PART I

Introduction

1 *You get what you ask for*

There is nothing either good or bad, but thinking makes it so.

William Shakespeare, *Hamlet*

Energy is full of paradox. Depending on the mix of resources used to generate power where you live, driving an "environmentally friendly" electric vehicle can increase carbon emissions relative to an equivalent petroleum-fueled mode of conveyance (Doucette and McCullough, 2011). Even if solar energy were ubiquitous, we would still require coal in the modern economy. Energy efficiency improvements do not reduce overall demand for energy products. Effectively reasoning about energy, despite numerous similar paradoxes and competing factors, is the primary function for this book.

A friend in the coal industry, with experience in pit mining, recently lamented about how much the environmental costs of energy extraction and the residual scarring on the landscape bothered him. At the same time, he quipped that "As long as people keep buying coal, I'll keep digging it up." People certainly do not keep lumps of coal sitting at home. Yet virtually all of humanity is dependent on coal in some form because of its role in electricity generation and in the process of steel-making.

Making good decisions about energy—despite these kinds of counterintuitive facts—requires context. Our modern society uses vast amounts of energy, even when compared to human civilization only a few generations ago. Our energy infrastructures are oft forgotten but are foundational elements of our society which are completely approachable if explored from the right perspective. Energy consumption is a part of everyday living, but energy issues are mistakenly treated as too complex or arcane to be considered by decision-makers in business or policy. Nothing could be further from the truth.

The networks which feed society's growing thirst for energy developed specific technologies and grew into their particular structure for specific historical reasons. Often, these reasons have more to do with the demand for energy—specifically the way in which we consume energy to do useful work—than with any particular attribute of how we locate, extract, transport, and transform the energy products being consumed. This book is structured as an explanation about *why* we consume energy to better understand *how* we supply it today and the implications for our collective future.

1.1 The energy we buy

So what exactly is the *energy* that we buy? What is this product that silently supports our entire economy and society? What form does our energy come in? What would happen if this product were interrupted or no longer available? What are the underlying services that the product enables? How can we start to determine ways to transition to a more sustainable energy future? Will the solution require a single replacement or a mix of many resources that balance the needs of the economy, society, and the environment?

Like virtually any other modern product or service, energy comes in many forms: electric energy, petroleum energy, solar energy, etc. Often, differing forms can deliver the same benefits, such as gasoline-powered vehicles or battery-powered vehicles. But sometimes only one form of energy is suitable for a particular task, such as using electric energy to charge a laptop. In many cases, one form has a competitive advantage over another based on the type of energy needed to do useful work. An example is using a natural gas boiler to run a central heating plant with electricity co-generation to heat and power maximally efficient commercial buildings.

Regardless of the form of energy selected for individual tasks, energy runs our society. The "energy problem" is not an isolated issue whose solution resides in an engineering or process optimization book. Rather, energy is a central component of modern issues on a global scale, including poverty, national security, health, commerce, and the environment. Energy underpins the creation and delivery of nearly all modern benefits to society. It feeds the processes that we deem necessary, as most visibly expressed by our wallets.

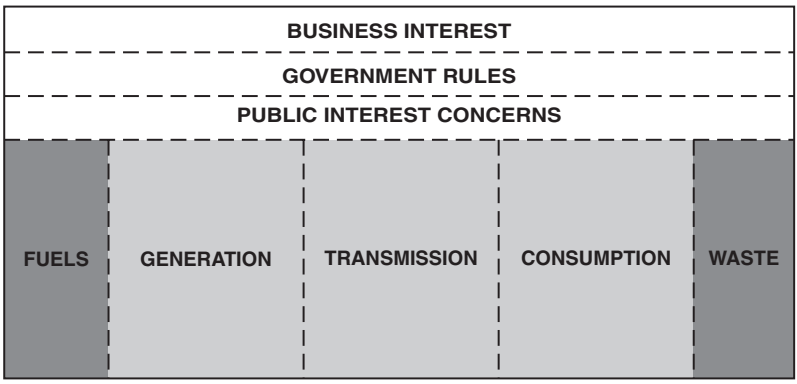

Figure 1.1 Major energy silos

1.2 A few guiding principles

Energy is more than just a supply and fuel source problem or an energy efficiency and consumption problem. The energy supply chain, from fuels to waste, is shown in Figure 1.1. Intersecting each of these silos are business interests, government rules, and public interest concerns. To truly understand and act on energy issues, one needs to understand the interactions between these foundational components of energy as an economic system which has significant overlap with the responsibilities of sovereign states. Figure 1.1 also shows a conceptual framework that depicts the major silos of the energy industry. The bottom silos in gray represent the infrastructure and supply chain. The top silos in white represent societal interaction with the infrastructure.

A few key points about energy help ground our exploration:

1. Energy itself is always conserved. Energy cannot be created or destroyed, but it can be transformed from one form to another to meet our specific needs. Each transformation incurs a loss in useful energy.[1] Generally speaking, the more times we convert forms of energy, the larger the losses.
2. Energy must always be in balance; what goes in must come out. Too frequently, the conversation about sustainable energy revolves exclusively around generation issues, such as promoting wind or

[1] Losses of *useful* energy can also be expressed as an increase in entropy, which is discussed in more detail later in the book.

protesting coal. Although these kinds of individual issue are an important part of the equation, they are only a small part of the bigger picture. We need to consider how to balance sustainable generation with rational consumption over the whole system.

3. Useful energy is foundational to society. At a basic level, useful energy from the sun is transformed into the food which we consume to survive. Beyond these needs, excess energy enables societal development and the emergence of specialized skills and services. Businesses generate revenue by consuming energy to do useful work. Governments consume energy to secure their resources, territory, and populations. Individuals consume energy to better enjoy their lives in increasingly controlled environments which provide light and thermal comfort, and are populated with a myriad of energy-consuming devices to enhance recreation and productivity. Each of these activities is enabled by society's growing ability to harness more useful energy.

1.3 Features versus benefits

Society buys energy for one simple reason: we value energy outcomes. We value the heat, light, or mobility that energy provides when transformed for our end uses. These outcomes, which are really aspects of consumer benefits, ultimately drive energy supply and infrastructure decisions. As a result, to truly understand key facets of today's energy issues, we must begin with an evaluation of end uses and work back towards the underlying infrastructure and resources available. Throughout the book, we will continually tie decisions and examples from each considered industry vertical back to the specific transformations that allow it to meet customers' demands.

Too much focus is often given to energy *features* without adequate attention to energy *benefits*. Energy features include topics such as fossil fuels, renewables, carbon sinks, or heat reclamation. These types of properties refer almost entirely to the energy sources we consume. Energy benefits are the services and outcomes we enjoy, ranging from an international cruise to a video call with family to modern refrigeration and food delivery networks.

As anyone with experience in sales knows, benefits sell products. Product benefits are usually driven by quantifiable demand. Benefits, not features, are ultimately what drive most consumers to open

their wallets. Product features describe product attributes that may influence a decision but rarely close a deal. This holds true for the energy sector as well. Societal demands for energy in previous generations shaped the current system and drove the construction of our existing infrastructure. However, the problems that we faced in the late 1800s are different than the problems of today or those likely to manifest in the future. Just like law, regulations, and most other human endeavors, energy infrastructure and delivery systems lag behind what is technologically feasible.

Our energy infrastructure—physical, financial, regulatory, political, and others—is very good at solving many problems from a century ago. For most industrial powers, this meant providing low-cost electricity to the largest number of people. As our society has evolved since, our requirements have shifted substantially. Today's society has a greater need for reliability, security, resilience, and sustainability in its energy strategy. Cost is still dominant, but other factors have grown substantially in importance. These ongoing shifts in demand will dictate much about how energy infrastructure will continue to evolve. By understanding why we consume energy, we can better understand where both energy products and services are likely to be headed.

This book emphasizes priorities and problem formulations to reframe much of the existing energy debate around possible actions. It eschews a focus on tradeoffs, which give readers binary solutions to complex problems, and embraces decision matrices to help provide a more nuanced decision-making tool to align actions with priorities. It explores interactions between siloed industry sectors. Because the discussion revolves around the core value proposition of energy consumption—doing useful work—readers can re-examine real-world technologies and services based on energy outcomes.

1.4 Where we are headed

The rest of the book is on society and the demands we place on energy. It explores the questions of "What are we buying?" and "Can we procure the same benefit while consuming less energy?" We make powerful contributions to energy policy and strategy each day by voting with our wallets. By internalizing energy outcome-focused thinking into everyday business decisions, we can become more conscious consumers who are equipped with the proper tools and

vocabulary. We can also better manage energy-related risks for our families, our organizations and communities, and our world by seeking a mix of efficiency and resilience.

A significant portion of the book is dedicated to electric energy infrastructure, as it is the most prolific and easily recognizable energy infrastructure in developed nations. However, many of the concepts applied to electric power systems are applicable to other energy infrastructures. The fundamental problem of delivering reliable energy services across a large, complex, physically constrained system is generic. Participation from numerous stakeholders with competing constraints and objectives requires a mix of economic and regulatory incentives to balance individual, organizational, and public goods under a wide range of environmental conditions. Although vocabulary does differ across verticals, the detailed examples used introduce many of the concepts required to support broader reading and study into specific kinds of energy systems or technologies.

The rest of this book looks at demand through a number of lenses:

- Part II examines historical demands to explain how the energy system evolved into what it is today. We use three frameworks to analyze energy consumption—energy balances, the energy supply chain, and the *wicked problem*. Wicked problems have no defined solution and typically involve multiple stakeholders with competing priorities or desired outcomes. We also define the six different silos introduced in Figure 1.1 and examine their intersections and how they influence each other.
- Part III explores critical demands facing energy infrastructure today. We apply the three previously introduced frameworks to decisions that managers face in five different energy infrastructures: electricity, transportation, waste, steam, and cyberspace. The cases and stories focus on how energy decisions can be catalysts, influencing and affecting stakeholders across large swaths of society.
- Part IV introduces changing demands to energy infrastructures as transactive systems and introduces complex adaptive system concepts as an important part of effectively managing future energy systems. We also investigate key attributes of energy risk management, infrastructure resilience to meet societal demands, and the movement towards energy-as-a-service. This section employs a mix of historic and recent case studies to illustrate key commonalities

with proven approaches managing critical energy delivery systems while simultaneously demonstrating that new requirements require procedural and technological innovation.
- Part V puts energy demand into a broader context via a targeted exploration of energy's role in the evolution of human civilization. An exploration of humankind's ability to harness ever more energy begins by tracing the evolution of energy and metallurgy through the Stone, Bronze, and Iron Ages. This exploration of energy's role in transforming our society underscores the importance of making educated energy decisions to meet our economic needs and societal values.

As we explore the energy issues, please keep in mind the entire supply chain from fuel through waste. Acknowledging the end-to-end requirements, costs, and constraints is often required to understand societal decisions about energy. Often, critical but sometimes non-obvious issues have significant influence over how we build the supply chain that ultimately delivers energy when, where, and in the form it is needed. The numerous interdependencies between these energy silos also means that seemingly simple changes can have ripple effects—both beneficial and detrimental—throughout the entire system. It is not uncommon for individual or groups of silos to advocate for opposing goals that sometimes impede the implementation of particular solutions.

1.5 Chapter 1 Summary

- This book explores the question "Why did our energy requirements result in the development of today's energy infrastructure systems?" Understanding the reasons behind the evolution of this large system is the first step in understanding potential ways forward. The efficacy of future changes depends on the understanding of end-use requirements and which products or services have direct substitutes or replacements.
- Infrastructure and supply-chain issues account for the physical nature of the energy system. Often, these components have engineer-optimized solutions that do not reflect the context of larger societal choices and values that become controlling.

- Societal issues arise between businesses, governments, and public advocacy groups as they interact with the infrastructure.
- A change made in any one energy silo will have ripple effects across the entire system. The effects—both good and bad—of changes across silos are not uniform.