Introduction: Setting the Stage for a Fossil-free World

THE STORY OF humankind is the story of energy. As civilization evolved over the ages, so did humanity's ability to harness energy and make more imaginative use of it. As humankind developed energy on a global scale, entire hydrocarbon industrial complexes sprung into existence. Often viewed as a boon in the early days, we are slowly realizing the harmfulness of an energy system that spews greenhouse gas (GHG) emissions into the atmosphere and is changing the climate in all sorts of detrimental ways.

Building our modern energy infrastructure has been a century-long exercise and is still a work in progress. To understand the need for transition from hydrocarbons to clean energy, it would be helpful to take a walk down memory lane and understand how we got here. After all, unless we know how we got to where we are today, how can we determine the course for the future?

Let us start from the prehistoric era, many thousands of years before the dawn of civilization. Primitive humans used basic sources of energy such as fire and muscle power to meet energy needs. As civilizations emerged and evolved, the muscle power of animals was harnessed to plough fields, transport goods and people and drive chariots into battle. Another source of energy discovered fairly early on was gravity, or potential energy, used by the Romans to move water through long and elaborate aqueducts.

For about two millennia, until the eighteenth century, there were no new path-breaking discoveries or developments, in either the usage or the sourcing of energy. Over this time, civilization evolved slowly and our relationship with energy stayed more or less static. Human intelligence and ingenuity had seemingly hit a cap. Man was limited by the speed at which a horse could run or the distance that it could traverse in a day. Those who had better or speedier horses could move faster and cover more territory. Think Genghis Khan who had bow-wielding warriors mounted on fast horses, or the Normans who conquered England atop their powerful destriers.

Then, in the eighteenth century, as the Industrial Revolution broke in Western Europe, the world changed forever. Technological advances spurred more diverse uses of energy with the inventions of steam engines and electricity, railways and cars, and light bulbs and printing presses. It was as if a new world had opened up. Humanity literally moved from darkness into light. Distances shrank, the day expanded, cities grew, factories sprung up, new hitherto undoable activities became commonplace. As the twentieth century unfolded, the world became brighter, shinier, with newer and limitless possibilities. Space exploration became a reality, as alas did wars and destructive new weapons.

Now, as you sit reading this book in the new millennium, you are probably in a heated or cooled room, there may or may not be a fan above your head, and there's a fairly good chance that the lights are on. You may have used an elevator, an electric shaver or hair dryer, looked at your smartphone many times, maybe seen the news on TV or used some sort of streaming service, driven to work or home, or used public transport today.

All of these small day-to-day tasks and the large, industrial processes that form our modern-day economy require energy that is ultimately generated through the burning of condensed organic matter (hydrocarbons such as coal, oil or gas) and that forms the basis of the hydrocarbon industrial complex today. We have come a long way from pulling horses and applying our own physical strength to automation and scaling the size of operations of our energy systems. Our discoveries and inventions have allowed us to do things today that were unimaginable just a century ago.

Unfortunately, this progress has come at a cost so steep that it threatens to wipe away a significant portion of humanity along with other life on the planet. Our current construct of society and industries has caused, and continues to cause, significant damage to the environment around us, and to the climate through the greenhouse effect. In fact, credible research shows that native species have reduced by one-fifth since the turn of the twentieth century, thanks to climate change.[1] This decimation of life on the planet is only beginning to accelerate and there is a real danger that humanity will be responsible for the extinction of an untold number of species.

Here is how. Carbon, methane and other GHG emissions released into the air in man's quest to harness energy hang in the atmosphere and encapsulate photons from the sun (instead of letting them simply bounce off the earth's surface and go back into the void of space). This causes temperatures to increase, oceans to warm up, and leads to many types of second-degree climate change phenomena. We will delve into this more in forthcoming chapters.

The science is indisputable. In fact, Exxon, a large hydrocarbon company, admitted in 2019 that in the 1970s its researchers had calculated the greenhouse potency of burning oil and gas. They were also quite accurate in projecting back in 1982 the exact likely increases in average surface temperatures on earth by the turn of the 21st century if oil and gas markets were to expand.[2]

1 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (May 2019), 'Nature's Dangerous Decline "Unprecedented" Species Extinction Rates "Accelerating",' Media Release, IPBES, Bonn, 2019, https://ipbes.net/news/Media-Release-Global-Assessment.

2 Exxon Research and Engineering Company (October), 'Controlling Atmospheric CO_2,' Figure 4, Internal Memo, 1979, (now) ExxonMobil, Irving, Tx.

Despite the research, despite the evidence, and despite the disappearance of many species (being likened to a mass extinction, which have previously occurred only at pivotal turning points in our planet's evolution), our rapacious appetite for energy continues to grow. As millions get pulled out of poverty and move on to the path of development, our quest to harness ever greater amounts of energy might harm our planet irrevocably.

Our hunger for more energy, therefore, needs to be met in fundamentally different ways going forward. The old way seems to have hit a natural cap. Nature is giving us many signals that this is the case, but these signs are disparate, disconnected, non-linear and not necessarily easy to interpret. As a result, at the aggregate level, humanity is not fully conscious of the urgency.

Many among us still oppose the science behind climate change, while many others do acknowledge it but have other priorities such as poverty eradication or faster economic growth for themselves or their countries. And it is hard to oppose them. One may argue, for example, that the United States of America (henceforth, the US) has no business asking low-income, high-growth countries like India and Bangladesh to curb energy use to power their economies, when the US itself has consumed its fair share of fossil fuels to attain high standards of living for its population.

The clear sense that I have is that while policy is extremely important in determining humanity's response to this crisis, market-based solutions will have to do the heavy lifting. And this is where the news is somewhat better. For as we look at the energy markets, and by that I mean the whole ecosystem—from development and generation of energy to its distribution and consumption and all the means by which all of this happens—we see, to paraphrase Sherlock Holmes, that change is afoot.

Energy transitions in the past

From a historical perspective, the first energy transition took place in the eighteenth and early nineteenth centuries, from muscle power to coal. The invention of the steam engine gave England a massive advantage, and led them (and the Europeans soon after) to conquer and colonize far-flung dominions, including India which was quite literally the (Kohinoor) jewel in the colonial crown. Having harnessed new forms of energy, Western European nations used this competitive advantage to dominate more ancient, well-established cultures. In addition to having figured out the use of gunpowder in weaponry (centuries after the Chinese), Europeans also figured out that coal burnt to heat water, creating steam that could be used to power newfangled engines, which in turn could power trains, run pumps, generate electricity and so on. This industrial prowess was far greater than the strength of well-chiselled muscles of humans and animals that the Asian empires, such as that of the Mughals in India, still relied on.

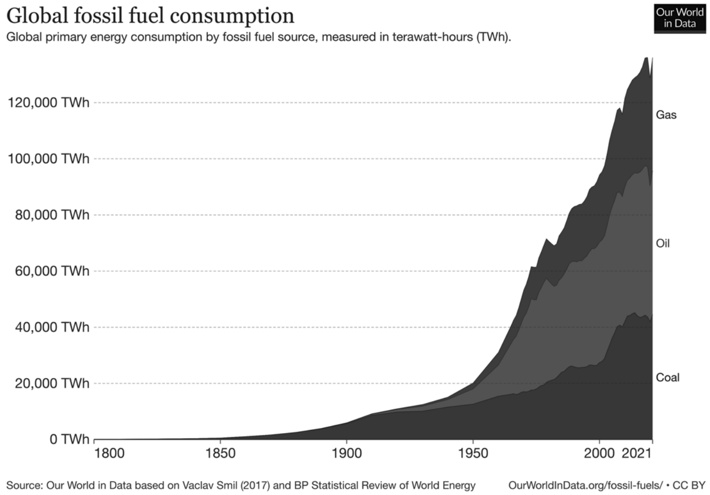
In the late nineteenth and through the twentieth century, a second energy transition manifested following the discovery of the uses of oil—a versatile fuel with properties that allowed it to be used for mobility. It replaced electric cars in the early twentieth century (more on this in the chapter on electric vehicles, Chapter 14), and began to be used for heating homes and offices and to power ships and planes. As the twentieth century marched on, it became the most ubiquitous form of energy. We discuss both these transitions in Chapter 2.

As different uses developed for these fuels (coal and oil), humans started extracting and consuming both with gusto. Man's hunger to go places, the desire for a better standard of living, for heating and cooling, for manufactured products, for comfortable buildings and homes, for the development of industrial applications and so on, led to the explosive growth in the extraction and use of both fuels during the twentieth century. In the search for oil, its marketing and distribution and its pricing, wars have been fought, geo-political rivalries shaped, economies created and destroyed, millions of jobs created and mammoth companies evolved. It wouldn't be out of place to say that the modern world started revolving around oil and its cousin, natural gas.

Interestingly, once it arrived on the scene, oil did not replace coal. The latter remained more widely prevalent, more abundantly available in more countries and, therefore, its trading and its price were never as volatile as were that of oil. Though its importance in energy generation and industrial applications was significant and its growth enormous, coal was just not as politically and militarily prominent as oil. Oil was the face of energy for the excitement it generated, while coal burnt silently in the background.

Measured in terawatt-hours (TWh, a unit of electricity consumption per hour),[3] coal accounts for roughly one-third of all global fossil fuel consumption today. But this was not always the case. For a good part of the nineteenth century, coal completely dominated energy systems. Oil took a large part of the market share starting in the 1950s and by the year 2000 accounted for roughly 50 per cent of the total fossil consumption. Coal came in at 30 per cent, and the balance was consumed in the form of natural gas.[4]

Figure 1: Global fossil fuel consumption[5]



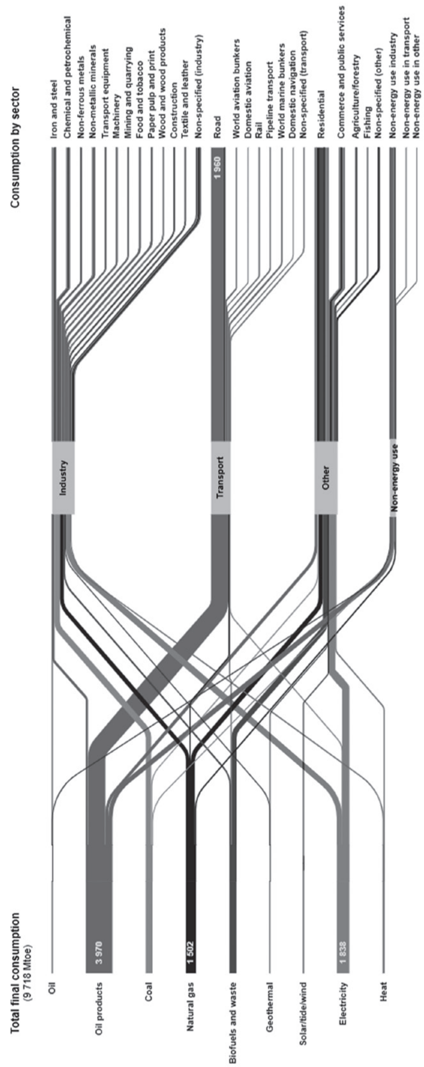
[3] For perspective, a one-ton air conditioner uses one kilowatt-hour (kWh) of electricity every hour, and one billion kWh equal one TWh.

[4] Ritchie, H. and Roser, M. (2022), 'Fossil Fuels', in Our World in Data, University of Oxford, web.

[5] Ibid.

Elements of the imminent transition

Figure 2: Global energy flow (2012)[6]



[6] International Energy Agency (2017), World Energy Final Consumption, IEA, Paris.

Right now, there are two different but important transitions taking place. The first is that electrification is increasing and becoming a larger part of the overall energy mix. Power, or electricity, accounts for approximately a quarter of total energy consumption today. It is used somewhat differently from oil. While oil is transported in its liquid form and consumed by flaring, electricity is carried through large grids that have been built over long distances with wires that go into every home, office, mall, hospital or factory where it is consumed.

More end uses of energy are moving to electricity. Electric vehicles are the most obvious example, such as metros, electric buses, electric cars, and even ships running on large batteries which can be charged through electric wires at ports. As mobility applications shift towards electricity, the share of electricity in the energy mix is on the increase since mobility accounts for almost a third of energy consumption today.

All this, however, would be useless from a clean perspective if we continued to generate electricity in the same old way, i.e. through coal. Today, half of all electricity generation—not to be mixed with fossil fuel consumption in general, which includes oil usage for mobility—comes from coal and another third comes from natural gas.

A 100 kWh of electricity produced through coal emits seventy-four pounds (lb) of carbon dioxide (CO_2), 53–54 lb of CO_2 in the case of oil, 40 lb of CO_2 for natural gas, and on a running basis 0 lb of CO_2 in the case of wind or solar.[7, 8] Therefore, it is imperative that we move to cleaner sources of electricity generation. This is the second energy transition taking place now, and it has just begun. And here the news is good. The growth of cheaper renewable energy sources stands out as the key development that allows us to hope that the future of humanity, in

7 The U.S. Energy Information Administration, 'How much carbon dioxide is produced when different fuels are burned?,' in Frequently Asked Questions, EIA, Washington DC, web.

8 To be sure, wind turbine and solar photovoltaic (PV) manufacturing processes are CO_2 intensive. The way to calculate the lifetime emissions from wind and solar energy is to divide total carbon emissions at the time of manufacturing, by the total number of units of electricity generated through the life of the project. These emissions are negligible by an order of magnitude vis-à-vis coal, oil and natural gas.

terms of our footprint and damage to the planet, will be fundamentally different from the past.

If we can move all our electricity generation to cleaner renewable energy sources, wouldn't that be a great thing? But that is easier said than done, as there are several very serious issues to be considered. We will cover both the opportunities and challenges in later chapters in significant detail, as well as map out new technology breakthroughs on the horizon that will catalyse the energy transition.

This book does not delve into the promise of nuclear power in detail. Nuclear is a clean source of power from a GHG-emissions perspective, but comes with its own set of fundamental challenges, which I see as being difficult to overcome. The construction lead times are often long that, in high interest rate environments, make the economics highly uncompetitive. We have also learned from Chernobyl, Ukraine and Fukushima, Japan that nuclear disasters are inevitable given human fallibility. There are the added risks of nuclear fuel being diverted to military applications, as has been suspected to be the case in Iran. And finally, after the radioactive fuel has been used for nuclear energy generation, its disposal, as has been a long-standing case of not-in-my-backyard political logjam is a major concern. All these factors make the universal growth of nuclear difficult.

Challenges: a glimpse

From an introductory perspective, here are some of the serious issues to consider when thinking about the impending great energy transition.

First, there are large industries that are dependent on the legacy electricity generation sources. The mining of coal, for instance, is a massive industry employing several millions of people. These jobs cannot be simply wished away. In addition, the workers—usually low-skilled and semi-literate—cannot easily be put to work in other industries. There are also jobs in the cleaning and moving of coal, in its trading, and in the operation of coal-fired plants. Over time, these jobs will have to migrate to other industries, and these workers will have to be retrained in growing areas such as wind or solar project construction and maintenance, or other such areas.

Second, massive investments have been made in the existing generation sources and these assets will run for the next twenty-five to thirty years. Equity investors and lenders have funded all these projects and need capital protection and returns on their investments. These investors have been 'locked-in' for a long duration. We have to be mindful that investments in such technologies are made very carefully so that this problem of technology lock-in does not get exacerbated, thus delaying or preventing the move to cheaper, cleaner technologies. Hence, decisions by developing countries such as India should be made keeping a longer time-horizon in mind, rather than focusing on decisions to optimize returns in the shorter term.

Third, the sheer growth that we need in renewable energy capacity is quite daunting. The total installed capacity of all electricity generation globally is approximately 8,000 gigawatt (GW) as of 2021 (IEA), of which renewables are now approaching 3,000 GW, and coal is approximately half or 3,000 GW. Assuming a global demand growth rate of 3 per cent in electricity, we will need approximately 180 GW of new capacity every year to meet that demand. Given the much lower plant-load factors (PLF) of renewable plants (usually a third of conventional plants), we will need three times this capacity in renewables to meet this growth requirement (approximately 500 GW) per year. But currently we are adding only about 150 GW of new renewable capacity every year globally!

At the current global pace, we are not even meeting the demand growth in the power sector through new renewable energy additions. Can you, therefore, imagine the enormity of the task that faces us—replacing the current non-renewable installed capacity of 5,000 GW? Assuming we decide to replace only coal-based plants to begin with, that would still require 3,000 GW equivalent of new renewable energy plants, or normalizing for the lower PLF, approximately 7,500 GW of new renewables capacity.

At the current pace of yearly installations of renewable energy, that would require fifty years of capacity growth. Assuming that new installations (to increase renewable capacity) grow at 10 per cent every year, it would still need nineteen years of capacity growth.

Now accounting for both the 3 per cent electricity demand growth being met through renewable energy, as well as a full replacement of coal, and assuming that renewable energy capacity installations grow at 10 per cent every year, the total time taken would be twenty-six years at least. And during this time, some 15,000 GW of renewable energy would be needed, or almost fifteen times the current total installed capacity of renewable energy globally, and more than two times all the current electricity generating capacity!

To be sure, this is a purely mathematical analysis and will be subject to many changes over time—technology and demand growth chief among them.

The amount of capital needed to set up this huge capacity, the land that will be needed, the grid build-out, the amount of equipment and project execution capacity—all this requires a certain physicality of effort that will throw up enormous challenges over the coming years. For example, our company, ReNew, which currently has 8 GW of commissioned capacity (of which 4 GW is wind and 4 GW is solar), has had to acquire and prepare 24,000 acres of land, construct 2,000 kilometres (km) of mostly rural roads, build 3,500 km of grid lines, and dig two million cubic metres (m^3) of earth. The effort, therefore, cannot be underestimated and could well become a constraining factor for growth in the renewable energy sector.

Fourth, with so much new renewable energy capacity coming on to the grids, intermittency management will become critical. We talk about this in the chapters on the smart grid and storage, Chapters 12 and 13 respectively, in the Indian context. There are ways to address this issue even now, but it needs some degree of policy intervention. The good news in this area is that technology is moving very rapidly and it is inevitable that soon renewable energy plus storage costs will become lower than conventional power costs. Intermittency will then stop being an issue. My estimate, based on everything that I have seen and adding in some of my own extrapolation, is that we will come to that point in a matter of three to five years (2024 to 2026), at most.

Fifth, public policymaking will continue to be critical. As can be seen, there will be many twists and turns in this sector as it unfolds. So far, policies have been supportive and have helped renewable energy get to a point where it is cheaper than conventional power. However, there are many issues around grid management which will still require government intervention to take to a point of maturity. These issues include the continued pressure on buyers of power to consume at least a certain minimum amount in the form of renewable energy, through the renewable purchase obligations (RPO) in India, and in certain other countries; the encouragement of storage or gas peaker plants; the development of ancillary markets; and the evolution of offshore wind.

At the same time, what is to be done with legacy technologies and how to manage their gradual decline and eventual phase-out are going to be other complex issues that policymakers will have to grapple with. In India, managing the health of the distribution sector is also going to be extremely critical.

Sixth, as discussed above, we need massive investment to increase power-generating capacity through renewable energy. Currently, approximately $300 billion is being invested every year globally on renewable energy generation, and this will need to be stepped up substantially and maintained for a considerable period of time. Over the next five to six decades if we have to totally recreate our power generation capacity, we will globally need an investment of around fifty to sixty trillion dollars—almost a trillion dollars every year. India itself will need an investment of more than $30 billion to $50 billion every year for the next ten to twenty years.

These are the investments needed in generation capacity only. Investments needed for grid build-out, storage or ancillary capacities, manufacturing capacities, infrastructure development and so on would be additional to all the above and could easily lead to numbers that are double these. For comparison, the oil and gas industry every year invests about \$500 to \$550 billion of new capital globally.[9]

It is not yet clear where all this capital will come from—would it come mostly from financial investors as we are seeing now, or would the large oil and gas companies, along with incumbent utilities, play a major role? So far, the latter two have not been really big players in this space. But it is inevitable that as oil and gas majors buy into the energy transitions that are in play right now, they will increasingly channel their investments into this area.

Clearly large new companies will also be created, but given that this is a capital-intensive sector, it is those with a ready pool and continued access to capital that will succeed.

Opportunities: a glimpse

Many new jobs will also be created from research and development (R&D), to manufacturing, to project execution and maintenance of assets, to digital experts, resource assessment experts, and site managers to general management. I estimate that most of the job losses in the legacy areas will be replaced by new jobs in the areas of solar energy (including floating solar installations, and rooftop or village-level solar installations), and wind energy (such as offshore wind-turbine farms). But all of this will require considerable re-skilling of manpower and also gut-wrenching changes, as jobs in legacy areas are lost and new jobs spring up in the new areas.

We will also discuss the versatility of renewable energy sources, particularly solar. There are truly many applications of solar energy and its great property is that it is scalable both upwards and downwards without significant changes in costs. Therefore, on a unit basis, a rooftop solar installation of a few kilowatts is only somewhat more expensive

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9 Fawthrop, A. (March), 'Oil and gas capital spending set for a 13-year low as market crisis deepens', *NS Energy*, 2020, https://www.nsenergybusiness.com/features/oil-gas-spending-cuts/

than a utility scale, large installation of hundreds of megawatts. Can you imagine putting up a small coal plant on your rooftop? Clearly not possible! However, setting up a small rooftop installation comprising of even a single solar panel of 300 watts is quite feasible and possible.

Similarly, installations on a farmer's field for powering water pumps, or on top of a dairy to heat water, or a small field to power a telecom tower in a rural area are all possible applications. I am sure that over time, the number of applications will only increase with new uses that we cannot even conceive of right now. Imagine if the windows of your home or car could generate power, store it cheaply for use when needed—you could reduce your dependency on any central supply dramatically. Solar energy, unlike any other source of power generation, truly holds the promise to make power generation universally accessible.

Technology will clearly play a key role in all this. And so will start-ups across the entire ecosystem and value chain. Any of you looking for new careers or new opportunities will find this an interesting sector. Technology will eventually enable us to hold the power of the sun in the palm of our hands, and to harness the force of winds to heat and light our homes. I will cover some of the truly innovative start-ups in Chapter 15.

Technology will also help evolve the storage ecosystem. This is essential if we are to be able to use increasing amounts of renewable energy, which otherwise has to be consumed when it is generated. Storage technologies will be critical in breaking the link between generation and usage and will increase manifold the power of renewables. We cover this in detail in the chapter on storage, Chapter 13.

Electric vehicles (EVs) are an obvious immediate and developing application of batteries. It is not clear to me yet whether EVs will be powered by replaceable batteries or rechargeable ones. If the latter, then will charging stations be at the home, office, in place of the current petrol pumps, or somewhere else entirely? And who will pay for setting up this infrastructure—will it be new companies, petrol pump owners, real estate companies, or somebody else? And will the power used to charge the batteries be allowed to come only from clean sources, or will it be polluting power? If it is the latter, and all it does is to move from one fossil fuel (oil) to another (coal), then what great advantage does an EV give us? And how will the transformation of mobility (to ride-sharing and eventually, to autonomous or driverless cars) impact all the preceding questions?

For me, these are all unanswered questions and surely there are many companies playing in the space, each with its own version of the truth. Who ultimately succeeds, only time will tell. This is an area that truly requires risk capital. There will be many casualties, but those who succeed will definitely need to be there early and will surely do very well.

Final thoughts

The climate conundrum that we face today is quite vexing. As I discuss in Chapter 6, while we need concerted action to deal with this serious issue, at a multilateral level, we seem to be moving away from such action—think of the back and forth that goes on at UN-sponsored climate talks. Indeed, at some points in history, the world has come together and agreed on ambitious, collective climate action as it did in Kyoto, Japan in 1997, and then in Paris, France in 2015. However, at other times—whether in Copenhagen, Denmark in 2009, or more recently in Sharm el-Shaikh in 2022 there has been no clear, ambitious push for climate mitigation.

The US hasn't helped by pulling out of the Kyoto Protocol and the Paris Accord due to the Democrat/Republican political divide that pushes and pulls its political establishment in either direction every few years. This is distressing and ultimately reinforces that we need market-based solutions to compel our politicians to act as needed, or better still, to take the need to act entirely out of their hands and put it in the hands of consumers and the market.

While there are many factors supporting the rapid rise of renewable energy going forward, the reality is that it will not be a straight path upwards. There will be policy missteps, blowback from commodity price volatility that will make fossil fuels cheaper or more expensive at different points of time, companies that are too aggressive and head towards bankruptcy (we have already seen many examples of this), false dawns in technology, and so on. However, I have no doubt that given the size of the opportunity and the need for it, and the scale of the transition that is upon us, we will make progress steadily in the direction of cleaner sources of energy.

Whether this will happen at a pace that meets our climate requirements I cannot say. However, the targets that have been set by countries under the Paris Climate Accord in COP21 clearly do not take us on the right path, and we will definitely need to do more. My belief is that if market-based solutions emerge providing an economic rationale for a certain course of action, then we can expect a higher degree of aggression, and my hope is that such market-based solutions will emerge across many different areas.

A country like India stands at a real inflection point. Our per capita consumption of power is less than a third of the global average. Our consumption of energy is similarly low. Our current power generating capacity is where China was at the turn of the millennium. In the twenty years after that, China has increased its total capacity by five times—an annual growth rate of almost 40 per cent in generating capacity and per capita consumption! Even if India grows at a more sedate pace, we would be looking to double or triple our energy consumption in the next fifteen years. As a result, over the next several years India will be the biggest contributor to energy demand growth globally and, therefore, the choices India makes will be critical to the evolution of the global story.

In this context, it is really heartening to note that Prime Minister Modi has set a significant target for the growth of renewable energy (including large hydropower) from the current installed capacity of 175 GW to 500 GW (by 2030), implying a growth rate of 15 per cent per year. Apart from utility-scale solar and wind plants, there are also plans for offshore wind-turbine farms off the coasts of Gujarat and Tamil Nadu, rooftop solar-panel installations, agricultural use of solar energy by incentivizing farmers, floating solar power plants on the surface of reservoirs, wind-solar hybrids, renewable energy with storage solutions, and the build-out of a base of EVs.

I am an optimist. And I believe that man's journey to the stars has just begun. This journey will continue to be inextricably linked with how well we are able to generate, harness and manipulate energy. Our success and failure as a race will depend on our innovativeness, creativity and ingenuity in solving our energy needs. We cannot at this point imagine the solutions that will doubtless emerge from the innovativeness of the human mind. For 2,000 years our capabilities were limited by horses and whatever we could fashion from other animals and our own physical limitations. The steam engine set us free, and allowed us to embark on greater voyages and journeys, led to more discoveries that unlocked new geographies, and more importantly, set free the human mind and human potential.

The story that we are about to embark on, the future that we need to embrace, the vision that we have to unveil, needs similar epoch-defining discoveries. Energy will be the fulcrum around which the human race will continue to evolve, and we have to find ways of making this journey cleaner, greener and cheaper. Some of the technological solutions are at hand, many more will evolve with time, and we must create the proper enabling environment where such changes can easily be adopted in a commercial and climate-friendly manner.

I do hope that you find the story of energy that follows in the next few chapters—its transition to a new, greener future, its many exciting new opportunities, and all the facets of its impending changes—to be interesting.