HIDDEN COSTS

Energy Lost from Mine to Car

The steps involved in mining and processing Canada's tar sands to produce oil offer an example of why unconventional fuels can be less attractive than traditional fuels, in terms of the amount of energy they yield versus how much is invested in producing them. First comes energy-intensive logging, digging, hauling, crushing, washing and heating of the sand-laden raw product to separate out the tarlike bitumen (*inner ring*). An on-site refinery called an upgrader must then cook the bitumen to turn it into regular crude oil, which is eventually transported by pipeline and sometimes tanker. Another method requires energy to create steam that melts the bitumen underground. Of course, all the operations require human labor (*second ring*). Distant refineries consume still more energy to turn the crude into gasoline and other fuels. Cleanup afterward includes water purification and land reclamation, both of which require yet more energy. Traditional drilling, extracting and refining conventional crude oil demand much less energy investment.

Illustration by Oliver Munday

Mason Inman is a freelance journalist in Oakland, Calif. He is now writing a biography of geologist M. King Hubbert, who is often called the "father of peak oil."

ENERGY

THE TRUE COST OF *Fossil Fuels*

As oil becomes more expensive, determining where to invest energy to get energy is increasingly important

By Mason Inman

CANADA'S TAR SAND PROJECTS SPRAWL ACROSS 600 SQUARE KILOMETERS OF NORTHEASTERN Alberta. Prime Minister Stephen Harper has called the industrial effort to extract oil from the deposits "an enterprise of epic proportions, akin to the building of the pyramids or China's Great Wall. Only bigger."

As traditional oil and natural gas reserves become increasingly difficult to find, and as demand rises, energy companies are turning to unconventional resources that, like the tar sands, are harder and more costly to access. Production of tar sands–based oil, for instance, has tripled over the past decade, reaching 1.6 million barrels a day in 2011.

Given that unconventional sources are needed, which ones make the most sense to extract? It takes an unusually high amount of energy to get at them—whether it be tar sands, natural gas from hydraulic fracturing shale, or old oil deposits that can be flooded with steam to scour out more petroleum. To help compare fuel sources with a common metric, ecologist Charles A. S. Hall of the S.U.N.Y. College of Environmental Science and Forestry has created a measure called the "energy return on investment" (EROI). It indicates the energy that fuels provide per unit of energy spent—a ratio of energy obtained. A higher EROI means more energy is available to put to work. On the opposite page and on the ones that follow, I examine the inputs and outputs of various fuel sources to explain their EROIs.

"Everywhere you look, the EROI is declining," Hall says of oil and gas. His modeling suggests that a modern economy requires liquid fuel with an EROI of at least five; as the EROI decreases, society spends so much money on energy production that the costs eat into funds that could be spent elsewhere, whether on education, health care or entertainment.

By that measure, few options in the transportation sector are appealing [*see top illustration on next two pages*]. Yet low-EROI fuels are increasingly needed to meet ever higher demand, according to the International Energy Agency (IEA). Already, the IEA warns, oil prices are in the "danger zone," threatening economic growth. The electric power industry enjoys better EROIs [*see bottom illustration on next two pages*] because of access to more abundant resources.

The EROI measure does not evaluate all the benefits and drawbacks of a fuel; notably, it does not address the environmental cost of greenhouse gas emissions or supply problems, such as the intermittence of wind or of solar power. Nevertheless, the EROI reveals how much energy to expect from a given source. It can also highlight how efforts to cut pollution—such as capturing carbon dioxide from coal-fired power plants—can drastically alter a fuel's affordability. By measuring the energy in versus the energy out, investment can be guided to the sources that most effectively keep the economy humming and that also can help build a sustainable future.

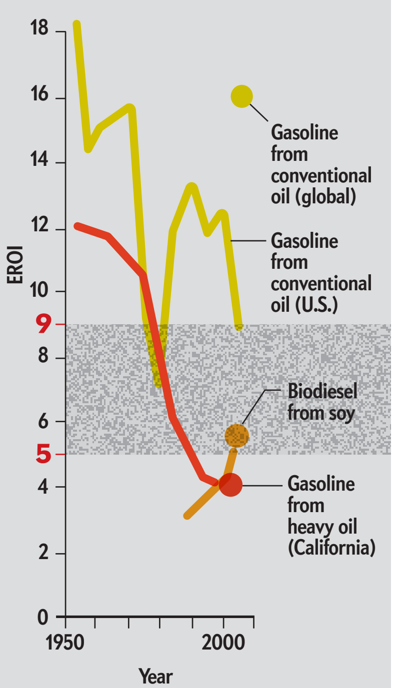
WINNERS AND LOSERS

The Decline of Cheap Energy

Many experts say that high-quality fossil fuels that are cheap to extract are dwindling, forcing the world to turn to energy sources that are more costly to produce. This situation is revealed by calculating EROI—the energy obtained per unit of energy spent to obtain it. Conventional oil has a much more favorable EROI than other sources of liquid fuel (*chart at top right*), but its score is declining steadily (*graph below*). Conventional sources of electricity also have high EROIs (*chart at bottom right*), which can pay off handsomely when used for transportation (*chart at far right*). "The age of cheap energy is over," said Nobuo Tanaka in 2011, when he was the International Energy Agency's executive director.

Oil's Advantage Drops

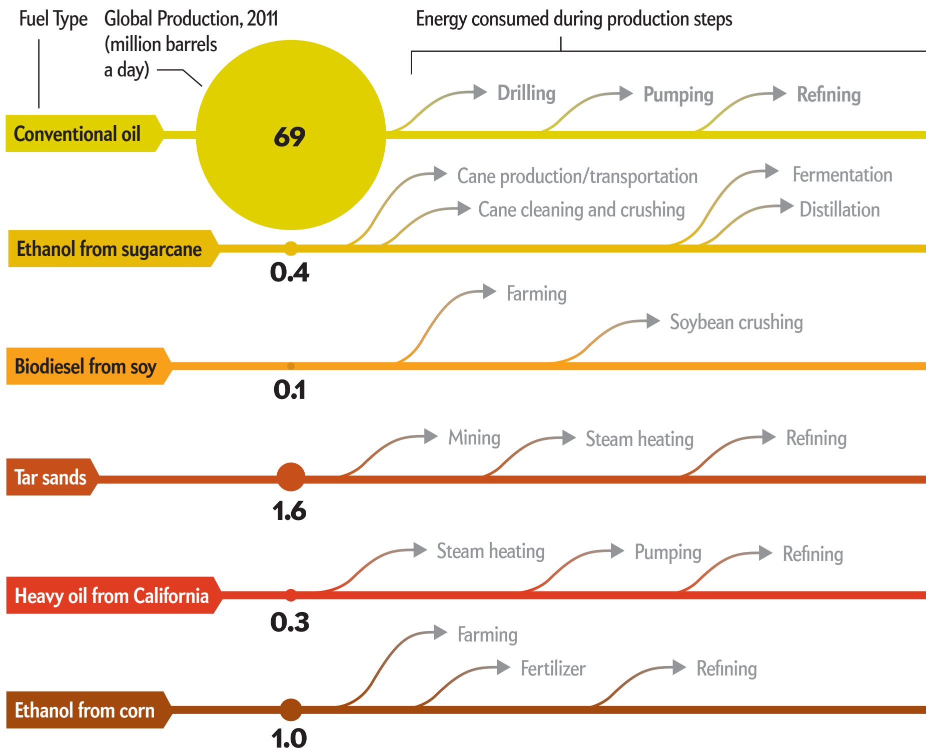
A modern economy requires fuels that have an EROI of at least five. For decades oil from conventional deposits soared above that threshold, but it is now dropping. Substitute sources such as heavy oil (thicker petroleum composed of longer hydrocarbon molecules) are more energy-intensive to produce, so they have lower EROIs. But alternative fuels, such as diesel made from soybeans, offer some hope.



DATA SOURCES: INTERNATIONAL ENERGY AGENCY; U.S. ENERGY INFORMATION ADMINISTRATION; U.S. DEPARTMENT OF AGRICULTURE; STUDIES BY CHARLES A. S. HALL ET AL. AND BY OTHER RESEARCHERS (*complete list of sources online at ScientificAmerican.com/apr2013/eroi*)

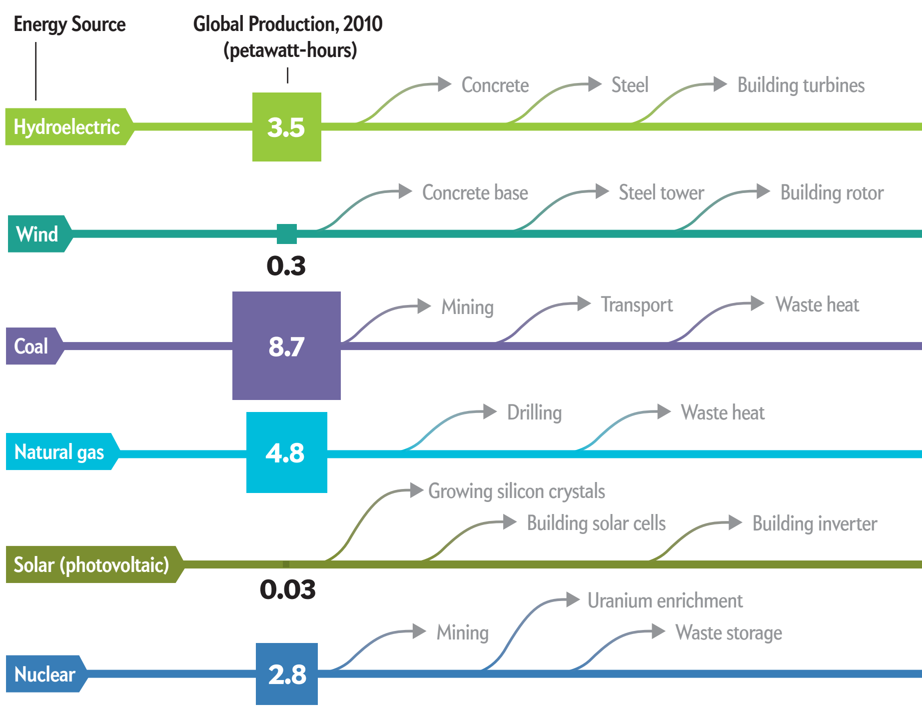
LIQUID FUELS: Crude Oil Gives the Best Energy Return—Today

Each raw material has to be extracted—from oil reservoirs or vegetation—and refined into gasoline or other fuels. Each step lowers the EROI. Values are recent industry averages or from typical installations.

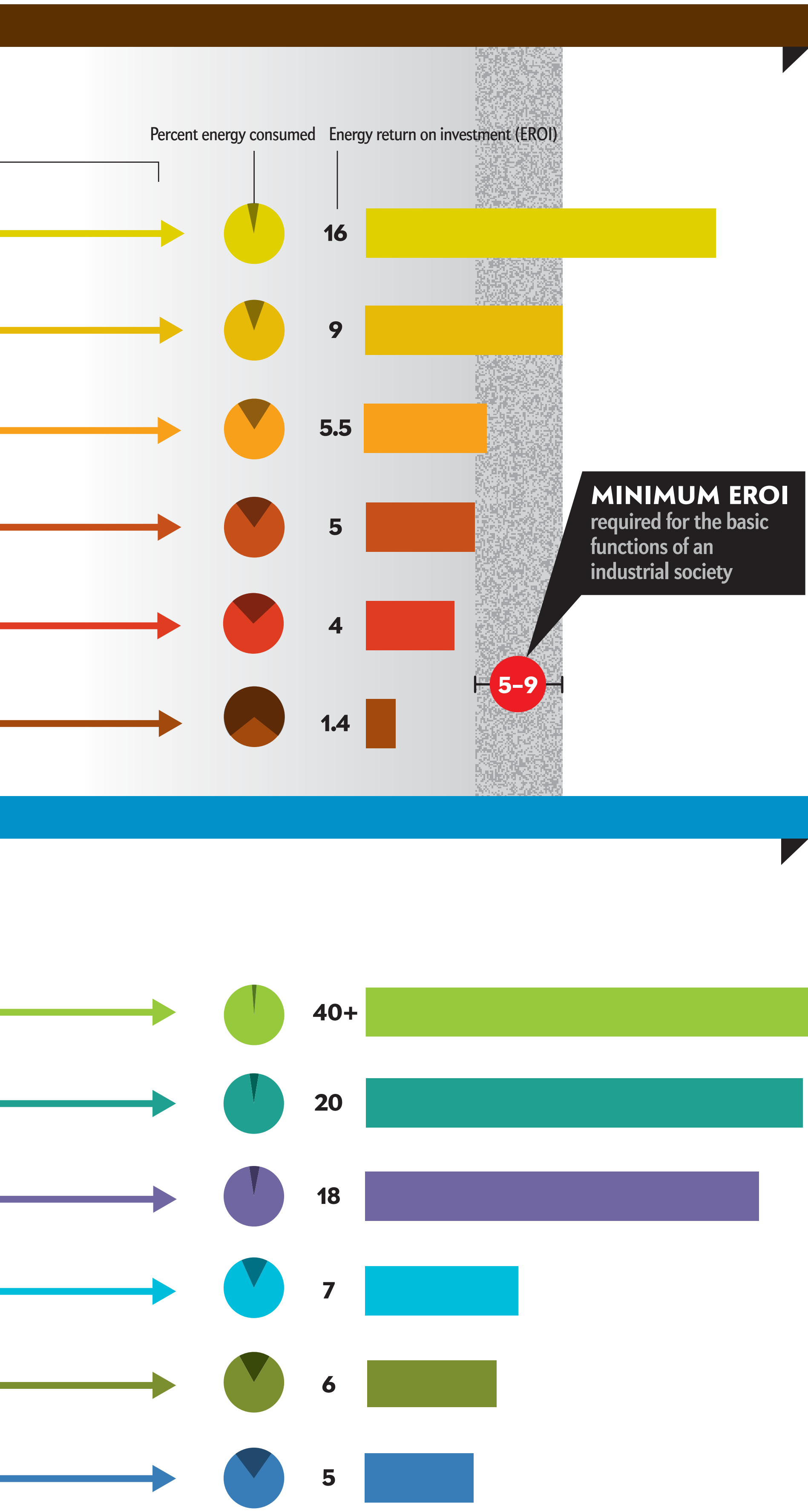


ELECTRIC POWER: Renewables Are Competitive with Fossil Fuels

Sources of electricity span a wide range of EROIs. Values are recent industry averages or from typical installations. Renewables do not include energy storage.



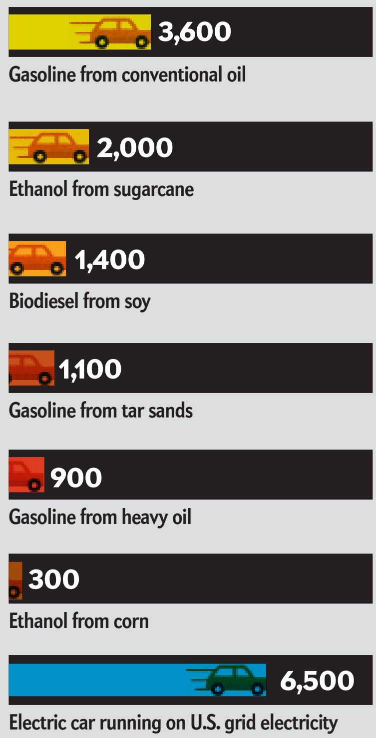
Graphic by Jen Christiansen



Mileage Return on Investment: Electricity Wins

Transportation fuels are not created equal. A car will go farthest on energy invested in generating electricity, then on conventional gasoline, followed by ethanol made from sugarcane. The miles traveled are based on the energy required to make each fuel, as well as its energy density (for example, ethanol's energy density is roughly 67 percent of gasoline's). For electric cars, this value does include electricity transmission, but not manufacturing batteries.

Distance Driven on One Gigajoule of Energy Invested in Fuel Production (miles)



MORE TO EXPLORE

Revisiting the Limits to Growth after Peak Oil. Charles A. S. Hall and John W. Day in *American Scientist*, Vol. 97, No. 3, pages 230–237; May–June 2009.

New Studies in EROI (Energy Return on Investment). Edited by Doug Hansen and Charles A. S. Hall. Special issue of *Sustainability*, Vol. 3; 2011. www.mdpi.com/journal/sustainability/special_issues/New_Studies_EROI

Energy and the Wealth of Nations. Charles A. S. Hall and Kent A. Klitgaard. Springer, 2012.

SCIENTIFIC AMERICAN ONLINE
For more on the calculations behind EROI and a Q&A with Charles A. S. Hall, go to ScientificAmerican.com/apr2013/eroi