# Future Design Challenges

# 23

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**Abstract**

One thing that never ends as long as humanity continues to exist: the emergence of new challenging problems that humanity must solve for their posterity through creative design. In the 1950s, few people would have thought that the invention of polymers with amazing properties would someday create new problems for humanity to solve. In the early decades of the twenty-first century, the pollution of the Pacific Ocean by the debris of solid plastics from countries around the Pacific rim is a major catastrophe with significant negative implications for the entire global community, especially for the people living in the nearby islands. Somehow, we must solve this problem without banning the use of plastics in the future, because the appropriate use of plastics fulfills human needs. Similarly, a century ago, few ever thought that the replacement of horse-drawn buggies with automobiles would result in global warming that might change and threaten the future of humankind. In each case, a new innovative technology begat new unanticipated technological or societal problems for future generations to solve or deal with. Therefore, it may be rational and reasonable to assume that current technologies and socio-political norms would someday become the source of new challenges for future generations to solve. In a way, it is the price humanity has to pay to make continuing progress through innovation and discovery. Thus, the saga of humanity continues. The natural progression always leaves new challenges for the next generation to solve—rationally and creatively. Therefore, the need for new knowledge and creative design will always be with humanity as long as humans exist. In the early twenty-first century, humanity is facing a unique set of challenges. Either people solve them in time, or the events will overtake humanity's ability to solve them, leading to instability in human and societal

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evolution. Some of these problems are results of the ever-expanding population of the world, which has been increasing at the rate of 1–2% a year and will exceed 8 billion people in the early part of the twenty-first century. An associated problem is a wide variation in the rate of population increase throughout the world, which results in migration and immigration of people from highly populated to less populated, from politically unstable to stable regions, and from poor regions to affluent areas of the world. The problems created by this imbalanced population increase and distribution will lead to many challenging design issues. If we cannot come up with the right design solution, humans might again resort to wars to settle their differences, which should be avoided at all costs. In this sense, the human ability to design will continue to be critical and in high demand. When and if new solutions do not emerge to deal with new problems, Nature may dictate the future of humanity, including a catastrophic demise of the world and humankind.

A partial list of significant design challenges humanity is facing in the early twenty-first century is related to, but not limited to, the following:

Energy needs;
Global warming;
Instability of weather patterns;
Need for portable water;
Pollution-free electric power generation;
Pollution-free transportation systems;
Protection of privacy in the information-intensive technological world;
Preservation of green plants;
Feeding of people,
Control of weather;
Prevention and elimination of contagious diseases;
The ability to maintain free society in a peaceful world;
Supplementary brain; and
Protection of fundamental human rights.

The solution to any one of these problems could consist of different kinds of design solutions—technical, scientific, socio-political, and economic as well as a combination of these fields. There could be more than one solution. Regardless of the specific approach chosen, the method and the process of developing design solutions are ecumenical, as described in Chaps. 1–3.

Furthermore, a solution to one of these problems may generate a set of new issues that the next generation must solve. The responsibility of the current generation is to educate the next generation well. That is the primary guarantee that their posterity can deal with their own set of challenges well.

The human ability to solve many of the above-listed problems are continuously improved because humans continue to invent new tools and advance sciences. Recent advances made in several fields such as artificial intelligence (AI), quantum computing, neuro-biological, brain sciences, nano-scale materials, and other areas of science and technology are most encouraging as well as promising.

Every problem discussed in this book, as well as many that are not addressed, will, ultimately, require "design solutions" similar to those discussed in the previous 22 chapters. The one(s) who create solutions to major challenging problems will richly be rewarded through various recognitions by humanity, which may include financial, intellectual, political, and personal recognition and esteem. Solve them we must, because the other option will only invite demise for humankind.

Often, we do not know which problem will require new designs. Also, at the beginning of the execution of design, one cannot have all the specific knowledge in the relevant field(s) because we may not have the requisite expertise. Once we understand the design task and associated questions (i.e., functional requirement (FRs)), we can acquire the necessary fundamental knowledge of the related fields quickly to develop design solutions in terms of DPs and PVs. Even the most complex problems can be systematically solved through design by following the steps outlined in this book. An exemplary design problem related to water and weather is discussed that can have a significant worldwide impact if a rational design solution can be devised.

## 23.1 Introduction: Continuing Human "Saga"

"*Inputs to an operating system generate outputs, some desired, some unwanted, and some even detrimental. Humanity must deal with the detrimental outputs of the system. They will not disappear by themselves*."

When people invented the internal combustion engines near the end of the nineteenth century, they thought that finally, they could have manure-free streets in addition to having faster moving vehicles. Automobiles, with other technologies, indeed led the industrial renaissance of the twentieth century. A century later, however, people are discovering that it is a major source of the environmental problem. The emission of carbon dioxide ($CO_2$) from these powerful engines, which have served humanity so well, is contributing about 30% of the $CO_2$ gases that are responsible for greenhouse effects and global warming that are threatening the very survival of human society as we know it.

Similarly, when the electrification of the rural community was finally accomplished in the United States, a new era of modernization came to every corner of the nation. It also enabled the modernization of many other countries. Electrification raised the standard of living, bringing in high quality of life through the replacement of human labor with machines and equipment powered by electricity. Now more than a century later, we are discovering that the generation of electricity through the combustion of fossil fuel is leading the world to global warming, threatening the very existence of the infrastructure of modern society and the habitat of animals and marine life. Similarly, through much research and development, engineers and scientists designed nuclear power plants to replace the fossil-fuel power plants to generate electricity without generating greenhouse gases. However, after accidents at a few of these nuclear power plants, people are abandoning this powerful technology for fear of new nuclear accidents and contamination, taking actions that will accelerate global warming.

These examples illustrate how technologies must continue to evolve to seek the next level of improvement and innovations to satisfy human needs and overcome problems created by past deeds of human beings. The consequence of technological advancement may generate new design problems that require unique solutions. In a larger scheme of things, these by-products of technological progress will always be there. It is a fundamental nature of systems, that is,

$$\text{Old system} + \text{design innovation} \rightarrow \text{new system} + \text{new by-products} \quad (23.1)$$

Equation (23.1) states that there are "new by-products" embedded in technological solutions (i.e., global warming with industrialization and invention of internal engines). Some of these by-products cannot be ignored over a long period, thus creating the need to design a new solution that can overcome the problem created while solving an old problem. Equation (23.1) can be used to achieve many positive results if humanity can deal with undesired by-products, if any, successfully and well. The conversion process indicated by Eq. (23.1) generates economic activity, creates jobs, and continues to advance knowledge in all spheres of human activity. The shortcomings of horse-drawn buggies created cars with internal combustion engines, which have served humanity well for over 100 years. Still, a new problem in the form of global warming emerged, forcing the creation of new alternative transportation systems. This continuing evolution of human society is part of the natural process.

So far, humanity has managed the process of evolution indicated by Eq. (23.1) well, mostly through the design of the next advanced solutions as well as through finding new solutions. Economic and financial investments in education, research, and development enabled the continuing evolution and advancement of human society since the Industrial Revolution, albeit a few calamitous blow-ups among people. For this process to go on, we need the enlightenment of the large fraction of people who support the dynamics of successful human, social, and economic progress. When this process fails, humanity frequently discovered themselves in ugly conflicts such as the First and Second World Wars. Humanity is often skirting the boundaries of these disasters, a symptom of a poorly designed socioeconomic–political system.

In this chapter, a few of the major problems that may require innovations, solutions, and design will be discussed as examples of future design tasks that may require the attention of the next generations of designers, leaders, and the society at large. Predicting future events and functions is not an easy task—with many risks of being wrong—perhaps best left to those with psychic minds. In the following sections, randomly selected topics are discussed with no assurance that they will indeed be the most important topics. For instance, if nuclear war engulfs the world, many things will change with irrecoverable dramatic ends of the world, which is hard to imagine at this time. In that sense, we should do everything we can to design a system that will prevent events that may culminate in such a disaster.

## 23.2 A Challenging Design Problem: Creating Forest in North Africa

Living beings such as animals and vegetation cannot survive in the absence of water, as well known. The availability (or scarcity) of water has determined the politics and conflicts among nations, especially in the Middle East. The control of water of the Jordan River (River Jordan) that flows through Jordan, Syria, and Israel is politically and historically significant. In China, there are five or more large deserts. The Gobi Desert, which is between China and Mongolia, is a vast and arid region. The sandstorm from the Gobi desert reaches Korea, Japan, and parts of the northern American continent every spring. People in Korea wear masks, and sometimes, schools close during the peak season of the sandstorm. In North Africa, the vast land area is mostly desert with limited human habitation. The world's largest Sahara desert covers about one-third of the African continent (about 3.5 million square miles) from the Red Sea on the west and the Nile River on the east (extending about 3,000 miles) and from the Atlas Mountains of the south to the Mediterranean sea of the north (about 1,000 miles).

Many theories have been advanced to explain how the deserts in North Africa were created. It appears that the changes in the weather pattern created the North African desert some seven million years ago. One theory is that when the North and the South poles became extremely cold, the moisture condensed at these two poles, thus depriving the moisture condensation in the hot regions near the Equator of Earth, creating the vast desert of North Africa. There is also a theory that when people and animals overglaze a particular area, the region becomes a desert, especially in a hot climate. For example, the urbanization of the suburb near Cairo and the Nile River created a small desert in the adjacent area between Cairo and the Nile River. The population density of these desert areas is very low since the climate is not very hospitable to people and other living beings, including vegetation.

Some of the deserts in the world became habitable through massive irrigation. The southern part of the State of California became thriving urban centers of the United States with extensive agricultural business and high-tech industries thanks to the water diverted from the Colorado River. Many other countries such as Israel, Saudi Arabia, and the United Arab Emirates converted desert into valuable urban centers by securing freshwater either through de-salination or divergence of rivers.

There is also a "theory," cum speculation that the presence of green plants and vegetation near the shore areas changes the weather pattern that brings in moisture to the area, which condensate and rain in the region with forest and vegetation. Assuming that these observations or theories are correct, can we design a solution to convert some parts of the desert areas into habitable land for plants, animals, and people? The first requirement for converting the desert into inhabitable land is to bring more water to the region. In many areas, the de-salination processes, such as the evaporation process or a reverse osmosis (RO) process, are used to generate freshwater. The evaporation process and RO processes of producing freshwater are energy-intensive processes, which are the major processes used for de-salination in many countries in the Middle East, including Saudi Arabia and all neighboring countries. These energy-intensive processes are expensive to operate. We should design a more energy-efficient de-salination process by making use of solar energy or wind power.

The following story illustrates how the desert can be converted into a modern university–city complex with lots of trees and vegetation when sufficient financial resources are available. A design challenge is how a similar transformation of the desert can be achieved at a lower cost of construction and maintenance, using less energy.

The KAUST Story:

About 40 miles north of Jeddah, which is a major city of Saudi Arabia on the Red Sea, there used to be a small town called Thuwal. Its western border is the Red Sea, and the desert surrounds it on the other three sides. Thuwal is also about 87 miles south of Mecca, the holiest city of Muslims—the birthplace of the Prophet Muhammad and the Muslim faith. Thuwal used to be a small fishing village until about 2009. In mere a decade, Thuwal has become a well-known city in the world because it became the home for King Abdulah University of Science and Technology (KAUST). King Abdulah of Saudi Arabia, a visionary and benevolent king, established the university because he wanted to see Saudi Arabia regain its eminence in mathematics and science.

KAUST was established in 2009 at a location that used to be a vast desert. Now its campus consists of 3,600 hectares (8,900 acres) of land with more than 16,000 palm trees, 17,000 other trees, modern research buildings with advanced instruments and equipment, academic buildings, a fire station, apartments for students, faculty housing, movie theatre, restaurants, etc. Its graduate students do not pay any tuition, receives a stipend for living expenses, and have access to some of the best-equipped laboratories. The student body is co-educational, international, and highly selective. The goal of KAUST is to become one of the best university of science and technology in the world. To achieve this goal, it has attracted leading researchers and students from many parts of the world.

KAUST is a private university with the second-largest endowment in the world, next to Harvard University. KAUST is a relatively small graduate school of science and technology with approximately 1,200 graduate students and about 200 faculty in 2020. It may double its size within ten years. Its physical facilities are most impressive. About two-thirds of the students and faculty, both men and women, are from outside of Saudi Arabia. There are many Saudi women students. KAUST is truly co-educational free from many restrictions of Saudi Arabia. In many ways, it is comparable to the leading universities in advanced nations on other continents. About half of the trustees of the university are non-Saudis.

KAUST survives and thrives because of the electric energy supplied by electric power plants that burn oil in Saudi Arabia. All the buildings are air-conditioned with the electrical energy provided by electric powerplants that combust oil. To generate freshwater, KAUST pumps water in from the Red Sea to its de-salination plants on the campus. The de-salinated water is used throughout the entire KAUST community. The water that keeps all the trees and vegetation alive is the re-circulated residual water after its primary use. Its annual water consumption varied from a high of 9 million cubic meters in 2015 to about six million cubic meters in 2019, decreasing every year since 2015. The electric power required for de-salination varied from 51 million kilowatt-hours (kWh) in 2014 to 33.5 million kWh in 2019. The beautifully landscaped green area of KAUST is 1.1 million square meters ($m^2$). The total number of people that work and live in the KAUST campus is around 7,200. The total power consumption in 2015 was 530 million kilowatt-hours (kWh), decreasing to 509 million kWh. The electric power used at KAUST for de-salination was from 9.6% in 2015 to 6.5% in 2019 of the total electrical energy consumed. On per capita basis, the total power consumption at KAUST was about 73,000 kWh per capita and for de-salination about 4,000 kWh per capita. To put these numbers in a proper context, the electricity consumption per capita of various countries in kWh are as follows: Saudi Arabia (9,400), U.S. (13,000), Sweden (13,000), Korea (10,400), China (3,900), and Norway (23,000). A conclusion from this rough analysis is that to solve the water problem in the North African desert (or any other dessert), we cannot only use the energy-intensive de-salination processes such as evaporation or reverse osmosis (RO) process. These high energy-intensive processes are needed when the rate of de-salination is high. However, in many situations, we may not need such a high rate of de-salination. Thus, we may have the possibility to design a new system of de-salination.

Saudi Arabia is exceptionally fortunate to be sitting on a vast reservoir of clean oil with the least amount sulfur, etc., below the sand, which was discovered in 1938. Its production cost is the lowest in the world, being as low as $3 a barrel of oil, which is only about 7% of the cost of producing oil by fracking of rocks in the United States. The amount of oil reserves in Saudi Arabia is difficult to estimate because of the yet-to-be-discovered fields. It appears to be huge. Just a the Stone Age did not end because the world ran out of stone (a statement made by a previous Oil Minister of KSA), Saudi Arabia may not be able to sustain its economy based on oil. Saudi Arabia will not be running out of oil any time soon. Still, because of global warming, the oil industry may, in the future, have a limited market because the world cannot depend on oil as their primary energy source. Saudi Arabia is well aware of this situation and is planning to change its economic structure to avoid being entirely dependent on the petroleum industry because of limited global demand for oil as the renewable energy sources take over the energy market. They are trying to create new economic engines that can create jobs for a rapidly growing population of the Kingdom, a goal of their 2030 economic plan.

The amazing thing about the modern world's economy is that the value of natural resources is minuscule in comparison to the value-added created by ideas that do not depend on natural resources. For example, the vast annual revenue of the giant oil company, Saudi Aramco, is much less than those of four companies in the United States, i.e., Microsoft, Amazon, Facebook, and Google, that does not depend on natural resources for their revenue. Thus, the need for the Kingdom of Saudi Arabia to restructure its economy is quite apparent, i.e., to go from a nation that depends on natural resources in the ground to an economy that is vastly different from the petroleum-based economy by finding new economic engines.

In the twenty-first century, the irony for Saudi Arabia is facing is the following: it is one of the most energy-rich countries in the world, not because of the oil under the ground, but rather the immense solar energy it gets from the Sun every day of the year! Yet, they are unable to tap into this vast energy source and capitalize on it. The following design task is formulated to solve this problem.

**The Design Problem for the Future Well-Being of the People Throughout the World:**

Suppose you are a bright graduate student at KAUST, doing design research under the guidance of a globally renowned KAUST professor Sandra Cavique-Foley. The design task is to design de-salination plants to establish “forest” in Saudi Arabia and Egypt along the coast of the Red Sea, using the uninterrupted supply of solar energy (except at night), the availability of the water of the Red Sea, and vast desert area in these two countries.

If the water from the Red Sea can be de-salinated inexpensively using solar energy, it can be used to grow plants in what is now desert. When a forest exists through this process, some claim that the weather may change in these areas because the trees will transform the weather pattern, generating additional condensation. The moist air will condensate, create more rain, and eventually make the current desert area into livable and arable land with trees and other vegetation.

State your FRs and develop ideas that can fulfill this dream. Then state the DPs that can satisfy the FRs. What would be your process variables (PVs)?

As you embark on this design assignment, you should remember that, in general, slow processes that require low levels of energy require larger equipment, which requires more capital investment. This is the case when we try to make use of the tidal wave of the ocean to generate electric power. This argument also applies to the case of electricity generation with windmills. It requires large long blades to be economical. One has to consider the financial viability of your idea as you decide on FRs, design parameters (DPs), and PVs.

## 23.3 Design Challenges Related to Renewable Energy

1. Issues associated with solar cells

    a. One big problem with the use of solar cells is that the output of electricity cannot be easily controlled or modulated quickly once installed. The output depends primarily on the availability of sunlight, which cannot be regulated. Thus, when the electricity generation by solar cells exceeds consumption, we must store it for future use or dissipate it, neither of which is a trivial task. Some countries may find it cheaper to give it away to their neighboring states if they can use the electricity. We need to design solutions for storing excess energy.
    b. Various electric energy storage schemes have been considered. One idea that has been promoted is to compress $CO_2$ gas in a closed cavity such as underground salt mine and generate electricity by decompressing $CO_2$ when electric power is needed. An idea of storing energy that is in use today is to pump water to a reservoir at a higher elevation, e.g., mountains. Then use the power of the waterfall by running a hydropower plant when needed. If such clean electrical energy is abundantly available, we can create hydrogen and oxygen through electrolysis, which can be used to power automobiles without creating $CO_2$.

c. Another solution is to limit the power generation by solar cells to be always below the demand level. When the demand exceeds the supply, supplementary electric power generation by other means can be used, such as conventional fossil fuel-burning power plants or through activation of nuclear power plants. One of the design issues is the creation of control system that can deal with a continuously varying demand and supply system.
d. The above-mentioned electric power transmission efficiency has other implications. If the electrical power can be transmitted less expensively, then electricity can be generated in hydrocarbon-rich and less densely populated areas. Then the electricity can be transmitted to highly populated urban regions. This transmission of power rather than crude oil will eliminate the oil consumption associated with transportation, which should help in $CO_2$ emission by ships. This transmission of electric power, especially wireless transmission, is a challenging issue in design.
e. One current popular solution is to put solar cells on top of the roofs of individual houses, which may alleviate the problems related to electricity transmission in addition to creating a distributed power generation system. Still, the electricity generated from the rooftops of these houses may not be sufficient to supply reliable electric power for industrial operations and transportation.

2. Wind Power

a. Wind power is another source of renewable electric energy. Windmills have been installed in many countries, e.g., Denmark, the United States, and many others. The power generation is proportional to the square of the blade length, requiring tall towers for installation.
b. The availability of wind power is often highly location-specific. In some countries, they are installed offshore or on top of mountains away from densely populated areas for noise reduction and safety. It has to be located away from urban areas to prevent the disastrous consequence of accidents due to fatigue of materials and noise. In many countries, they are often installed offshore, which solves many problems if the initial capital cost of installation can be justified and is reasonable.
c. Wind power has the same issue as solar power in terms of the storage of excess electric energy.

3. Nuclear Power

a. The nuclear power plant supplies a significant fraction of electricity in many countries, e.g., France, South Korea, Japan, and China. In many countries, they have operated these power plants for decades without any major accidents.
b. The biggest threat to the use of nuclear power is the fear factor. The past accidents that occurred, for example, in the Soviet Union as well as in Japan,

were truly horrendous. There are indications that the accident in Fukushima, Japan, was due to the coupling of FRs at the system level. Building safe electric power plants based on fusion is still a dream that requires creative design for containing energy that is at extremely high temperatures.

c. The design challenge is to develop 100% accident-free nuclear power plants. This means that the design must be thoroughly reviewed for any coupling at the system level, i.e., in physical layout, software design, and operational level.
d. Some countries have considered building small modular nuclear reactors that are safer than large plants.
e. A more serious challenge in the use of nuclear power plants for electricity generation is the disposal of the spent nuclear fuel, which must be stored forever with 100% assurance. One way is to send the spent fuel toward the Sun, which will be a challenging design task.

## 23.4 Design Problems Related to Transportation

Transportation of goods and people is both a necessity for economic activities and fulfills the basic human desire to expand the sphere of human activities and interactions. As the population continues to grow, both the issues and needs related to transportation will continue to expand. Unfortunately, one major villain for causing global warming is also the transportation of goods and people; the most guilty one being automobiles, followed by airplanes and ocean-going vessels, because ground transportation is the dominant mode of transportation of goods and people. Roughly 30% of the $CO_2$ emission is from the internal combustion engines of automobiles and airplanes, another 30% coming from electricity generation. Currently, the primary emission that concerns regulators is that of cars. In both cases, alternative power sources consist of batteries, electric motors, and engines.

The most often-cited solution is to use lithium batteries that supply electric power to electric motors. There are three problems associated with this solution: the cost, weight, and safety of batteries. The weight of batteries can be as much as 30% of the total vehicle weight. The other potential issue is the possible explosion of the lithium batteries. As the number of accidents increases, the explosion of these batteries during a collision can have a disastrous effect, especially if water seeps into these batteries. These batteries contain both the oxidizer and the fuel, which can be activated by water.

A successful alternative design is the use of wireless electric power transmission to propel the vehicle. At the Korea Advanced Institute of Science and Technology (KAIST), a university specializing in science and technology, a new of kind electric vehicle was invented. It receives electric power wirelessly from power supply systems embedded under the pavement and stores some of the energy in the on-board batteries to use it to propel vehicles on roads without the embedded power supply system. In 2019, the “On-Line Electric Vehicle (OLEV)” was running in five cities in Korea including at KAIST. The number of batteries on board is small since the bus receives most of its electric power from the electrical power supply system embedded in the underground. The size of the battery depends on the length of the underground power supply system and the speed of the vehicle. The OLEV vehicles are quiet, and the driver does not have to worry about the supply of fuel. The OLEV system has been running in Korea since 2012, very reliably and quietly without any significant issues. It may soon be installed outside of Korea. When the electricity is generated from renewable sources and nuclear power plants, OLEV is entirely emission-free. Its installation is simple and straight forward, especially when installing new roads.

Also, there are possibilities of reducing fuel consumption of jet airplanes through several concurrent means. The problem of current airplane design is that it has to have powerful engines to propel the airplane to “lift-off speeds, about 160 miles an hour” on a fixed-length runway. However, when the airplane reaches the cruising altitude, the engine is too big and generates aerodynamic drag, which in turn consumes more fuel. In other words, the need for “take-off” from ground determines the engine size, which at the cruising speed, is too big and adds to fuel inefficiency.

There are several possibilities of reducing engine size. One is to reduce the mixing section of the engine by coming up with faster means of mixing fuel with oxygen, such as impingement of fuel and oxidizer rather than depending on the slow diffusion process. Another method of reducing the engine size is by assisting the airplane in reaching the lift-off speed by providing an externally assisted take-off force. For instance, an external “train” can pull the plane forward to help the acceleration of the airplane, similar to the way fighter planes take off from the deck of naval carrier ships. The simplest solution is to extend the length of the runways to enable aircraft to reach the take-off speed without having large engines. All of these possibilities offer exciting design tasks.

## 23.5 Design Problems Related to $CO_2$ and Methane Gas ($CH_4$) Emission

There have been many proposals for dealing with $CO_2$. The most commonly discussed solution is to bury $CO_2$ in-ground, dissolve in the ocean, or pump liquid $CO_2$ into ground or under the ground floor of deep sea. Another possibility is to convert $CO_2$ to other more useful materials. The difficulty is developing technologies that are economical and use less energy to transform. Becasuse $CO_2$ is one of the most stable forms of carbon products, it isn't straightforward to develop inexpensive and environmentally acceptable conversion technologies. A research center established at KAIST under the joint sponsorship of KAIST and Saudi Aramco has been working on this problem for the past several years.

Methane ($CH_4$) is another environmentally harmful gas. The primary sources of $CH_4$ are agricultural processes, degrading plants, and from cracking for oil. The quantity of $CH_4$ emission is about 9%, which is less than the emission of $CO_2$. Still, its environmental impact in the atmosphere can be substantial relative to its small quantity. The diffused sources of $CH_4$ gas are harder to control than the $CO_2$ emission from internal combustion engines and electric power plants. However, as the $CO_2$ emission is reduced, the discharge of $CH_4$ will receive more attention.

The free energy of $CH_4$ is high, and therefore, it should be easier to convert it into other useful products, the most stable reaction products of $CH_4$ being is $CO_2$ and $H_2O$. Thus, $CH_4$ can more easily be transformed into other useful materials because $CH_4$ can be reacted with other substances more efficiently than $CO_2$.

## 23.6 Future Roles of Artificial Intelligence (AI) and Quantum Computing in Design

Axiomatic Design (AD) teaches how to create an original design from scratch correctly. Its axioms and theorems also explain how to find design flaws. This process is going to benefit if the database on past designs, constitutive relationships, various FR-DP-PV relationships, and past failures were readily available. A promising approach is to generate plausible concepts by going through vast databases to mine the data in the literature, hoping to find the right design solution. This approach makes use of three development: the ability of computers to store a vast database, process an extensive database rapidly at low cost, and the recent advances in AI with the potential to extract the desired information quickly from the vast database. A promising approach is to generate plausible concepts by going through vast databases to mine the data in the literature, hoping to find the right design solution. This approach makes use of three development: the ability of computers to store a vast database, process an extensive database rapidly at low cost, and the recent advances in AI with the potential to extract the desired information quickly from the vast database.

AI can be used in many designed systems to make better decisions expeditiously and to improve the effectiveness of the decision-making process. This use of AI is possible because of the availability of high-speed computers, the vast memory space available at low cost, and the development of sensors that can monitor the behavior of the system. Already commercial software systems that incorporate AI are being introduced. Such development will need a supervisory AI system that can check for the correctness and accuracy of the AI decisions made.

Like many new technologies, one of the dangers is that AI may be used for unsavory purposes. It can be used to cheat in elections for public offices, oppress less fortunate people, and create systems that favor those with means at the expense of democracy. If the history of technology provides a lesson, humanity eventually finds positive and beneficial applications of technology. However, people were concerned about the possible negative impact of new technologies on human beings, society, and individuals. So far, problems created by new technologies have been solved through technologies, often advancing societal goals in addition to technological advances. As long as we do not let technologies dominate human decisions, we may be in good stead.

Many software and computer companies are active in these fields. Broadcom of the United States (stock listing: AVGO) launched Automation.ai, an AI-based software platform for supporting decision-making processes across different industries. It deals with large volumes of data, which is challenging to do by digital transformation, which can lead to slower decision-making. According to Broadcom, Automation.ai is a platform designed to ease complications stemming from the interference of diverse tools and data, and thereby facilitate informed decision-making. It correlates and examines data to another software called Digital BizOps to analyze the data and combine them to generate solutions to aid decision-making. According to the company's brochure, the technique harnesses the power of machine learning, intelligent automation, and internet-scale open-source frameworks to transform data. It is not clear if Automation.ai can develop design solutions based on an original set of FRs.

Many other companies, such as IBM, have also been exploiting AI and quantum computing, using their ability to store and manipulate vast data to improve decision-making through cloud computing. IBM has been one of the first industrial firms to work on quantum computing from many decades ago. Many of these tools, including those of IBM and Broadcom, are based on their idea that there are vast data available in the literature and companies that can be exploited and recombined to create solutions to existing or new problems. The idea is to do what people can do faster, utilizing the capability of machines to gather and sort out the data quicker and more extensively. Ultimately, the hope is that the machines will also become smarter than people in creating and designing new solutions. If this can be done, the same thing will happen to scientists and engineers that happened to factory workers due to automation using robotic technologies. Then, engineers and scientists must work on a higher intellectual platform to do things that machines cannot do, which will turn out to be a challenge. Computers are getting smarter faster than perhaps an average person!

Some people are concerned that AI, the especially advanced form of AI, will overtake the human ability to solve problems and create new solutions. In other words, machine intelligence will be superior to human intelligence. That has been the case for decades. For some tasks, machines have done a better job than human beings ever since the Industrial Revolution. That is why we use many different kinds of devices and tools. Now the computer can perform better than human beings in some logical reasoning fields. This trend will continue. However, as machine intelligence improves, so will human intelligence, often faster than machines.

## 23.7 Design and Large Databases

The collection and management of the vast data that exist throughout the world is a significant challenge. Cloud computing has enabled the creation and management of an extensive database. Major corporations have jumped into the business of managing the database and extracting the desired information. For most people, it will soon be reasonable to assume that anyone can obtain personal information and manipulate them by companies, individuals, and the government using facial recognition. Regulating these activities will be extremely difficult. Individuals should assume that it will be challenging to maintain personal secrets confidential because the data have been automatically collected and stored through various means by the government, merchants, schools, hospitals, and the like. Ultimately, the government must regulate the use of these personal data, because no individual can manage, protect, and restrict the use of personal data collected by machines and organizations of various kinds.

The irony of the situation discussed above is that eventually, machines may know more about us than we know ourselves! Under that circumstance, each morning, we should consult the computer what we should do that day. Similarly, in the evening, we should ask the machine to review what we have done during the daytime and assess our performance and effectiveness, hoping that we can improve our performance and efficiency the following day!

## 23.8 Design Issues Related to De-Salination

Today de-salination has become big business. Most de-salination processes in use today are done using either reverse osmosis (RO) processes or various evaporation processes. These processes are energy-intensive since these processes break the atomic bonds between sodium chloride molecules and water molecules, both of which are energy-intensive. Therefore, these are high-cost processes.

There are other possibilities for de-salination, such as de-salination by phase separation. One of the techniques developed at MIT is to apply an electric potential across the flowing brine water to create two streams: one salt-rich stream and the other with low salt content. Then, the stream with high salt contents was separated continuously from the lower concentration stream by draining off to a sink. By continuing this process, what flows to the end of the stream is the water with low salt concentration. The methods such as this need new design solutions.

Another possibility investigated at MIT and KFUPM is the use of graphene to separate water molecules from other molecules. Making the graphene sheets without flaws such as large holes is a challenging task. However, it is a conceptually promising means of making atomic-scale filters.

There may be other effective designs that are economical and reliable.

## 23.9 Design of Software

Software is embedded in almost every product, in addition to substantial central computing facilities that are maintained by all major corporations, universities, and government agencies. Many software system developers often start coding their software without first designing the software system, which may result in coupled systems, requiring extensive revisions and testing.

One of the problems many software developers are facing is that they often build new software systems on existing legacy software codes and policies. It isn't very easy to know the intention of the designer of the original software unless they have made thorough documentation on the system.

When large software systems are being developed, the design matrix must be concurrently constructed to be sure that there is no coupling of FRs in the software system. The current practice is to develop software codes and test before designing the software system.

## 23.10 Control of the Weather Pattern

If we can control weather patterns, we can change the world for the better. Then, we can improve many things such as agriculture, quality of life, prevention of forest fire, conversion of dessert to useful land, low consumption of energy to heat houses and factories, and many other beneficial things. Now unstable weather patterns are causing significant problems in many parts of the world. For instance, a hurricane that begins off the east coast of northern Africa due to high water temperature and wind patterns creates vortices above the warm water. The vortices move toward the southeastern area of the United States, where the temperature is lower, creating hurricanes in the fall of every year and causing human tragedy as well as a lot of economic losses. With global warming, the problem is going to get worse, more tropical storms, the creation of more dessert, higher water levels, and unpredictable weather patterns.

Hurricanes are caused by instability. When hot air forms a vortex motion on top of the surface of the warm ocean water, it sucks up the water vapor, which strengthens the vortex motion as it continues to move on top of the warm water. This vortex motion generates strong wind as it grows. When the vortex moves toward the colder surface of the land and the moisture condenses, it can unleash rains with strong wind on the cold land surface. The damage done by these hurricanes, wind, rain, surging ocean waves causes tremendous damage every year.

On the other hand, the weather pattern in Saudi Arabia and northern Africa is the opposite. The whole region is hot throughout the year, and the Red Sea is relatively small to develop unstable air-motion and create vortices. Therefore, the hot vapor of the sea cannot be picked up and dumped on the top of the tropical land. Thus, the region around Saudi Arabia is arid and became a dessert.

The design question is the following: Can we create and control vortices using the instability phenomena of the circular motion of atmosphere by creating a large number of small vortices artificially at different parts of the ocean surfaces to control the weather pattern of Earth. If we can do that, we can change Earth to make it more habitable, useful, and productive. The author of this chapter believes it can and should be done.

## 23.11 Design of a Better Educational System

Human beings are created equal. However, the quality of education often ruptures this "god-endowed" equality. The secondary variables such as family background, financial resources, family stability, neighborhood, quality of education, and early childhood education have deterministic effects on the well-being of the individual as well as their society. Often, education has created a demarcation line between those who will do well in society and those who would have problems in a merit-based society. Therefore, parents in all countries are concerned about the education of their children.

Similarly, the future development of a nation depends on the quality and effectiveness of its educational system. Yet the educational system in many countries is not effective and efficient for a variety of different reasons. In fact, in many countries, educational systems are the primary reason for the lack of advancement in the country. Ultimately, the educational system of most countries is determined by design. In most nations, the emphasis is on teaching rather than learning, i.e., *teaching methods, teaching materials, teaching techniques,* and less on *learning methods, learning efficiency,* etc.

Many of these nations should redesign their educational systems. It should be designed to bring out the best in their young people, must be rational, and must be merit-based. It must emphasize ethical behavior, the concept of equality, the importance of guarding justice, and doing one's best in their profession. All these features must be designed in the curriculum, institutional culture, and reward systems. The future of a nation depends primarily on its educational system, because other socioeconomic-political factors are more difficult to change without improving educational systems.

## 23.12 Design of a Democratic and Transparent Government

Eventually, most nations will have a democratic form of government as a consequence of significant advances in telecommunications, computers, and sensors that can record most transactions and documents. It will be challenging to hide corruptive practices, illegal activities, dictatorial practices, and unsavory acts.

Technologies will make it increasingly difficult to lie to the public for too long! When technology is appropriately used, it will make society, politics, and government more transparent.

Recently, one of the most advanced democracies in the world has gone through significant debates about the effectiveness, adequacy, and reliability of its election system, which is the underlying lynchpin of democracy. Even after so many decades and centuries of maintaining effective democracy, people are finding that modern technology can undermine the election system, especially when foreign adversaries are interested in disrupting the system to bias the outcome in their favor. In addition to the external interference, governments in many countries are tilted in favor of those governing the nation. Such corrupt practices lead to both unfair and undemocratic practices. We need an improved system for transparency in governments, an effective governing structure, and a reliable election system to sustain democracy. Truly democratic and fair practices can exist only with the citizens are well educated, and laws and democratic principles rule governments. We will also need continuous improvement in protecting the election system and in preventing unlawful practices.

Democracy is a way of governing by following the majority opinion for a fixed period and then reset the rule the group must adopt until the next period, i.e., *functional periodicity*. As Churchill said in 1947 in the House of Commons, "No one pretends that democracy is perfect or all-wise. Indeed it has been said that democracy is the worst form of government except for all those other forms that have been tried from time to time…." It took about two thousand years from Aristotle to the first English democracy. It changed the question from "who must rule?" to "how to rule?" and "what to achieve?" To achieve this goal of a democratic nation, FRs must be established for the government and society through free and democratic means based on fundamental governing rules and principles. FRs are typically related to security, prosperity, welfare, health, aspiration, and freedom of the people. Corrupting democracy leads to unpeaceful and conflicted societies.

## 23.13 Design of Improved Health Delivery Systems

The quality and cost of healthcare are two major issues that concern average citizens in most countries. Gradually, every country is moving toward some form of universal healthcare for all its citizens that can deliver the best care at the lowest cost, which may be an oxymoron.

Many things must be done right to enact and maintain an affordable and effective healthcare system. We need to design a healthcare system that has the following qualities:

(a) High-quality hospitals with best trained medical staff, the right equipment, and facilities,
(b) Efficient medical and pharmaceutical systems,

(c) Incentive system that rewards the medical skill, knowledge, efficiency and dedicated work, and minimum bureaucracy.

Many countries have done much to improve their system, but none seem to satisfy all these criteria.

## 23.14 Design of a Peaceful World

Almost everyone is seeking to live in a peaceful world. Yet, it has eluded humankind for centuries. There are many reasons for it. Perhaps the most prominent causes are human greed, a fundamental desire to protect one's tribe and family, even at the expense of others. Sometimes, national and regional interests, different religious beliefs, limited resources to share, creeping dictatorship, and others tend to override democratic tenents and a sense of justice. People have attempted to create a peaceful and prosperous world through the establishment of the United Nations (UN), the Worlds Health Organizations (WHO), the World Bank, and others. Their effectiveness of these world organizations was checked by bureaucracy, lack of real power to implement the best practices, limited incentives for good work, and financial dependence on the member nations.

One significant danger is that many unstable people may have access to weapons of mass destruction such as nuclear bombs, biochemical agents, disruption of the electric power grid, and spreading of false information. We need to design means of controlling and safeguarding these weapons of mass destruction.

## 23.15 Design of Better Drugs for Brains

We have many brain-related illnesses such as Alzheimer's disease, autism, and others. Yet, one of the least developed fields of medicine is those related to the human brain. We have limited knowledge of the details of brain functions. Consequently, we do not have a systematic means of diagnosis and fundamental expertise in developing new pharmaceutical medicine that can deal with human memory, enhanced brain functions, and the like. Can we design a system that can assist brain functions through the use of embedded electronic microchips and the like rather than depending on medication?

## 23.16 Design of Computer Assisted Brains (I.E., Supplementary Brain)

The brain is the most complicated and complex organ in human beings. The brain performs various functions. Many of the workings of these functions of the brain are yet to be fully understood.

The brain retains information and analyzes them. It assembles and synthesizes new information to create new ideas. Its logic circuits deduce conclusions from a random set of data. Many other characteristics and functions of the brain we do not yet fully understand. Some people retain and perform more of these capabilities than others, e.g., Albert Einstein, Ludwig van Beethoven, Thomas Edison, Abraham Lincoln, and others. We do not know whether these exceptional people had more powerful brains or had used their brainpower more wisely and cleverly.

If we assume that human brainpower can be supplemented and complemented through external means by attaching human-made nano-devices to human neuron cells in the brain, we may be able to make "super-human beings." The goal is not only to provide more memory and logic capabilities to the brain but also to give higher and faster reasoning and synthesis power to the person with this "supplementary brainpower." Then, human beings must make sure that the person with such power does not become abusive to harm other people. Morality and ethics must be built in such devices to be sure that we do not create a monster. Human record on morality and ethics is not particularly reassuring.

Physiological functions of humans are affected by *human thought processes*, although some people tend to minimize the effect. Human thought processes must affect biological processes. The following true story supports this view:

Why Do People Sweat when They Eat Spicy Food?

In many countries, especially in the United States, the human palate has changed during the past 50 years. More people eat spicy, hot food more than ever before. The meat and potato culture of Americans has given away to spicy Mexican, Korean, Chinese, and Indian food in major metropolitan areas of the United States. The massive immigration of people from these countries has changed the palate of Americans gradually. Now the minorities in the United States constitute a significant fraction of Americans, which is more multi-racial and cross-cultural than ever before.

One of these hot dishes that have become very popular in the United States is "Kimchi," a Korean fermented cabbage, famous for its hot spice and garlic. Many people sweat when they eat kimchi for the first time, especially if they have not had spicy food before. What is interesting is that once people start eating this dish, they can no longer do without eating it once in a while. Koreans eat kimchi almost every day with their main meals. Most people have attributed their sweat when they eat kimchi to hot spices (primarily hot pepper, garlic, salt) that somehow affected their biological and physiological systems.

One day an engineer who had researched mass production technologies was watching a television program on mass production of kimchi in factories. He was fascinated to learn that they were using a mass-production system similar to those used in making automobiles to make kimchi. It was astonishing and interesting to learn that kimchi is no longer produced by housewives sitting around a table, which used to be the case it was made in Korean households.

After watching the kimchi-manufacturing program for 20–30 min, he was surprised to realize that he was sweating heavily. His shirts got wet, wiping away the sweat from his face with paper towels, although he has not eaten anything spicy that morning! He called his wife to see him sweating so heavily. She was surprised as well. This sweat was purely psychosomatic. When learning of this experience, most people cannot quite believe what they have heard. Some might have tried to replicate the experience.

It is abundantly clear that we have a lot to learn about the brain. What we know and what we need to know are separated by a wall of missing information and knowledge. Much investment will be required to close the gap. Future research should seek a better balance between molecular-level scientific research and hypothesis-based research to solve some of the urgent human sufferings such as autism soon. These two different approaches will reinforce and complement each other for faster advancement in this remaining frontier of human knowledge and technologies.

## 23.17 Recycling of Materials

The world is rapidly becoming inundated with junk, toxic, and harmful materials. When scientists first invented polymeric materials by creating long-chained molecules, the resulting high molecular materials solved many problems that were impeding the progress of societal functions. Only 70 years later, after the invention of high molecular materials, the world is running out of space to store these materials after using them because human beings consume so much of these non-degradable materials. We need to design solutions for this waste disposal problem. There may be several approaches: first, rapidly degrading these materials to convert them to the original elements without harming nature. Second, recycle waste into useful products. Third, levy enough taxes to finance recycling efforts. Forth, forbid the use of some of these materials through international agreements and legislation, and finally, incorporate, during the design stage, a life cycle scenario to have a net-zero impact on the environment.

## 23.18 Design Problems Related to Self-Driving Cars

Many companies are developing self-driving automobiles. Their goals are admirable, but there will be many accidents and fatalities before a reliable system can be installed unless they are correctly and adequately designed. Problems will arise in the least expected situations, where machines are not pre-equipped to deal with for lack of a database. Keeping everything else the same and only equipping cars with sensors of many different kinds may be a wrong approach. We need to consider all the issues of such a system and developing a systems solution involving "smart cars," intelligent roads, design of decision-making systems for a group of automobiles nearby, etc. We need to construct FRs, DPs, and the design matrix, considering the interaction of multiple vehicles, conflicting requirements of the vehicle in the proximity, etc. The issues involved are not confined to the car, but the entire system comprising a group of the vehicle with different goals and needs.

## 23.19 Concluding Remarks

This chapter dealt with the challenging design problems of the future. The preceding chapters showed that if people can identify the problem, they can come up with design solutions, following the steps outlined in this book. There may be exceptions when the underlying science base is absent.

In many fields, humans have designed many incredible things. Various designs and advanced technologies created since the Industrial Revolution attest to the human ability to develop artifacts based on needs and goals. They invented things to solve problems they identified to achieve specific goals. Chapter 1, through Chap. 3, attempted to provide a logical structure for these designs to enhance, expedite, and provide an intellectual framework for creating these designs. We showed how to identify and define the problems, which were then transformed into a set of FRs, followed by the development of DPs to satisfy the FRs. If some of the early pioneers had known AD, they might have done a much better job of synthesizing solutions more quickly! What people have achieved during the past four centuries, at an ever increasingly faster rate, gives us confidence in what humans can do to deal with future challenges.

The purpose of this last chapter is to speculate and consider what kinds of future problems people will be called upon to solve through design. Some may be difficult to address through design. However, what may be surprising to some is that the basic AD methodology presented in this book will be equally applicable to all future design problems. What would be equally remarkable to those learning design for the first time is that the thought processes are similar, i.e., the same thinking process and structure regardless of what we have to design. What was different in designing the OLEV and the laminated coffee cup was the specific basic knowledge involved in each field, such as physics of electromagnetic fields, materials behavior, mechanics, thermodynamics, the need for relevant data, etc. That is why designers need to learn the fundamentals of physics, chemistry, mathematics, and other related subjects as much as possible. The same person who designed OLEV had designed the coffee cup manufacturing systems and organizations in diverse fields using the same process of design outlined in this book.

What the designer must know is the basic principles covered in this book and ask questions to be able to define the design goals to proceed with the design task. One can learn what one does not know to complete a design task. When one does not have the necessary knowledge and cannot answer basic questions, then one should acquire the required knowledge from appropriate books and colleagues, and proceed to design. The person who knows the "question to ask" can develop design solutions! One should not be afraid of tackling a new problem, provided that we are willing to acquire the missing knowledge to be able to ask field-specific questions relevant to a given design task. As one executes more and more design tasks, it becomes easier to be an ecumenical designer, who can function in many different areas. It isn't straightforward to know everything from the beginning, but one can always learn.

The preceding statements apply in many fields. The power of AD enables to organize one's thought, quickly identify what needs to be done, identify the missing knowledge, facilitate the quick acquisition of the tasks involved, and come up with a conceptual design. When the design goals are clear, the designer can acquire the necessary knowledge quickly. These steps are discussed and illustrated in the preceding chapters. If one knows what one ought to know but does not have detailed knowledge, the learning efficiency improves a great deal. Many students spend a great deal of time to learn new subject matters. The effectiveness of learning can be low when one does not know what the question is and what one wants to achieve by learning the subject. To paraphrase it, "when people do not know the question, they cannot find answers." What AD enables the designer to do is quick identification of missing knowledge when attempting to define the FRs, DPs, and PVs.

There are two kinds of design tasks that are challenging and uniquely suited for human designers. The first is the ability to define the design problem, for which only human beings are uniquely qualified. The second is the ability to design logically and rationally, following the steps outlined in this book. The cost of creating something new based purely on experience and trial-and-error methods may be too high with the uncertain and precarious outcome. (Question: Was the failure of Boeing 737 MAX due to a coupling of FRs?) Creative solutions often follow the identification of the most important and critical problem, followed by the development of an uncoupled design.

Among the most critical problems, humanity must solve in the early twenty-first century through design is global warming. Yet, the response of most nations to this existential threat is so slow that we may not solve it in time. In comparison to what many countries spend on defense, hardly any money is spent on global warming. If all nations spend one-tenth of what they are spending on military defense to solve the global warming problem, we may have a chance of preventing this impending disaster before it is too late. The development of practical solutions to global warming problems will require the human ability to design rationally, logically, and without committing significant errors.

Another equally important issue that also requires "design thinking" is the re-orientation of our thinking on "world peace" and "human prosperity and advancement of human habitat." Since the end of the Second World War in 1945, many nations spent more financial resources to develop weapons and in defense because of perceived external threats to their existence. Although many useful technologies resulted from defense research (e.g., GPS, the Internet, new materials, and many others), the world is yet to find peace. In retrospect, it is clear that if leading nations had spent 50% of its defense-related resources for the "peace dividend" for economic and educational development of developing countries, the world today might be more secure, peaceful, productive, healthy, and more prosperous.