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100 Percent Clean, Renewable Energy and Storage for Everything

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Preface

The world is on a path to transition away from fossil fuels to clean, renewable energy in order to address environmental pollution, global warming, and energy insecurity. However, unless such a transition occurs quickly, efficiently, and most everywhere, the world risks substantially increased mortality, warming, and economic instability compared with today. This textbook lays out the scientific, technological, economic, political, and social aspects of how to transition the world rapidly to entirely clean, renewable energy for all purposes.

Evolving out of a course I teach at Stanford University, it includes a description of how to transition the world's current combustion-based energy to 100 percent clean, renewable **wind, water, and solar** (**WWS**) electricity and heat for all energy purposes; how to store electricity, heat, cold, and hydrogen; how to keep the electric power grid stable; and how to address non-energy sources of emissions.

Whereas many textbooks teach about clean, renewable technologies, this one also teaches about what is needed to transition towns, cities, states, provinces, and countries entirely to clean renewables and storage. It also describes how to develop science-based clean, renewable energy plans for cities, states, and countries. These plans have been used to justify 100 percent renewable and zero emission laws and policies, including the Green New Deal, in many countries, states, and cities. They have also been used to justify 100 percent renewable commitments by many international companies. The textbook further discusses the history of the 100 Percent Movement, which evolved from a collaboration among scientists, cultural leaders, businesspeople, and community leaders. Finally, it discusses progress to date in transitioning to 100 percent WWS and policies needed to complete the transition.

Motivation for transitioning

This book is motivated by the fact that air pollution, global warming, and energy security are three of the most significant problems facing the world today. Most scientists recognize that solutions to these problems must be implemented rapidly. Every year that indoor and outdoor air pollution continues, 4 to 9 million more children and adults die from it. If at least 80 percent of emissions that cause global warming are not eliminated by 2030, and if 100 percent are not eliminated by 2050 or sooner, globally averaged temperatures will likely rise at least 1.5 ^{o}C above those in the early 1900s. This will likely trigger more glacier and sea-ice melting, sea level rise, coastal flooding, severe storminess, wildfires, air pollution mortality, heat-related mortality, drought, famine, agricultural shifts, climate migration, species extinction, coral reef damage, and more. In addition, if limited-resource fossil fuels are not replaced with sustainable clean, renewable energy, energy prices will probably rise dramatically, causing economic, social, and political instability worldwide.

The solution to these problems is to transition world energy in all energy sectors to 100 percent WWS electricity and heat, combined with storage, and to address non-energy sources of emissions.

The main idea behind the solution comes from the fact that air pollution health and climate problems result from the same source: combustion. That is, combustion of fossil fuels, biofuels, bioenergy, and open biomass. To solve the problems, it is necessary to move away from combustion by electrifying and providing direct heat without combustion. For the electricity and heat to remain clean and available for millennia to come while not creating other risks, they need to originate from clean, renewable and sustainable sources, namely WWS.

WWS includes energy from **wind** (onshore wind, offshore wind, and airborne wind electricity), **water** (hydro, tidal and ocean current, wave, and geothermal electricity and geothermal heat), and **sunlight** [solar photovoltaic (PV) electricity, concentrated solar power (CSP) electricity and heat, and captured solar heat (solar thermal)]. WWS needs to power **all energy sectors**, which means electricity, transportation, building heating/cooling, industry, agriculture/forestry/fishing, and the military. Whereas human-designed energy systems cause about 95 percent of **anthropogenic** (human-produced) air pollution and 75 percent of anthropogenic greenhouse gas emissions, this book also discusses methods to address non-energy anthropogenic emissions that affect air pollution and climate. The book also describes technologies available for electricity, heat, cold, and hydrogen storage.

Many solutions to date that have focused on the climate problem have included some technologies that are less helpful than WWS technologies. This book describes such technologies. The reason they are less helpful is that they raise costs to consumers and society, slow solutions to pollution and warming due to their long planning-to-operation times, increase emissions relative to WWS sources, and/or create risks that WWS sources don't have. Given the limited time and funding to solve pollution, climate, and security problems, it is essential to focus on known, effective solutions. Money spent on less-useful options will permit more damage to occur.

Some technologies that are clean and renewable are not discussed here because it seems they will not be commercially available in the next decade. One example is a technology that takes advantage of salinity and temperature gradients in the ocean to generate electricity. If such a technology does come to fruition, it could be included as a WWS resource.

Why 100 percent clean, renewable energy and storage for everything? Why not 50 percent, 80 percent, or 99 percent. The first reason is that the health plus climate cost of every tonne of air pollution, down to the last tonne, is so enormous that it outweighs other uses of the money required to remove the pollution. More importantly, one more person should not die or become ill from air pollution. Species extinction, global-warming-driven wildfires, supercharged hurricanes, and smog should no longer occur. Gas wells, coal mines, oil pipelines, gas stations, coal-fired power plants, gas storage reservoirs, diesel cars, jet fuel airplanes, and bunker fuel ships should no longer be needed. Nuclear power plant meltdowns and nuclear waste pileups should no longer occur. We don't want to drink chemicals in our water due to oil, gas, coal, or uranium mining leaks. We don't want to see more wars over fossil fuels. We don't want any more oil spills devastating the oceans, lakes, or rivers. Blackouts due to reliance on centralized power plants should be a thing of the past. Plus, we want to eliminate high energy prices that arise from fuel shortages and the need to transport fossil fuels long distances.

Aside from the fact that it is technically and economically possible to transition everything to 100 percent clean, renewable energy and storage, 99 percent is not an ambitious goal to shoot for. Did Magellan aspire to circumnavigate 99 percent of his way around the Earth? Did the Apollo 11 crew aspire to reach 99 percent of its way to the moon? No. 100 percent is the goal because that may be the best society can do and may result in the cleanest air and most stable climate for future generations. Societies often strive for the best and safest.

Can society reach the goal of 100 percent? This book examines the science, engineering, economic, social, and political aspects of transitioning towns, cities, states, countries, businesses, and the world to 100 percent clean, renewable WWS energy and storage for everything. Such a transition will address air pollution, global warming, and energy security simultaneously. The book also examines ways to reduce major types of non-energy emissions. It concludes that a transition among all energy and non-energy sectors worldwide is technically and economically possible. The main obstacles are social and political.

Intended audience, level, and scope

This book is written to be accessible to everyone concerned with renewable energy and storage, including those studying Renewable Energy, Sustainability, Environmental Sciences and Engineering, Earth Sciences, Climate Sciences, Atmospheric Sciences, Electrical Engineering, Mechanical Engineering, Geography, Health Sciences, Economics, Business, and Policy departments as well as researchers, professionals, policymakers, advocates, and interested readers in many areas.

The book assumes no prior knowledge of yet provides needed information about energy systems, electromagnetism, thermodynamics, dynamical meteorology, radiation transfer, mechanical engineering, aerodynamics, economics, weather, climate, and air pollution sufficiently for readers to understand how wind turbines, solar photovoltaics, concentrated solar power systems, hydropower systems, pumped hydropower storage systems, batteries, flywheels, gravitational mass electricity storage, underground thermal energy storage systems, thermal mass storage in buildings, generators, hydrogen fuel cells, heat pumps, electric vehicles, hydrogen fuel cell vehicles, arc furnaces, induction furnaces, resistance furnaces, dielectric heaters, and transmission/distribution systems work.

The book also gives information about how to determine wind and solar resources, the maximum wind and solar potentials of the world, the impacts of wind turbines on global temperatures and hurricanes, the effects of tilting and tracking solar panels on electricity output, the efficiencies of wind turbines and solar photovoltaics, and rates at which different electricity storage technologies can ramp up.

By the end of the book, readers will understand why all the technologies covered throughout the book will help to solve the air pollution, climate, and energy security problems we face and why other technologies are not so useful.

Readers will be able to calculate the private (business) and economic (social) costs of energy technologies and of energy systems. They will understand the methods of matching electricity, heat, cold, and hydrogen demand with clean, renewable supply and storage over time at low cost. Finally, they will understand the origin of the 100 percent clean, renewable energy movement, the progress made to date in transitioning the world to 100 percent, and the policies needed to complete the transition.

Structure

The book is structured in the order that I teach the material in a course. It starts by defining the air pollution, global warming, and energy insecurity problems we seek to solve (Chapter 1). Chapter 2 discusses WWS electricity and heat generating technologies; transportation technologies; building heating and cooling technologies, high-temperature industrial heat technologies; and appliances and machines needed for a transition. It further discusses energy efficiency measures, electricity storage, heat and cold storage, and hydrogen storage. Finally, it discusses methods of addressing non-energy sources of greenhouse gas and aerosol particle pollution. Chapter 3 goes into depth about why we don't need natural gas as a bridge fuel, fossil fuels with carbon capture, nuclear power, biomass (with or without carbon capture), biofuels, synthetic direct air capture, or geoengineering.

Because a 100 percent WWS world is mostly electrified, Chapter 4 focuses on electricity basics. Because solar photovoltaics (PV) and wind power will likely comprise the largest share of energy generation in a WWS world, Chapter 5 discusses solar PV and solar radiation, and Chapter 6 discusses onshore and offshore wind. Chapter 7 moves on to discuss steps in developing a 100 percent WWS roadmap for a country, state, or city. Chapter 8 explains how to match power demand with 100 percent WWS supply plus storage.

Finally, Chapter 9 outlines my personal journey toward 100 percent; the 100 Percent Movement that has arisen around the WWS roadmaps; laws and commitments that have been implemented to date due to them; and the policies needed in the future to finally solve the problems of air pollution, global warming, and energy security.

Pedagogical features

The book is supported by a comprehensive set of pedagogical features:

- An introduction and end of chapter summary to clarify each chapter's objectives and to ensure understanding of the material discussed
- Highlighted key terms and clear definitions throughout the book
- Numerical examples in each chapter that explain how to apply important equations
- Abundant tables, diagram and photographs that illustrate important and interesting aspects of the field
- Problems and exercises at the end of each chapter that consolidate and extend student understanding
- A list of recommended readings in the further resources section at the end of each chapter
- A glossary of acronyms and a list of conversion constants and units in the appendices

In order to assist with teaching information in the textbook, teaching materials have been developed to accompany the course and are available online. Such materials include a teaching guide, a model syllabus, lecture slides for each chapter, a solution manual, and a test bank.

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Appendix

References