Chapter 5
The Oiliness of Everything: Invisible Oil and Energy Payback Time

Just as fish swim in water, but are essentially unaware of it, we swim in oil. You can't understand the predicament we're in until you can see the oil that saturates every single aspect of our life. To illustrate how energy permeates society, let's look at the life cycle of a simple object, the pencil. I've condensed and reworded Leonard Read's 1958 essay *I Pencil, My Family Tree* to show the fossil fuel energy inputs with ***Energy-Using ACTIONS Italicized*** and **objects made with energy underlined**. As you read each italic and underlined word, think energy.

> My family tree begins with … a Cedar tree from Oregon. Now contemplate the antecedents—all the people, numberless skills, and fabrication: All the **saws**, **trucks**, **rope**, and **other gear** to ***HARVEST*** and ***CART*** cedar logs to the **railroad siding**. The ***MINING*** of ore, ***MAKING*** of **steel**, and its ***REFINEMENT*** into **saws**, **axes, and motors**. The ***GROWING*** of **hemp,** and bringing it through all the stages to heavy and strong **rope**. **The** ***BUILDING*** of **logging camps** (**beds**, **mess halls**). ***SHOPPING***, ***DELIVERY***, and ***COOKING*** **food** to feed the working men.
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> The **logs** are ***SHIPPED*** to a **mill** in California. Can you imagine how many people were needed to ***MAKE*** **flat cars**, **rails, &** **railroad engines?**
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> At the **mill**, cedar logs are ***CUT*** into pencil-length slats, ***KILN-DRIED, TINTED, WAXED,*** and ***KILN-DRIED*** again. Think of all the ***EFFORT*** to make the **tint** and the **kilns**, ***SUPPLY*** the ***HEAT***, ***LIGHT***, and ***POWER***, the **belts**, **motors**, and all the **other things** a **mill** requires. Plus the men who ***POURED*** the **concrete** for the **dam** of a **hydro-electric plant** which ***GENERATES*** the mill's ***POWER***! Don't overlook the workers who have a hand in ***TRANSPORTING*** **60 train-cars** of **slats** ***ACROSS*** the nation.
>
> Once in the **pencil factory**—worth millions of dollars in **machinery** and **buildings**—each slat has **8 grooves** ***CUT*** into them by a **groove-cutting machine**, then the **lead-laying machine** ***PLACES*** a piece of **lead** in every other slat, ***APPLIES*** **glue** and ***PLACES*** another **slat** on top—a lead sandwich that's mechanically ***CARVED*** into seven pencils. My "lead" is **graphite** ***MINED*** in Sri Lanka.

A.J. Friedemann, *When Trucks Stop Running*,
Energy Analysis, DOI 10.1007/978-3-319-26375-5_5

> Consider the miners and those who ***MAKE*** their **tools** and **paper sacks** in which the graphite is ***SHIPPED*** and those who ***MAKE*** the **string** to ***TIE*** the **sacks** and the men who ***LIFT*** them aboard **ships** and who ***MAKE*** the **ships**. Even **lighthouse keepers** and **harbor pilots** assisted in my birth.
>
> The **graphite** is mixed with **clay** ***FROM*** Mississippi with **ammonium hydroxide** in the ***REFINING*** process. Then **wetting agents** and **animal fats** are ***CHEMICALLY REACTED*** with **sulfuric acid**. After ***PASSING THROUGH*** **many machines**, the mixture appears as endless extrusions as from a sausage grinder, ***CUT*** to size, ***DRIED***, and ***BAKED*** for several hours at **1850 °F**. The leads are ***TREATED*** with a ***HEATED*** mixture of **candelilla wax** ***FROM*** Mexico, **hydrogenated fats**, and **paraffin wax**. My cedar ***RECEIVES*** six coats of **lacquer**, with ***REFINED*** **castor oil**. Observe the **labeling**, a film ***FORMED*** by ***APPLYING HEAT*** to **carbon black** mixed with **resins**.
>
> My bit of **metal**—the ferrule—is **brass**. Think of all the **persons** who ***MINE*** **zinc** and **copper** and ***MAKE*** **sheet brass**. Those black rings on my ferrule are black **nickel**. Then there's my crowning glory, the **eraser**, made by ***REACTING*** **rape-seed oil** ***FROM*** Indonesia with **sulfur chloride**, and numerous **vulcanizing** and **accelerating agents**. The **pumice** comes ***FROM*** Italy; and the pigment which gives "the plug" its color is **cadmium sulfide**.
>
> Does anyone wish to challenge my assertion that no single person on the face of this earth knows how to make me? Millions have had a hand in my creation, no one of whom knows more than a few of the others. There isn't a single person who contributes more than an infinitesimal bit of know-how. Yet neither the miner nor the logger can be dispensed with, any more than the chemist at the factory or the worker in the oil field—paraffin being a by-product of petroleum. I, Pencil, am a complex combination of miracles: a tree, zinc, copper, graphite, PETROLEUM and so on."

If pencils are swimming in oil, think of the energy embodied in a wind turbine with its 8000 parts coming from hundreds of suppliers around the world, the roads over which hundreds of trucks arrive with workers, cement, rebar, and turbine parts, and the hundreds of miles of transmission wires, towers, and substations the electricity travels over. I, Wind Turbine, would be thousands of pages long.

Every year, the world uses one cubic mile of oil. What would it take to replace that? Well, you could build 52 nuclear power plants every year, for 50 years. Or any one of the other options, every year, for 50 years (Goldstein 2007):

- 4 Three Gorges Dams (18,000 MW), OR
- 52 nuclear power plants (1100 MW), OR
- 104 coal-fired power plants (500 MW), OR

- 32,850 wind turbines, (1.65 MW), OR
- 91,250,000 rooftop solar PV panels (2.1 kW panel)

Any of these would take 50 years to replace ONE year's worth of oil.

How Energy is Used in the U.S. Economy

In 2012, the U.S. consumed 18 % of total world energy, which includes petroleum, natural gas, coal, and electrical generation (EIA 2015).

As you can see in Fig. 5.1, petroleum represented 36 % of all energy used in the United States. Of that petroleum, 71 % was used by transportation, 23 % by industry, 5 % by residences and for commercial uses, and just one percent to generate electric power. This chart also shows that transportation is 93 % dependent on petroleum, though for ships, locomotives, and trucks, it is closer to 99 % since they use little to no ethanol, biodiesel, or natural gas.

The 64 % of remaining U.S. energy use (not fueled by petroleum) goes to generate electric power, heat homes and buildings, the high heat required by industrial processes, and so on.

Fossil fuels—petroleum, natural gas, and coal—provide 82 % of U.S. energy. Since they are finite, it is hard to conceive of a more critical goal for society than figuring out how to best spend our remaining fossil fuels.

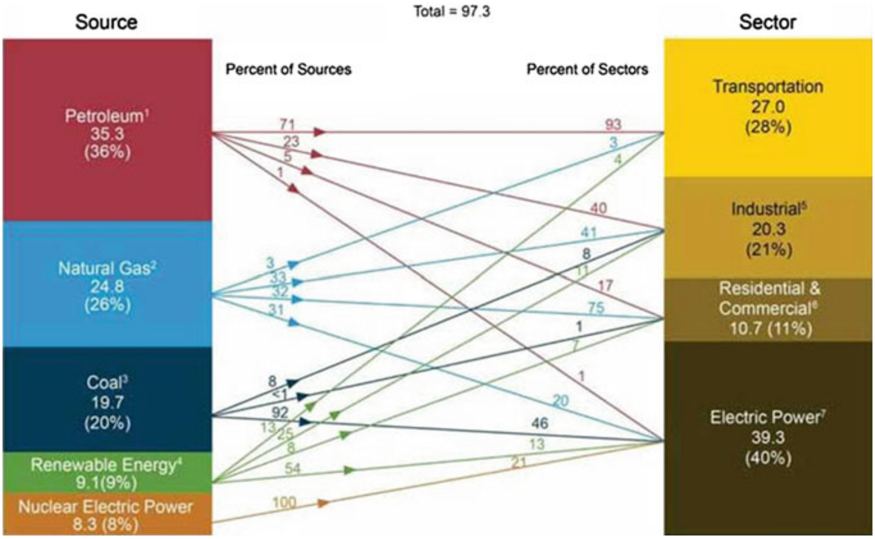

Fig. 5.1 Primary energy consumption by source and sector 2011 (Quadrillion BTU). *Source* EIA (2012)

Energy Return on Investment or EROI

How can we make the best choices about how we spend our remaining energy? Life cycle studies—remember the pencil—can help business analysts find cost-cutting measures. But when it comes to examining the efficiency of an energy source, for instance an energy generating wind turbine and whether or not a better option exists, you need to determine the Energy Returned on (Energy) Invested, the EROI. This is the total energy generated by the wind turbine over its lifetime divided by the energy to build, operate, and recycle it. Its EROI should inform our energy choices.

Clearly fossil fuels have an unquestionably high EROI, because all of our infrastructure and manmade goods were built with fossil energy, and fossil fueled industrial agriculture has dropped the percent of U.S. farming population from 90 to 1 % now (USDA 2012).

When You Do an EROI Analysis, Clearly a Low EROI Is a Problem

There are many investigators that argue that what is important is a positive EROI [e.g. see review by Farrell et al. (2006)]. But it seems clear that to run a modern society you need not just a positive, but a very positive EROI.

Charles Hall, one of the founders of EROI methodology, initially thought an EROI of 3 was enough to run modern civilization, which is like investing $1 and getting $3 back. But after decades of research, Hall concluded an EROI of 12–14 might be necessary to sustain culture and the arts, 12 to provide health care, 9 or 10 for education, 7 or 8 to support a family of workers, 5 to grow food, and so on down to a 1.1 EROI to extract oil, where all you "can do is pump it out of the ground and look at it" (Lambert et al. 2014).

Murphy (2011) found that so much net energy is provided by any energy resource with an EROI of 11 or higher, that the difference between an EROI of 11 and 100 makes little difference. But there is such a large, exponential difference in the net energy provided to society by an EROI of 10 versus 5, that the net energy available to civilization appears to fall off a cliff when EROI dips below 10 (Mearns 2008).

Weissbach et al. (2013) found that it is not economic to build an electricity generating power source with an EROI of less than 7.

There are many problems with EROI studies. They're bound to miss a few steps and exclude energy inputs that are indirect but vital. For example, the Great Pencil Saga left out packaging, distribution, and the final ride to the garbage dump. This can be a problem in EROI studies—when boundaries are too narrow, leaving out steps, operations, and energy inputs such that a misleadingly high EROI is calculated.

Another problem is that EROI research has tended to use national level data rather than site-specific actual data in part because privately owned enterprises tend not to keep track of energy inputs but rather just economic data. Additionally, they tend not to want to share their data with scientists, and when they do, it is in their self-interest to provide only data from their best performing locations.

In my opinion the study that ought to be a role model for EROI standards and methodology is Prieto and Hall's "Spain's Photovoltaic Revolution" (2013), (and also see Murphy and Hall's (2011) protocol for determining the EROI of fuels). The Spanish government saw much good coming from promoting solar power for their sunny environment. Spain imports 90 % of its fossil fuels, more than any other European nation, so it would seem that this would lower expensive oil imports as well. There'd be long-term research and development, a Spanish solar industry, and many high-tech jobs created, since the components for the solar plants would be manufactured locally. To encourage the solar industry, the government provided high subsidies (as much as 64 cents per kWh) to encourage the PV industry.

Prieto and Hall (2013) calculated the EROI of photovoltaics in Spain using a comprehensive approach to energy inputs. Where money is spent they attempted to calculate an energy cost for that money spent. They derived an EROI of 2.45: 1, whereas Raugei et al. (2012) used more narrow boundaries and calculated an EROI nearer to 6–12:1 (unfortunately, a number of issues make it hard to compare the two).

Prieto and Hall used several years of Spanish government data, from over 50,000 large installations at optimal, efficient, multi-megawatt, and well-oriented facilities. Author Prieto actually built some of these Spanish facilities himself, so he understood how to account for every penny. Their study included dozens of parameters not considered in other solar PV studies. The result was a very low EROI of 2.45 in sunny Spain. Even if solar panels were 100 % efficient, the EROI would only go up by a third. And since the Prieto and Hall book was published, Prieto has found additional inputs that would have led to a negative EROI, such as labor energy and the energy to stabilize the electric networks. Not everyone accepts this analysis, but I do think that at a minimum its comprehensive nature is a model for EROI analysis.

Additionally, Spain's photovoltaic revolution, when seen in the clear light of day, was a financial fiasco.

Because the government subsidy was so high, far too many solar PV plants were built quickly—more than the government could afford. This might not have happened if global banks hadn't got involved. They handed out credit like candy.

Even before the financial crash of 2008 the Spanish government began to balk at paying the full subsidies, and after the 2008 crash in Spain (which was partly brought on by this over-investment in solar PV), the government began issuing dozens of decrees lowering the subsidies and the allowable profit margins of the private solar PV sector. In addition, utilities were allowed to raise their electric rates by up to 20 %.

Despite these measures, the government of Spain is still spending about $10.5 billion a year on renewable energy subsidies and on many lawsuits against the lowering of subsidies and profit margins (Parnell 2013a, b). Many solar companies went bankrupt after the financial crash, and about 44,000 of the nation's 57,900 PV installations are almost bankrupt (Nikiforuk 2013). Nor were new jobs, research, and development created, since most of the equipment and solar panels were bought from China.

The end result was a massive transfer of public wealth to private solar PV investors of about $2.33 billion Euros per year. Businesses that depended on cheap electricity threatened to leave Spain.

Conclusion

Replacing oil is a challenge to civilization, and life as we know it. Meanwhile, as long as we have oil, we live in a can-do world. Out of water? Drill a thousand feet deeper or build a desalination plant. Out of fish? Catch the last schools with sonar and spotting planes and then move your efforts to Antarctica. Just wave the magic oil wand, and voila, you can do anything.

But just because it is possible to do anything doesn't mean it should be done. If what we do with the remaining oil is build millions of wind, wave, solar, nuclear, and other energy facilities, then we'd better be damned sure that all the oiliness is accounted for in EROI studies and that we're not wasting the remaining precious oil.

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