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Technical Learning Needs for Today's Energy Professional

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Abstract

Energy professionals in the U.S. and Canada are increasingly tasked with the challenge to help transition to energy systems which deliver desired services, while reducing impacts, improving affordability, and supporting a myriad of societal goals such as stable employment. This article argues for specific technical learning needs to enable professionals to help fulfill this challenge. First and foremost, professionals are encouraged to embrace a systems approach to analysis, design, operation, and maintenance of energy systems. Critical technical learning needs include basic analytical skills in thermal, fluid, and electric systems, and a set of energy-specific concepts including supply-demand interactions, embedded energy, embodied energy, active-passive design, power density, and scale.

Key words: energy systems, professional training, energy transitions, energy management.

It is widely accepted that cleaner yet affordable energy supplies are critical to achieve common societal goals such as improved public health and low unemployment rates, while maintaining the integrity of earth's ecosystems [1]. Many professions and disciplines play a role in achieving these goals. In this article I attempt to answer this question: what are the key technical learning needs (concepts, skills, models) for today's energy professional? I attempt to answer this question while focusing on the U.S. and Canada. First I define who is included as an "energy professional," then briefly overview the critical problems to be solved. Next I argue that all energy professionals should embrace a systems perspective, and then present the critical technical concepts to be learned.

By "energy professional" I am referring to individuals trained in engineering, science, architecture, planning and related disciplines. These are the individuals who provide key roles in the design, maintenance, operation, maintenance and retrofit of energy systems for a wide range of applications such as buildings, urban infrastructure, vehicles, and industrial plants. Some common job titles are *energy manager*, *energy engineer, consultant, planner, designer,* and *technologist* – to name a few.

In this article I focus on the direct technical issues inherent in energy systems design and analysis. The scope is on the physical elements of energy systems that deliver energy services. Some noteworthy limitations of the scope are addressing learning needs in environmental sciences (including air, land, and water cycles), biological sciences (essential for understanding biofuel-based systems), social sciences (including applied economics and behavior change [2]), health sciences (such as epidemiology), and policy sciences (including a wide range of qualitative and quantitative concepts and skills).

When thinking about energy and society today, climate change is typically at the top of the list of problems to solve. The most complete, clear, and concise summary of the technical and policy solutions to climate change that I know of was published in the U.S. Proceedings of the National Academy of Sciences [3]. The author, Granger Morgan of Carnegie Mellon, lays out the solutions needed to stabilize earth's climate in a three-page expert opinion piece.

With few exceptions, all climate solutions revolve around the conversion and utilization of energy. The challenge is massive and there is no singular solution. Urgent action is needed to increase the efficiency of conversion, reduce the greenhouse gas intensity of supply (through renewables, nuclear, and carbon capture), reduce end-use consumption, and extract carbon from the atmosphere. Dr. Morgan accurately makes the blunt statement that solving the problem requires "… a portfolio of everything we've got."

The problems to solve will vary by location. Because I am focussing on the U.S. and Canada, it is critical to emphasize that these two countries have one thing in common: they are amongst the highest per-capita consumers of energy globally. What is not unique is their level of economic success and quality of life. To illustrate by example, the chart in Figure 1 shows final energy per capita and employment for a sampling of countries, ranked from lowest to highest energy consumption [4, 5, 6]. Figure 1 provides evidence that employment rates are relatively high for Americans and Canadians, but overall no better than many other countries. Yet their energy consumption is an outlier, ranging up to double final energy consumed as compared to many European and Oceanic countries. Similar conclusions are drawn when looking at statistics for life satisfaction, gross domestic product, leisure time, and other quality of life metrics; the U.S. and Canada perform well, but they do not excel. What they do "excel" in is having the highest per capita energy consumption. While it is true that some countries (particularly countries with low average income) face the challenge of increasing the supply of reliable, low-polluting energy carriers to their citizens to improve their quality of life, Americans and Canadians clearly need to reduce their consumption.

I have briefly described the key challenges for today's energy professional. In short, our societies are in need to transition to energy systems which allow earth's climate to stabilize (as well as mitigating many other impacts not mentioned), while delivering energy services which support societal goals [1]. For energy professionals to effectively contribute to solutions for these challenging problems, the starting point is to understand that earth's ecosystems have natural stocks and flows of energy, and that our anthropogenic systems are constructed within these natural systems. The key word here is *systems*.

Figure 2 and Table 1 provide a model to understand and assess the physical attributes of all anthropogenic energy systems [7]. The model illustrates how energy systems are essentially a linked chain that begins by extracting or capturing some energy resource from earth's ecosystem, converts this energy into different forms (or carriers), and ultimately delivers a service. It is comprised of six building blocks and three connectors.

As depicted in Figure 2, it is useful to think of energy systems in terms of a *supply side* (or energy sector) and a *demand side* (or service sector). There is almost always a mismatch between demand and supply in both space and time. *Spatial mismatches* create the need for connectors (transport, transmission, distribution) to link energy supply systems with end-use technologies. *Temporal mismatches* create the need for energy storage at one or more points in the system. In modelling real energy systems, it is important to understand they can seldom be represented as a single linear chain as illustrated in Figure 2. Real systems are usually more accurately represented as a complex web made of multiple chains of elements, particularly modern systems commonly found in high-income contexts. Likewise, some simple energy systems lack elements described in the model (e.g. biomass energy use for cooking in some low-income countries has no transmission system).

The model in Figure 2 also conveys simple, but important technical terminology. Energy professionals should understand the concepts and conversions of primary energy (that is usually, but not always, counting energy input to transformer technology), secondary energy (typically defined as energy carriers not counted as primary), final energy (typically energy that is metered and sold to end users), and useful energy (the form most directly linked to the provision of service).

Finally, the same model in Figure 2 can aid in examining energy systems from perspectives other than physical attributes. These other perspectives include (but are not limited to) benefits, impacts, and economics. Every building block and connector can be analyzed for the benefits it provides (like jobs), the impacts it imposes (like environmental risks), and the economics involved (like government royalties or price elasticities). The model can also be used as a tool to help frame and understand the history of energy resources, conversions, and uses which have formed societal transitions [1]. It is beyond the scope of this article to delve into these other perspectives. But energy professionals will be more effective and well-rounded by recognizing that energy systems are important for more than just technical performance.

There are several basic technical concepts and skills related to energy which, I argue, all energy professionals should learn. Professionals should study the basics of thermodynamics (first and second laws), heat transfer (conduction, convection, radiation), fluid mechanics (particularly Bernoulli's theory with losses), and electric power fundamentals (inductive systems, real power, apparent power). All professionals do not need to understand the derivation of the applicable physical laws or be expert system designers, but they should develop the skills to utilize the simplest analytical relations for thermal, fluid, and electric energy systems analyses.

The combination of the systems model and basic technical concepts forms the basis for understanding more complex concepts and skills related to energy systems analysis. These include: *interactions of supply and demand* (e.g. to assess how to power a home 8,760 hours annually from solar energy), *embedded energy* (the energy locked up in materials [8]), and *embodied energy* (the energy consumed to produce a product or service). *Active and passive* approaches to energy system design represent another critical skill; a common example is the design and analysis of buildings, where active equipment (e.g. forced air heating, lighting) works together with passive elements (e.g. glazing, insulation). *Power* density [9] and the *scale* [1] of energy flows are additional fundamental concepts which should be understood to some degree.

In practice, energy professionals usually specialize in one aspect of energy systems. There is an endless list of specializations such as: solar hot water design, transportation planning, electric transmission system maintenance, electric battery design, building energy auditing, steam system operation, and so on. Specialization is powerful and enables professionals to excel in their area of expertise. At the same time, I advocate that all energy professionals understand the systems model and a basic set of fundamental concepts and skills which are common to all current and future energy systems. No matter what resources, carriers, or conversion technologies win in future markets, effective application of technical basis (e.g. laws of thermodynamics), more complex concepts (e.g. power density), and the systems model presented in this article will be essential to increase the likelihood that energy systems evolve to solve today's critical problems.

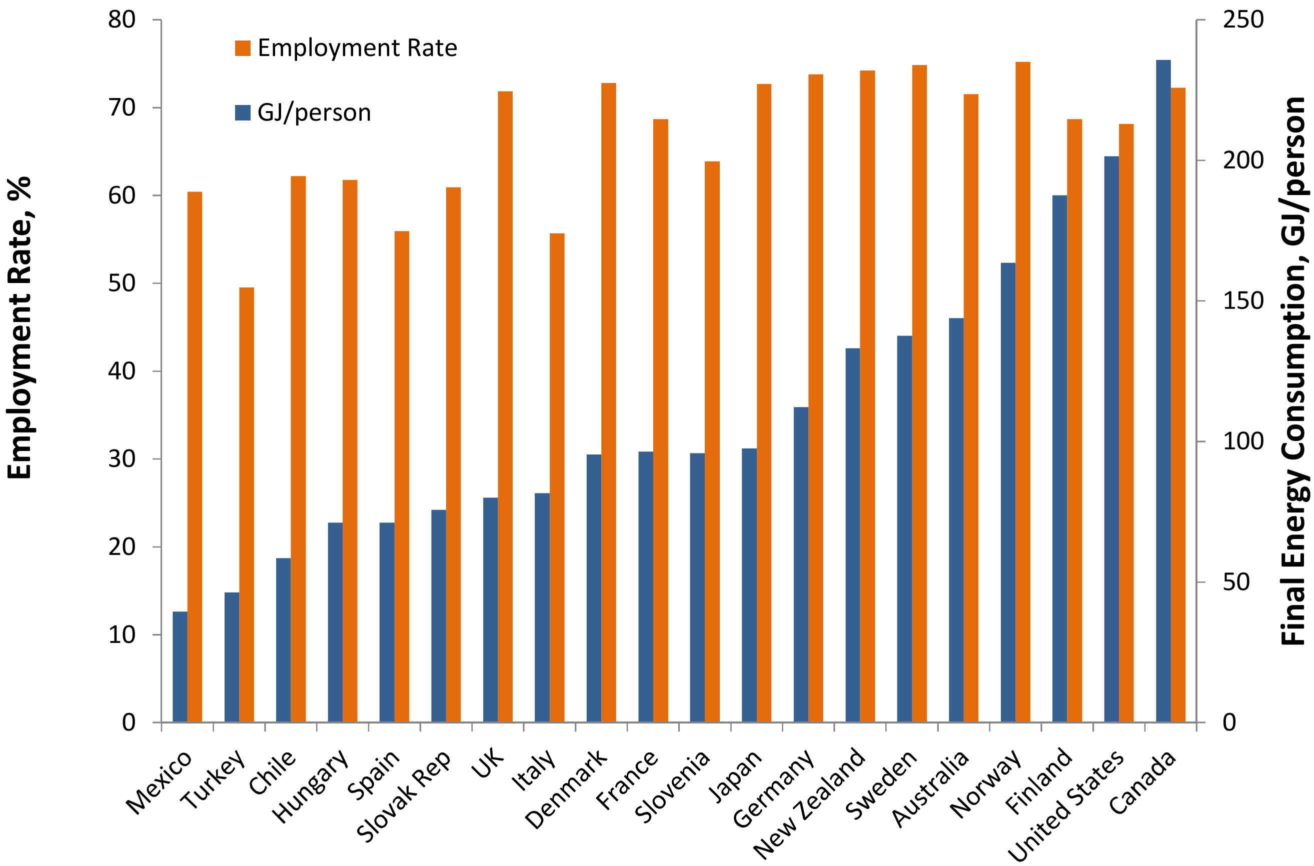

Figure 1: Employment Rate versus Per Capita Final Energy [4, 5, 6]

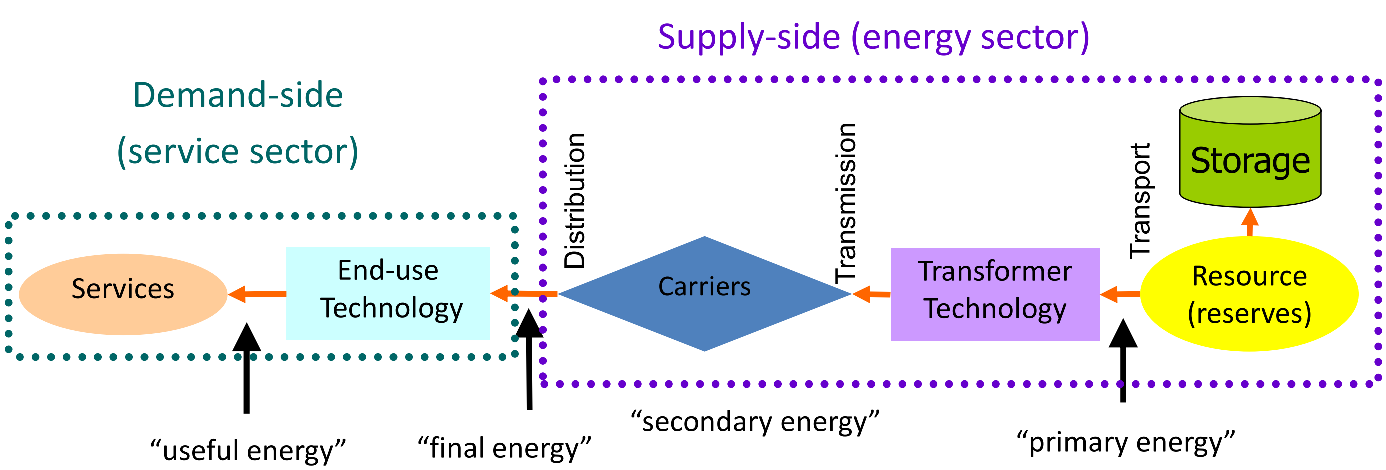

Figure 2: Simplified Model of Anthropogenic Energy Systems

Table 1: The six building blocks and three connectors model of anthropogenic energy systems.

Element Type	Element	Description	Examples
Building Block	Energy Services	Desired products and services that require consumption of energy carriers. Global energy services fit into eight categories [7]	Cooked food, steel beam, thermal comfort, communication
	End-use technology	Converts energy carrier into a desired service. Also known as service technology	Gas stove, arc furnace, smart phone, automobile
	Energy Carriers	Forms of energy as a natural resource or transformed into alternate forms.	Electricity, wood pellets, hydrogen, sweet natural gas
	Transformer Technology	Supply-side converter of energy from one form to another	Nuclear power station, petroleum refinery, gas sweetening plant
	Storage	Energy in a static or stable state that can be held for periods of time, and withdrawn to help match supply and demand	Hydroelectric reservoir, natural gas in a salt cavern, electric energy in a battery
	Resources	Energy forms stored or moving through earth's ecosystems	Uranium ore, solar radiation, biomass, raw coal, wind
Connector	Transport systems	Systems to move solid, liquid, or gaseous carriers over short or long distances. Usually ships, trains, or trucks.	Super-tanker carrying oil, train moving raw coal, truck hauling wood chips
	Transmission	Infrastructure to move energy carriers at high pressure or voltage, typically longer distances.	High voltage cables, high pressure natural gas pipelines
	Distribution	Infrastructure to transport carriers at low pressure or voltage, typically shorter distances	Low-voltage cables, district energy hot water piping

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Biography. Eric Mazzi is a mechanical engineer and policy professional, with 30 years of experience in professional practice and academia. He is the principal of Mazzi Consulting Services, and an Adjunct Professor at the New York Institute of Technology in the M.S. Energy Management program.