Thermal Load Demand in the U.S.

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Advances in Direct-Use Workshop
Matching Low-Temperature Geothermal Resources to End-Use Demand
March 18th, 2015

Cornell University
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Cornell's research on low-temperature geothermal energy characterization and utilization

Thermal energy spectrum in the U.S.

Integrated use of geothermal energy & biomass for the Cornell University campus

Profitability of direct-use: The economics of direct-use geothermal systems - GEOPHIRES

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1968 Low-Temperature Heat Demand in the U.S.

TID-4500 Distribution, UC-13
Nonnuclear Energy Sources and
Energy Conversion Devices

LAWRENCE LIVERMORE LABORATORY
University of California/Livermore, California/94550

UCRL-51747

ANALYSIS OF POTENTIAL NONELECTRICAL APPLICATIONS OF GEOTHERMAL ENERGY AND THEIR PLACE IN THE NATIONAL ECONOMY

Gordon M. Reistad

MS. date: February 14, 1975

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MASTER

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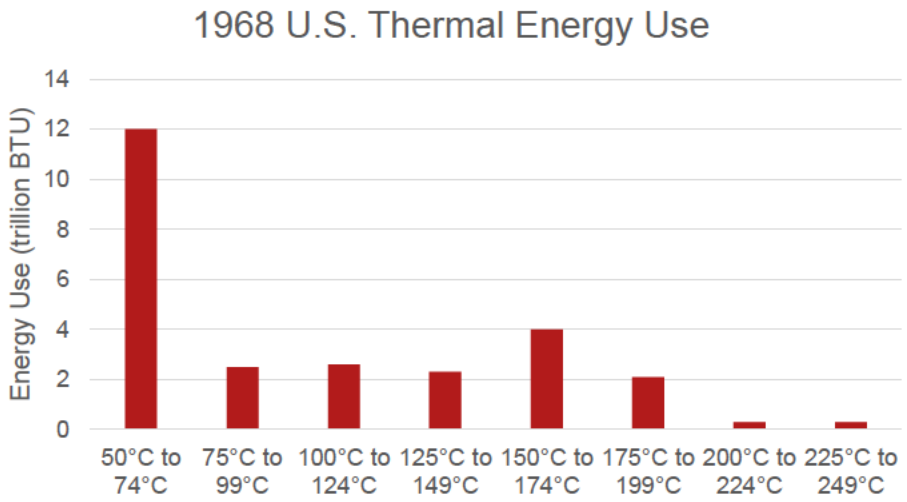
"Much of the current interest in geothermal energy is directed toward its use in electricity generation. However, potential nonelectrical applications for this energy resource should also be considered."



Reistad, G. M. Analysis of potential nonelectrical applications of geothermal energy and their place in the national economy. No. UCRL-51747. California Univ., Livermore (USA). Lawrence Livermore Lab., 1975.

→ 28% of U.S. primary energy demand consumed as heat below 120ºC

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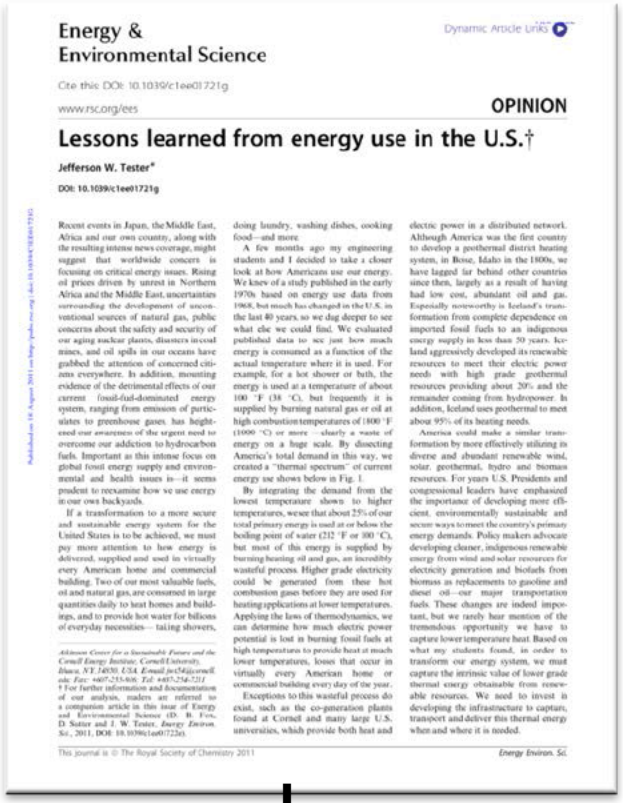
2008 Thermal Spectrum of Low-Temperature Energy Use in the U.S.



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OPINION

Lessons learned from energy use in the U.S.†

Jefferson W. Tester*

DOI: 10.1039/c1ee01721g

Recent events in Japan, the Middle East, Africa and our own country, along with the resulting intense news coverage, might suggest that worldwide concern is focusing on critical energy issues. Rising oil prices driven by unrest in Northern Africa and the Middle East, uncertainties surrounding the development of unconventional sources of natural gas, public concerns about the safety and security of our aging nuclear plants, disasters in coal mines, and oil spills in our oceans have grabbed the attention of concerned citizens everywhere. In addition, mounting evidence of the detrimental effects of our current fossil-fuel-dominated energy system, ranging from emission of particulates to greenhouse gases has heightened our awareness of the urgent need to overcome our addiction to hydrocarbon fuels. Important as this intense focus on global fossil energy supply and environmental and health issues is—it seems prudent to reexamine how we use energy in our own backyards.

If a transformation to a more secure and sustainable energy system for the United States is to be achieved, we must pay more attention to how energy is delivered, supplied and used in virtually every American home and commercial building. Two of our most valuable fuels, oil and natural gas, are consumed in large quantities daily to heat homes and buildings, and to provide hot water for billions of everyday necessities—taking showers, doing laundry, washing dishes, cooking food—and more.

A few months ago my engineering students and I decided to take a closer look at how Americans use our energy. We knew of a study published in the early 1970s based on energy use data from 1968, but much has changed in the U.S. in the last 40 years, so we dug deeper to see what else we could find. We evaluated published data to see just how much energy is consumed as a function of the actual temperature where it is used. For example, for a hot shower or bath, the energy is used at a temperature of about 100 °F (38 °C), but frequently it is supplied by burning natural gas or oil at high combustion temperatures of 1800 °F (1000 °C) or more—clearly a waste of energy on a huge scale. By dissecting America's total demand in this way, we created a "thermal spectrum" of current energy use shown below in Fig. 1.

By integrating the demand from the lowest temperature shown to higher temperatures, we see that about 25% of our total primary energy is used at or below the boiling point of water (212 °F or 100 °C), but most of this energy is supplied by burning heating oil and gas, an incredibly wasteful process. Higher grade electricity could be generated from these hot combustion gases before they are used for heating applications at lower temperatures. Applying the laws of thermodynamics, we can determine how much electric power potential is lost in burning fossil fuels at high temperatures to provide heat at much lower temperatures, losses that occur in virtually every American home or commercial building every day of the year.

Exceptions to this wasteful process do exist, such as the co-generation plants found at Cornell and many large U.S. universities, which provide both heat and electric power in a distributed network. Although America was the first country to develop a geothermal district heating system, in Boise, Idaho in the 1800s, we have lagged far behind other countries since then, largely as a result of having had low cost, abundant oil and gas. Especially noteworthy is Iceland's transformation from complete dependence on imported fossil fuels to an indigenous energy supply in less than 50 years. Iceland aggressively developed its renewable resources to meet their electric power needs with high grade geothermal resources providing about 20% and the remainder coming from hydropower. In addition, Iceland uses geothermal to meet about 95% of its heating needs.

America could make a similar transformation by more effectively utilizing its diverse and abundant renewable wind, solar, geothermal, hydro and biomass resources. For years U.S. Presidents and congressional leaders have emphasized the importance of developing more efficient, environmentally sustainable and secure ways to meet the country's primary energy demands. Policy makers advocate developing cleaner, indigenous renewable energy from wind and solar resources for electricity generation and biofuels from biomass as replacements to gasoline and diesel oil—our major transportation fuels. These changes are indeed important, but we rarely hear mention of the tremendous opportunity we have to capture lower temperature heat. Based on what my students found, in order to transform our energy system, we must capture the intrinsic value of lower grade thermal energy obtainable from renewable resources. We need to invest in developing the infrastructure to capture, transport and deliver this thermal energy when and where it is needed.

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† For further information and documentation of our analysis, readers are referred to a companion article in this issue of Energy and Environmental Science (D. B. Fox, D. Sutter and J. W. Tester, *Energy Environ. Sci.*, 2011, DOI: 10.1039/c1ee01722e).

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ANALYSIS

The thermal spectrum of low-temperature energy use in the United States†

Don B. Fox,[a] Daniel Sutter[ab] and Jefferson W. Tester*[ab]

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A detailed analysis of U.S. energy consumption was performed to determine the amount of primary energy consumed as a function of its utilization temperature from 0 to 260 °C. The study highlights the changes that have occurred in U.S. energy use since the 1970s and suggests how renewable energy could provide a large fraction of the energy used for direct use at low end-use temperatures that is currently mostly supplied by high grade fossil fuels. For example, most of the low-temperature energy used for water and space heating is provided by combusting natural gas and oil at very high temperatures. This process downgrades the thermodynamic potential of the fossil fuels for generating power resulting in large reduction in the exergy or availability of the combustion products. By focusing attention on the thermodynamic losses inherent to our current energy system, we suggest a paradigm shift in the way we view and use energy by strategically matching the source providing the energy to the end-use temperature of the application. Thermal energy demands below 260 °C could be supplied more sustainably without large exergetic losses by geothermal or solar thermal energy resources, as well as by waste heat from fuel combustion processes. In addition, direct thermal use of available low-temperature thermal energy results in higher overall efficiencies compared to electricity generation by avoiding the substantial 2nd Law losses incurred in converting thermal energy to electricity. Using the U.S. Energy Information Administration database as a primary source of information, we found that the total thermal demand in the temperature range from 0 to 260 °C in 2008 was 33.5 EJ (31.7 quads), which is about one third of the entire U.S. demand. More than half of the thermal energy demand below 200 °C (55%) comes from the residential sector, while the rest comes from the industrial (24%) and commercial (21%) sectors. Additionally, almost 80% of 33.5 EJ is used to provide heat below 150 °C. Space heating and water heating have end-use temperatures of 40 to 60 °C and are responsible for 38% of the thermal energy consumption below 260 °C in the residential and commercial sectors.

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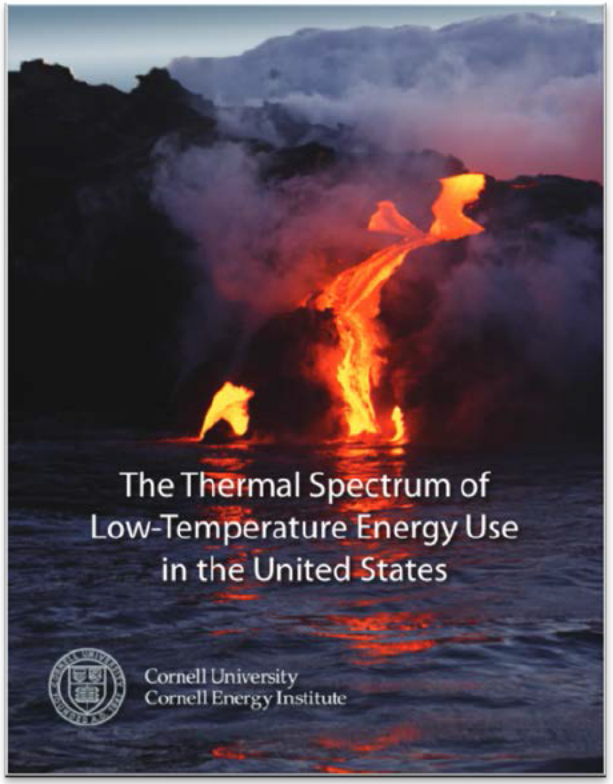
† Electronic supplementary information (ESI) available: Full report. See DOI: 10.1039/c1ee01722e

1. Introduction

Fossil fuels have remarkable properties as energy carriers such as high specific energy density (*e.g.* lower heating value of gasoline is 43 MJ/kg) and high combustion temperatures ranging from 1000 to 2500 °C, depending on fuel-air composition, combustor design, and other factors. These characteristics enable fossil fuels

Broader context

In discussing options for our energy future, alternatives for electricity production and transportation fuels typically receive a disproportional amount of attention compared to direct thermal use. Even less attention has been given to understanding the efficiency of how energy is used in direct thermal applications. By using a comprehensive thermodynamic framework, low temperature thermal demand can be systematically quantified to reveal a range of applications that present a natural market for renewable energy. Although this article focuses on the thermal spectrum of the U.S. as a whole, our methodology can be applied with less coarse graining to individual heat markets such as chemical manufacturers, private homes, food industries, and dairy farms to quantify the potential for low temperature renewable energy sources as scalable replacements for the fossil fuels now used for these energy intensive applications. To produce the most effective energy policies, characterizing energy use as a function of temperature provides vital information for making informed decisions for transforming energy systems to more sustainable pathways.



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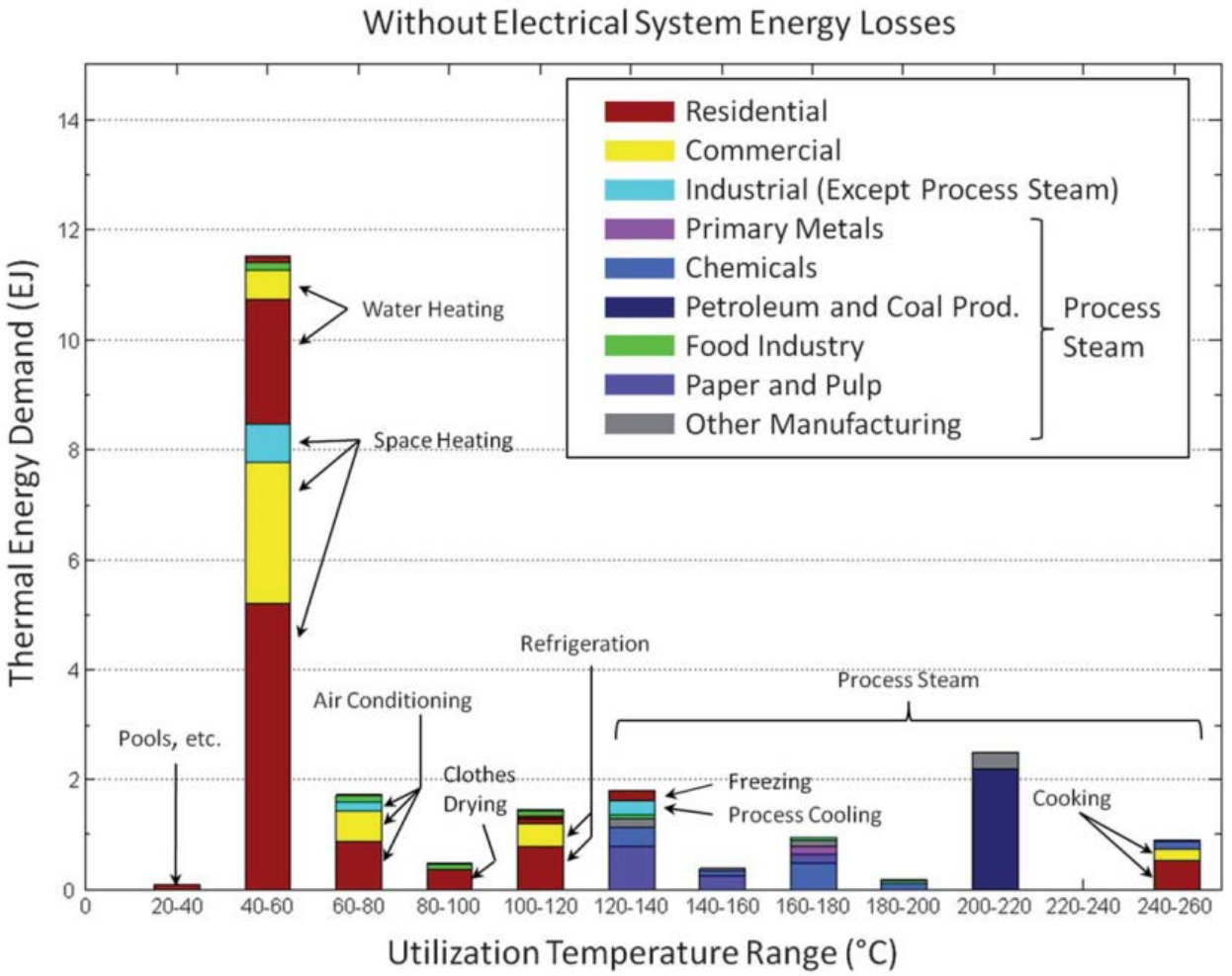
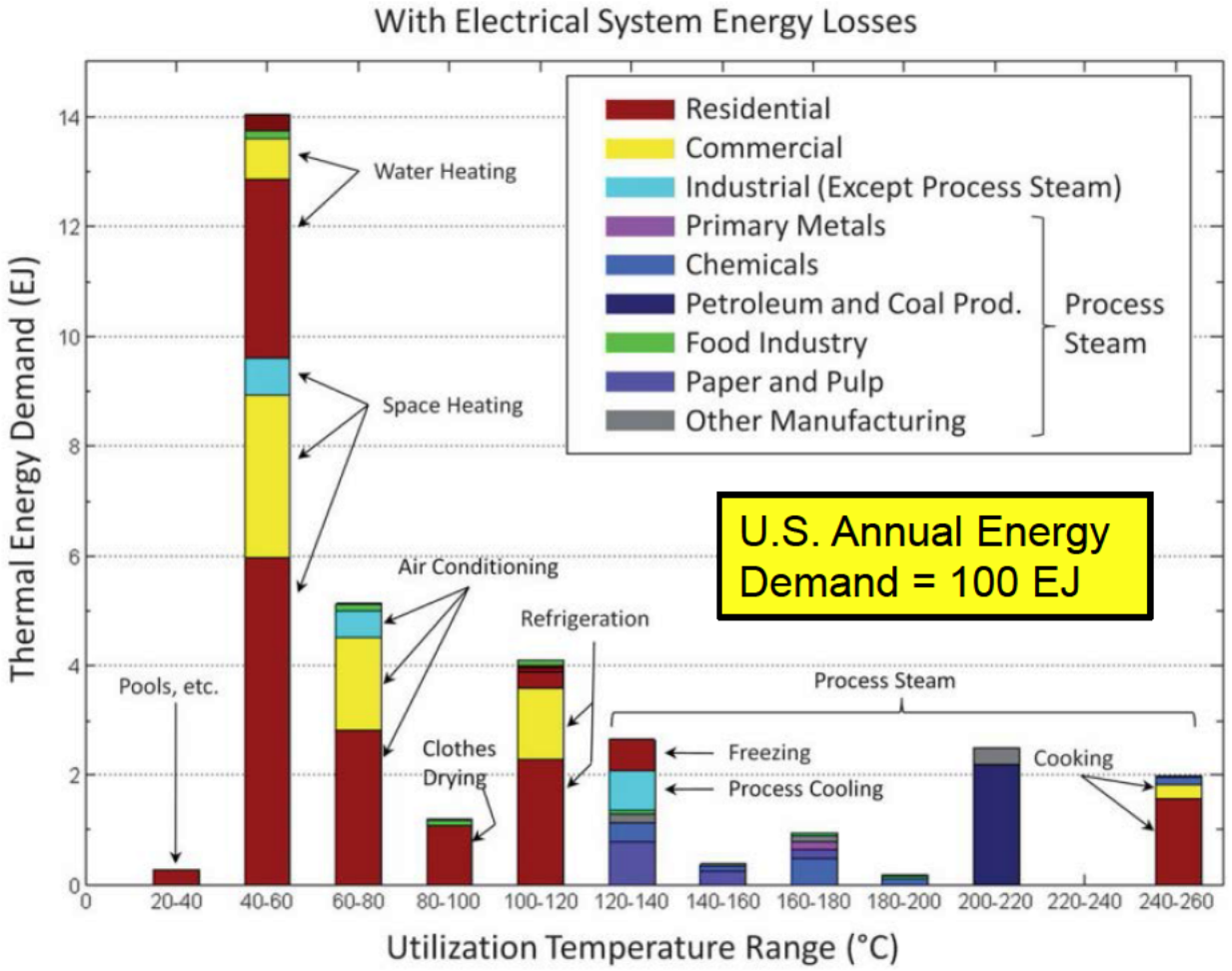
"An important but relatively unpublicized renewable opportunity is to begin utilizing our abundant indigenous geothermal and solar energy resources at temperatures that closely match the temperatures required where the energy is actually used."

2008 Low-Temperature Thermal Energy Demand in the U.S.



2008 Low-Temperature Thermal Energy Demand in the U.S.



→ 24% of U.S. primary energy demand consumed as heat below 120ºC

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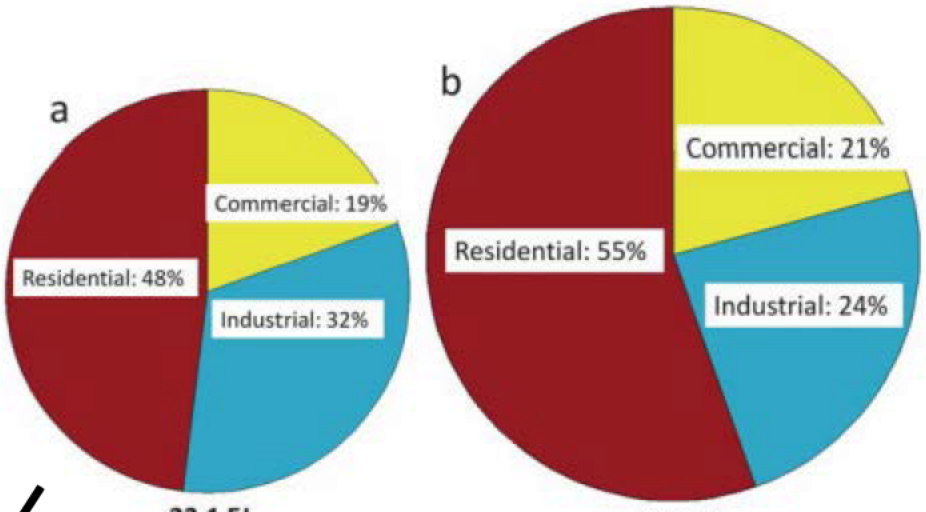
Thermal Demand Sector Distrubution



Without Electrical Energy Losses

With Electrical Energy Losses

→ 50% of U.S. thermal energy under 260°C consumed in residential sector

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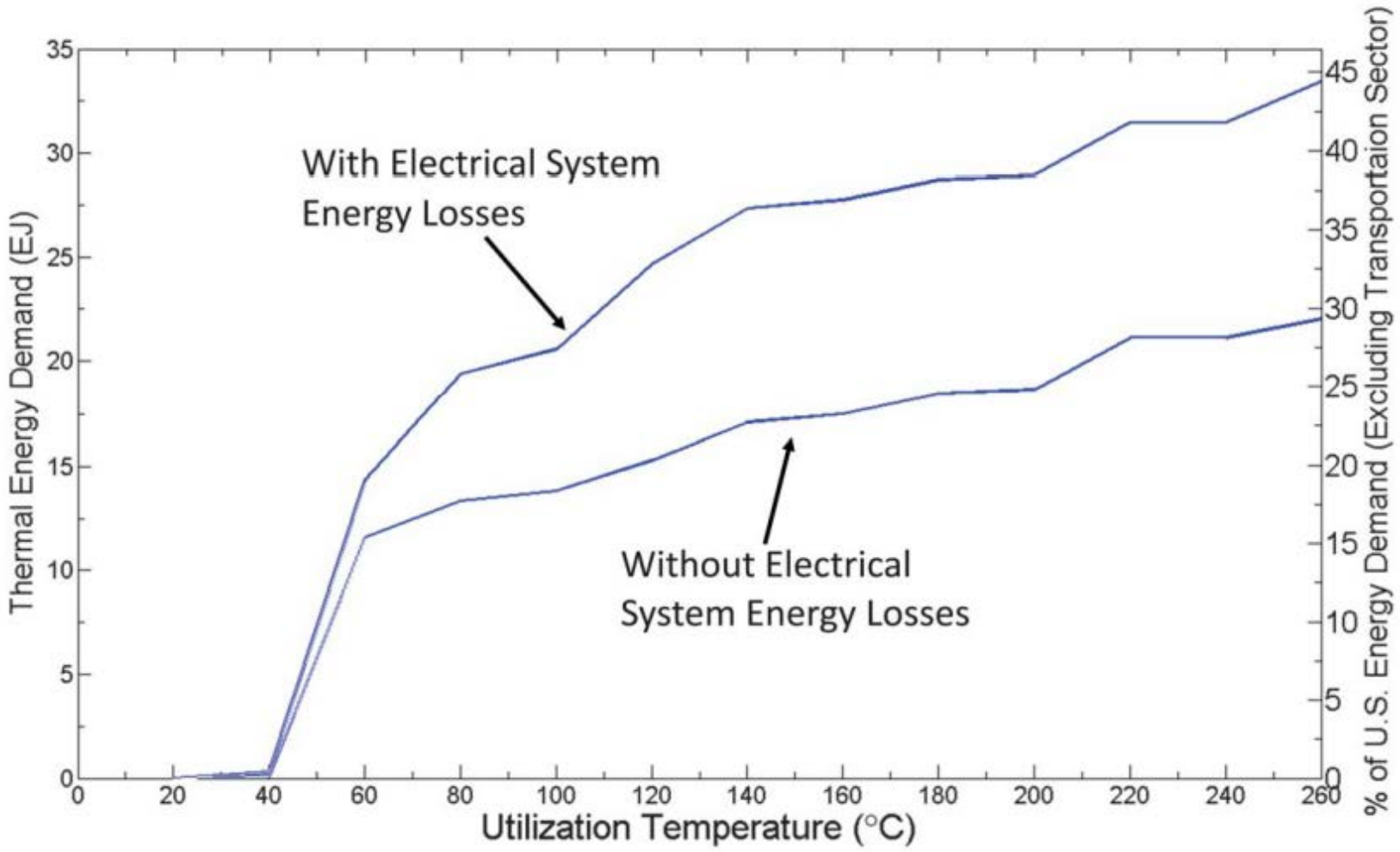
2008 Cumulative Thermal Energy Demand in the U.S.



→ 45% of U.S. energy demand (excl. transp.) consumed as heat below 260ºC

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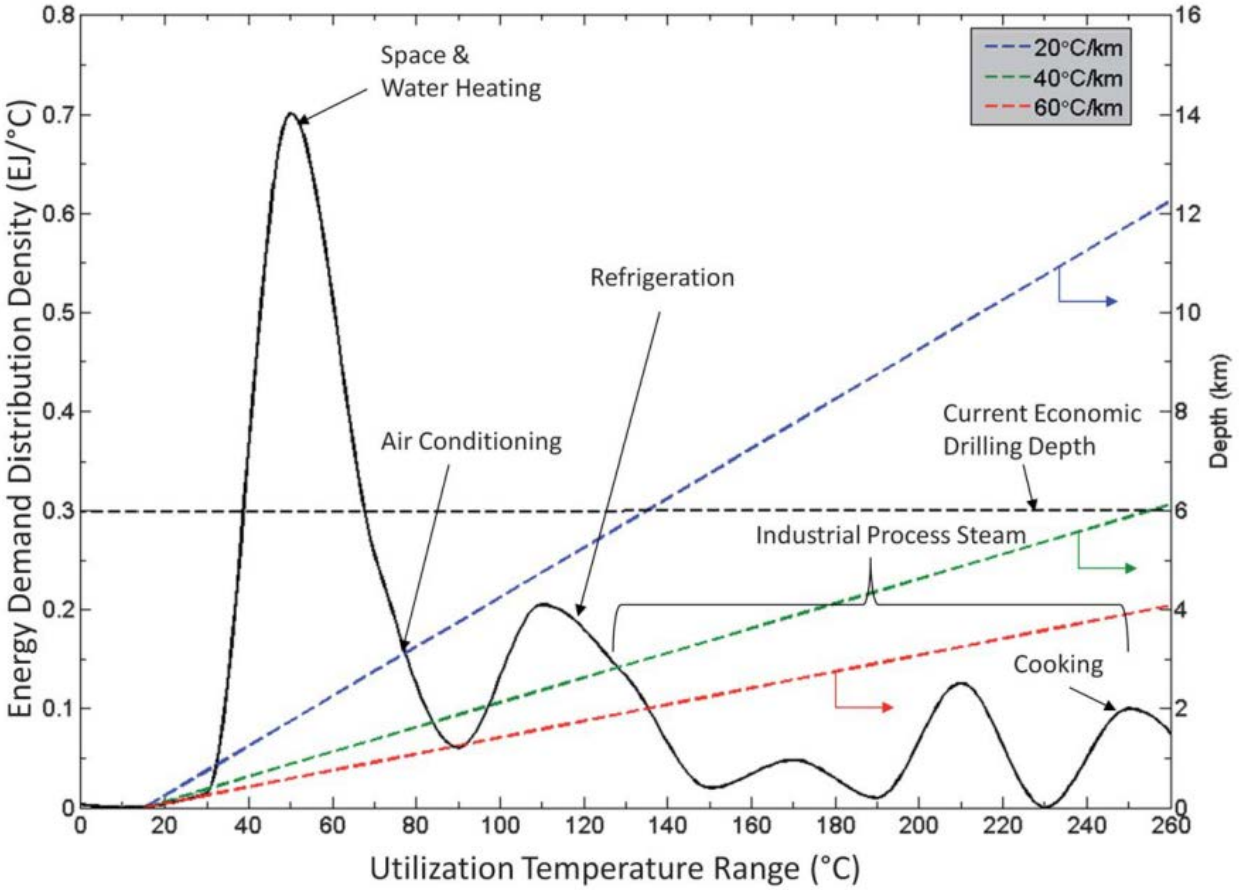
2008 Energy Demand Distribution Density



→ Space & Water heating around 50ºC is dominant thermal energy use

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Conclusions

- 2008: About a quarter of U.S. primary energy demand consumed as heat under 120ºC. (Electricity accounts for 40%)
- Similar picture in 1968.
- Dominant low-temperature thermal energy consumption in residential sector for space & water heating, but often forgotten in national energy debate.

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Thank you! Questions?

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Daniel Sutter (now at EPFL, Switzerland)

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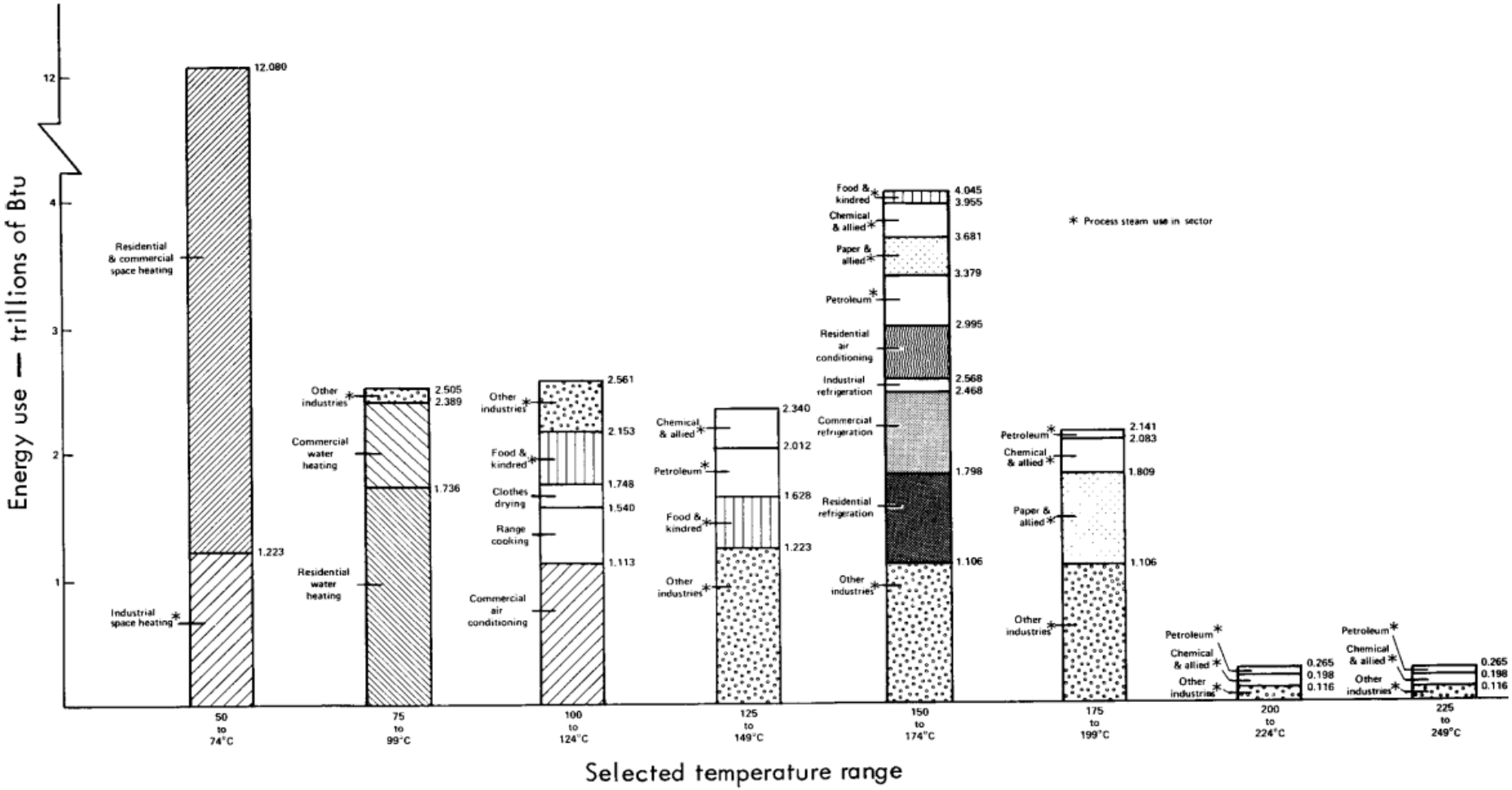

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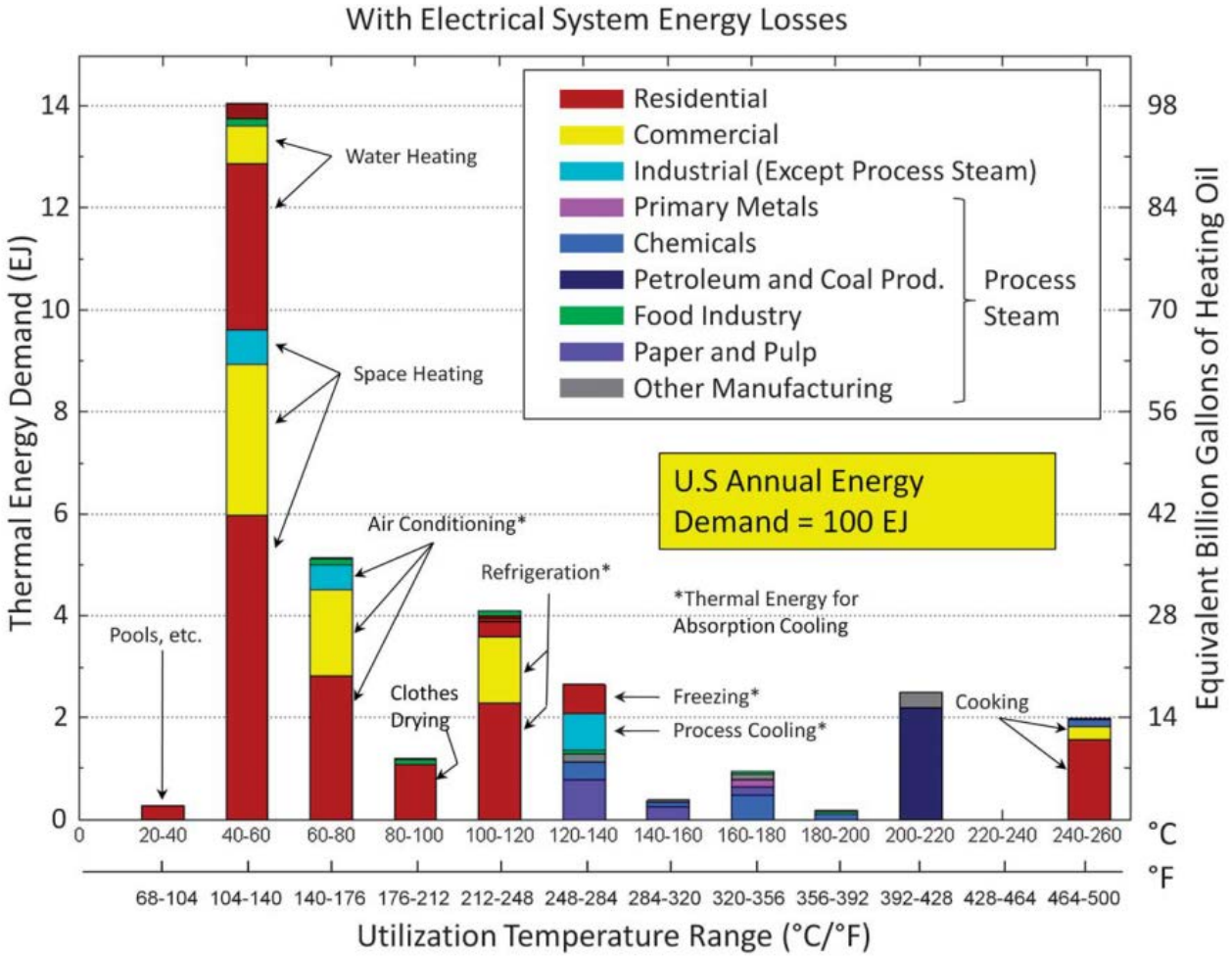

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