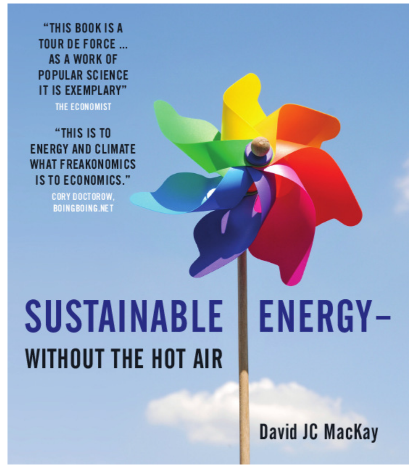
Visualizing Sustainable Energy for the USA

David J.C. MacKay



Let's express energy consumption and energy production using simple personal units, namely kilowatt-hours. One kilowatt-hour (kWh) is the energy used by leaving a 40-watt bulb on for 24 hours. The chemical energy in the food we eat to stay alive amounts to about 3 kWh per day. Taking one hot bath uses about 5 kWh of heat. Driving an average European car 100 km uses 80 kWh of fuel.

In total, Americans use **250 kWh per day per person** for transport, heating, manufacturing, electricity, and so forth. That's equivalent to every person having 250 lightbulbs switched on all the time. And, as figure 1 shows, most of this energy today comes from fossil fuels. What are our post-fossil-fuel options?

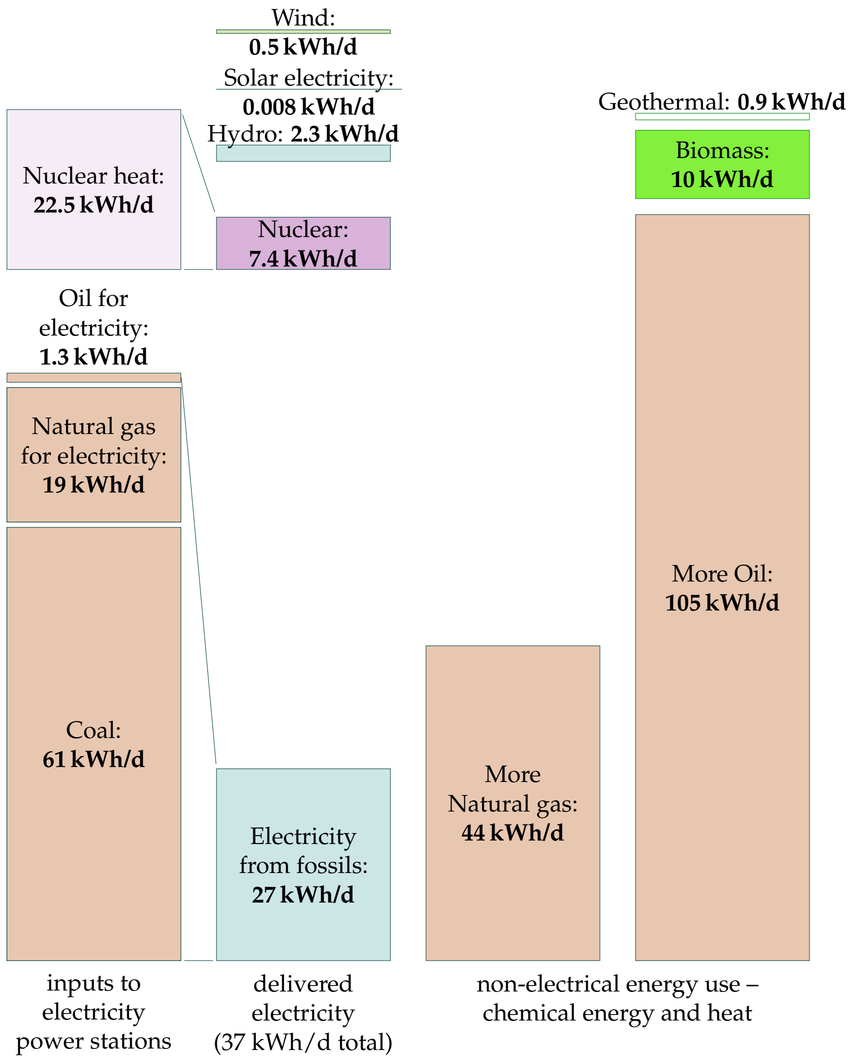
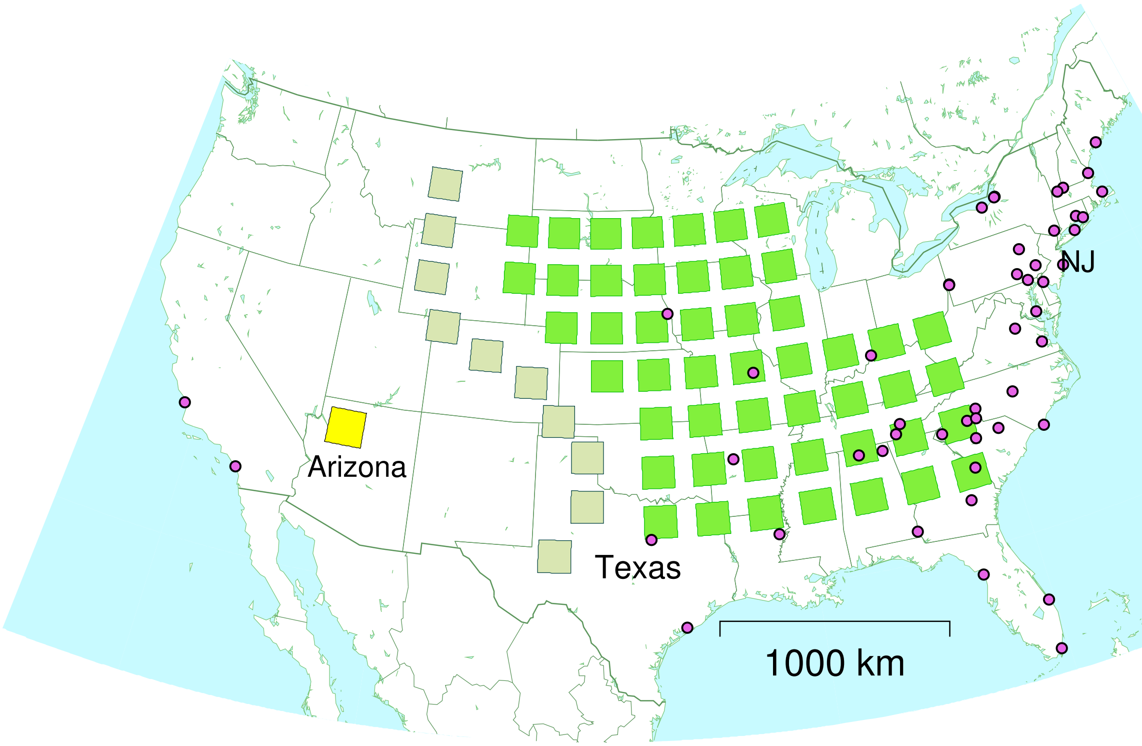


Figure 1. Current consumption per person in the USA is about 250 kWh per day per person. The first two columns show where the electricity (37 kWh per day per person) comes from: 90% of it comes from about 81 kWh/d/p of fossil fuels (mainly coal and gas) and 22.5 kWh/d/p of nuclear heat. A further 44 kWh per day per person of natural gas and 105 kWh per day per person of oil are used for heat, for chemical processes, and for transport. Geothermal sources and biomass contribute smaller amounts.



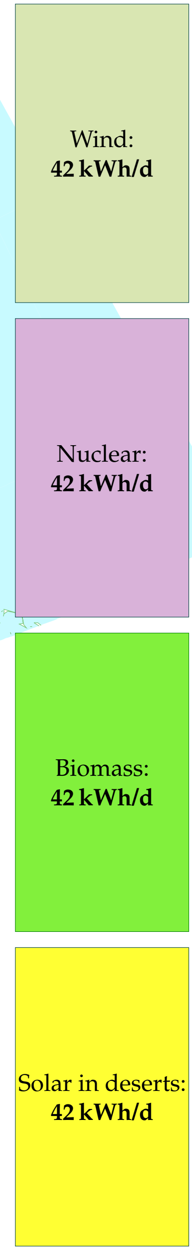


Figure 2. Visualizing sustainable energy options *(DRAFT)*.

The ten grey-green squares represent wind farms. Each square is 20 000 km^2 in size – the size of New Jersey.

Purple dots: nuclear power stations (not to scale) – 5 GW average production at each of 100 sites. (I haven't put all 100 on the map yet.)

Light-green squares: bio-energy plantations. (Some of these could occupy the same land as the wind farms.)

Yellow square in Arizona: concentrating solar power facilities in deserts.

Among the **energy-saving** options, two promising technology switches are the electrification of transport (electric vehicles can be about four times as energy-efficient as standard fossil-fuel vehicles) and the use of electric-powered heat pumps to deliver winter heating and hot water (heat pumps can be three or four times as energy-efficient as standard heaters). Energy can also be saved by making vehicles lighter, by insulating buildings better, and by improving the engineering of appliances such as refrigerators.

Among all the **energy-supply** technologies, the four with the biggest potential today are solar power, wind power, bio-energy, and nuclear power.

Figure 2 visualizes the sizes of solar, wind, bio-energy, and nuclear facilities that would each supply **42 kWh per day per person**. (Remember, the total power consumption today is six times as big – 250 kWh per day per person.)

To supply 42 kWh per day per person from solar power (for everyone in the USA) requires concentrating solar power stations with total area equal

Assumption: concentrating solar power delivers an average power per unit area of 15 W/m^2.

to one eighth of Arizona. That's a little bigger than New Jersey.

To deliver 42 kWh per day per person from wind would require wind farms with a total area roughly equal to the area of California (ten New Jerseys) – a two-hundred-fold increase in US wind power.

Wind farms: 2.5 W/m^2.

To get 42 kWh per day per person from bio-energy would take roughly 10% of US land area (fifty New Jerseys).

Energy crops: 0.5 W/m^2.

To get 42 kWh per day per person from nuclear power would require 525 one-gigawatt nuclear power stations - a roughly five-fold increase over today's levels.

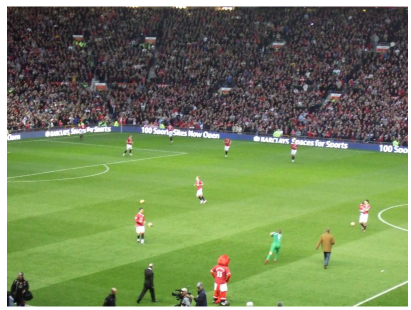
Let's re-visualize these national numbers in personal terms. What would individuals or communities need to do?

To obtain 42 kWh per day from solar power, one person requires either roughly 80 square metres of solar photovoltaic panels; or a share of a concentrating solar power station, namely 30 mirrors, each one square metre in size, and a one-four-hundredth share of a solar collector tower.

Photos by eSolar.com

We can get 42 kWh per day per person from wind (on average) if every 300 people have one 2-MW turbine.

To get 42 kWh per day from bio-energy, each person needs the output of 1 acre (4000 square metres) of land – that's half a football field.



To get 42 kWh per day per person from nuclear power, each city the size of Denver, Boston, Las Vegas, and Portland would have its own one-gigawatt nuclear power station, occupying about one square kilometre. Bigger cities would have proportionally more – 7 for Los Angeles, 5 nukes for Chicago, and 4 nukes for Houston, for example.

I hope these numbers convey the scale of action required to put in place a sustainable energy solution.

It's not going to be easy to make a energy plan that adds up; but it is possible. We need to get building.

Sustainable Energy – without the hot air

David J.C. MacKay

This remarkable book sets out, with enormous clarity and objectivity, the various alternative low-carbon pathways that are open to us.

Sir David King FRS
Chief Scientific Adviser to the UK Government, 2000–08

For anyone with influence on energy policy, whether in government, business or a campaign group, this book should be compulsory reading.

Tony Juniper
Former Executive Director, Friends of the Earth

MacKay's book shows how, when it comes to energy, you too can do the simple arithmetic and learn the simple scientific facts needed to work out what energy you need and where it might come from.

Prof David Mumford
Professor of Applied Mathematics, Brown University
Member of the US National Academy of Sciences

Common sense, technology literacy, and a little calculation go a long way in helping the reader sort sense from nonsense in the challenges of developing alternatives to fossil fuels. MacKay has provided a high priority book on a high priority problem.

Professor William W. Hogan
Raymond Plank Professor of Global Energy Policy
John F. Kennedy School of Government, Harvard University

This is a complete resource for assessing the many options for choosing between different energy options and for using energy more efficiently. Teachers, students, and any intelligent citizen will find here all the tools needed to think intelligently about sustainability. This is the most important book about applying science to public problems that I have read this year.

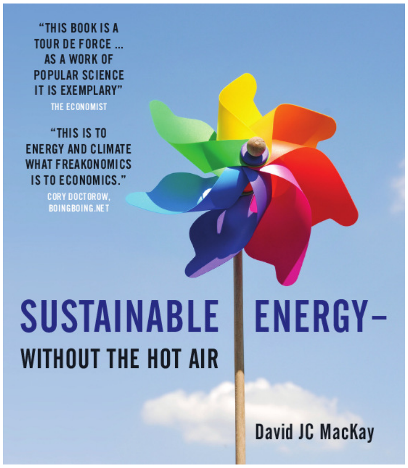
Prof Jerry Gollub
Professor of Physics, Haverford College and University of Pennsylvania
Member of the US National Academy of Sciences

MacKay's book is the most practical, solidly analytical, and enjoyable book on energy that I have seen. This heroic work gets the energy story straight, assessing the constraints imposed by physical reality that we must work within.

Prof Tom Murphy
Associate Professor of Physics, UC San Diego

This book is a tour de force . . . As a work of popular science it is exemplary.

The Economist



"Sustainable Energy – without the hot air" was published by UIT Cambridge on 2nd December 2008 in the UK, and on 1st May 2009 in North America. The book is also available for free online at `www.withouthotair.com`.

David MacKay FRS is Professor of Natural Philosophy in the Department of Physics at the University of Cambridge. In October 2009 he was appointed the Chief Scientific Advisor to the UK Department of Energy and Climate Change.