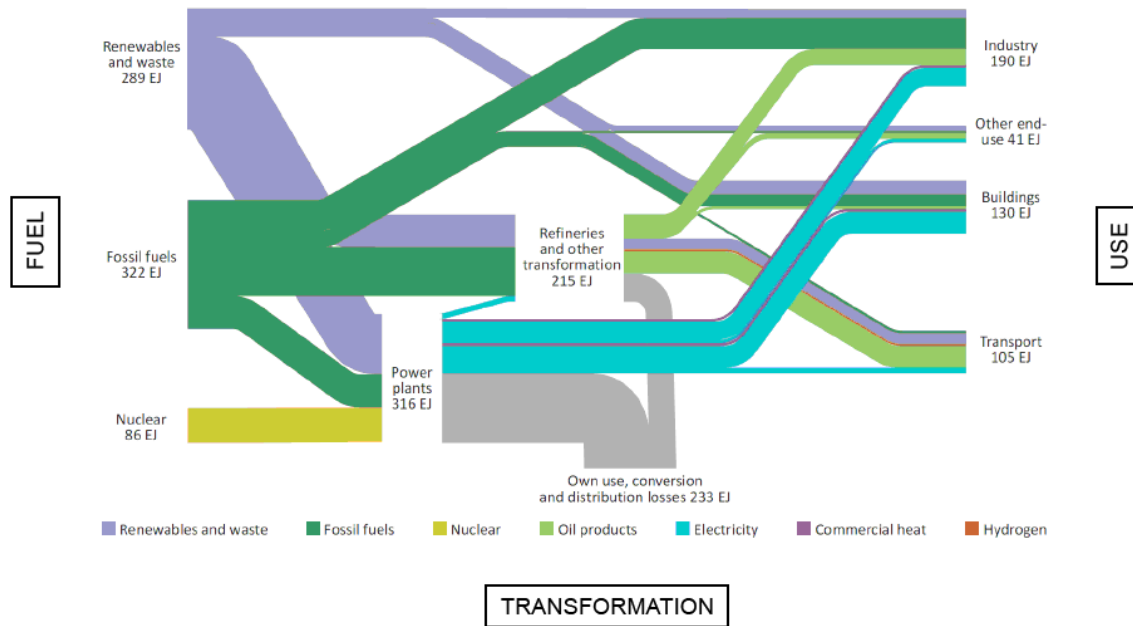


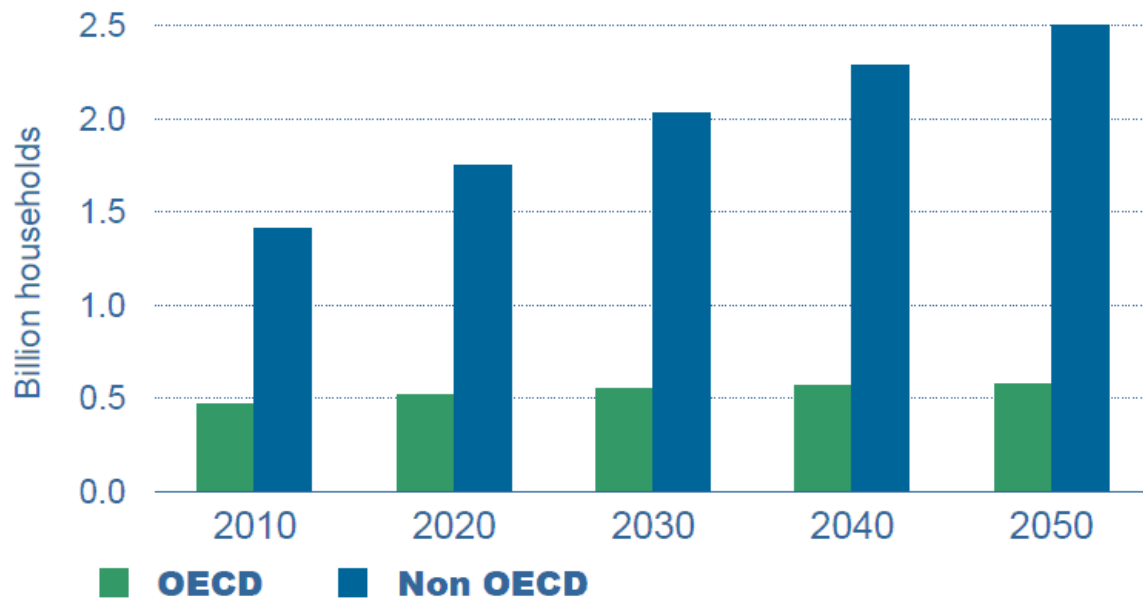
Figure 1.2 – World energy flow in 2050 (IEA 2DS scenario) [2]

1.6.3 Electricity demand growth

Three factors will continue to increase the demand for electricity throughout the world:

- Natural growth of already electrified countries, due to population growth and new electrical needs.
- New electricity demand from countries that are developing their electrical infrastructure.
- Increase in *plug loads*, as consumers around the world gain access to more electronics, from laptops and mobile phones to devices that have not been developed yet.

Figure 1.3, also from IEA, illustrates the increase in total number of households from OECD (Organisation for Economic Co-operation and Development) countries and non-OECD countries.



Note: 75% of current buildings in OECD countries will still be standing in 2050

Figure 1.3 – Increase in total number of households from OECD and non-OECD countries [2]

Figure 1.3 shows the challenge that non-OECD countries will face in meeting electricity generation requirements over the next 40 years. This challenge might result in a greater effort to optimize the balance between generation and load where the growth is expected. Additionally, the Smart Grid might be needed more in non-OECD countries, where more power infrastructure must be built.

As for electric generation, the IEA 2050 2DS scenario proposes a lower electrical energy demand on a per household basis, even though electrical energy consumption doubles from 2012 to 2050. Much of this growth comes from supplying more households with electricity. The 2DS scenario also envisions more diversity with regard to electricity generation, with fossil fuels giving way to the emergence of renewables and the expansion of nuclear power. This diversity is needed to reach a low carbon situation as proposed by the 2DS scenario.

1.7 Energy delivery in 2012

Figure 1.4 summarizes energy delivery as it is in 2012, mostly composed of centralized generation, transmission, and distribution systems that move energy to final use. Operations and controls are implemented on generation and transmission systems to optimize energy flow, including network stability. In Figure 1.4, the traditional parts of the value chain are incorporated into the following areas:

1. **Generation.** Into the *Make* domain. Also included in the *Make* domain is all of the distributed generation, regardless of location.

2. **Transmission and distribution.** Included in the *Move* domain, including not only traditional transmission and distribution, but also other methods of moving electricity from source to load.
3. **Customer.** Included in the *Use* domain, along with internal industry consumption of electricity.

These *Make*, *Move*, and *Use* domains are virtual and changeable. For instance, storage alternates between two domains: the *Use* domain when being charged, and the *Make* domain when providing electricity. This ability to move between these virtual domains is a concept that is central to the development of this document. The vision contained within is based on breaking down the traditional walls and physical thinking about the industry. (The authors realize that geography and physical infrastructure will continue to be critical to the success of the industry, but feel that the traditional terms bring strong constraints to the discussion.)

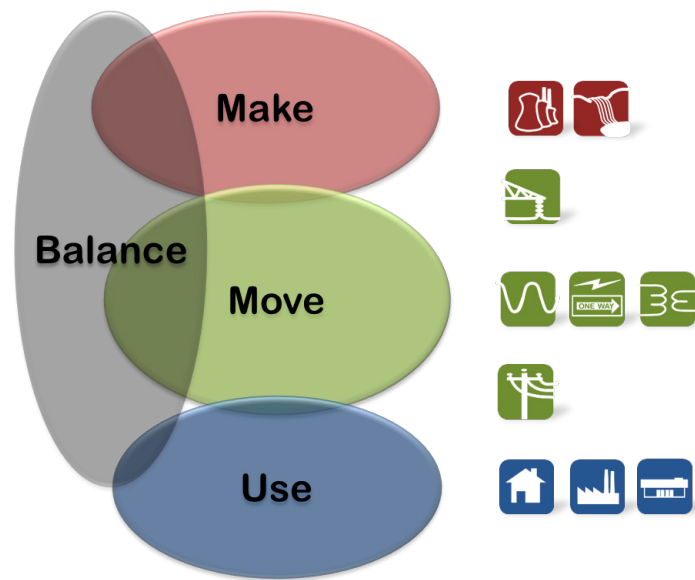


Figure 1.4 – Energy delivery in 2012
(see Annex A for definitions of icons)

1.8 Energy delivery in 2050

Energy delivery in 2050 can be represented by Figure 1.5, where usage is shown at two times the 2012 level. Optimized operations cover *Make*, *Move* and *Use*.

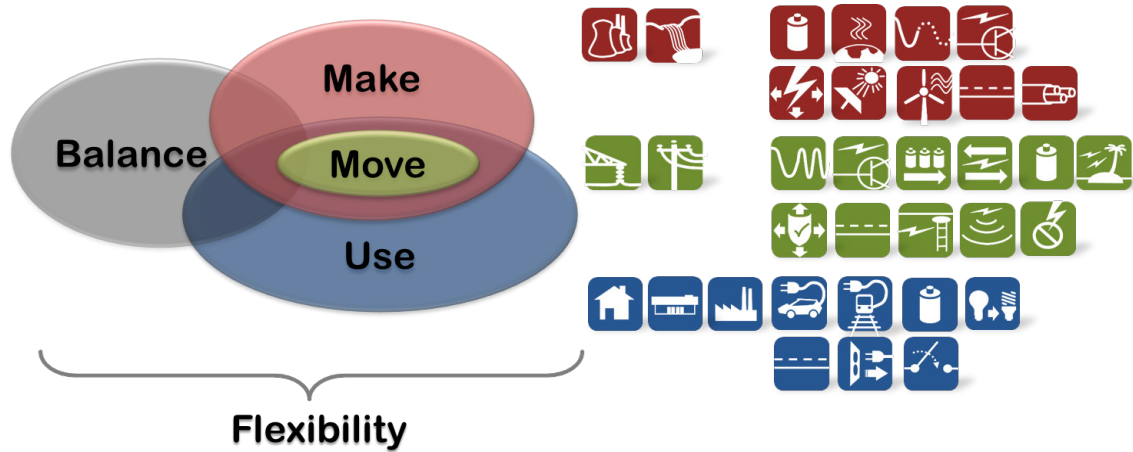


Figure 1.5 – Energy delivery in 2050
(see Annex A for definitions of icons)

The next chapters explore the ways in which energy delivery can be met in 2050.