In and out have to equal: materials balance and the environment: Or what goes in must come out

Revised August 30, 2018

Lecture on *Materials Balance* -E.R. Morey -.wav file of a past lecture

Analysis of Environmental Pollution, Alan Kneese, *Swedish Journal of Economics*, 1971 - this article is a classic

Earth as a space ship, Kenneth Boulding, 1965 for other stuff by Boulding see http://www.colorado.edu/econ/Kenneth.Boulding/ Ken Boulding was a great economist and a member of this Department. He retired the year before I arrived at CU. He died a few years ago.

Pearce and Turner Chapter 2: The Circular Economy –David Pearce was a leader at the interface of environmental economics and ecology. He died recently, went to the hospital feeling sick and died a few hours later. See David Pearce at Wikipedia

NPR: New antismog restrictions will increase global warming, 01/25/2010, audio at http://www.npr.org/templates/story/story.php?storyId=122626662&ps=rs

I have added my comments to these readings as pdf notes

Materials Balance: An introduction. Edward Morey, August 29, 2018

Environmental economists have a way of thinking about the world that is more inclusive and extensive than the way most other economists think about the world

(For your essay topics, if you are writing an essay, ask yourself whether materials balance is relevant.)

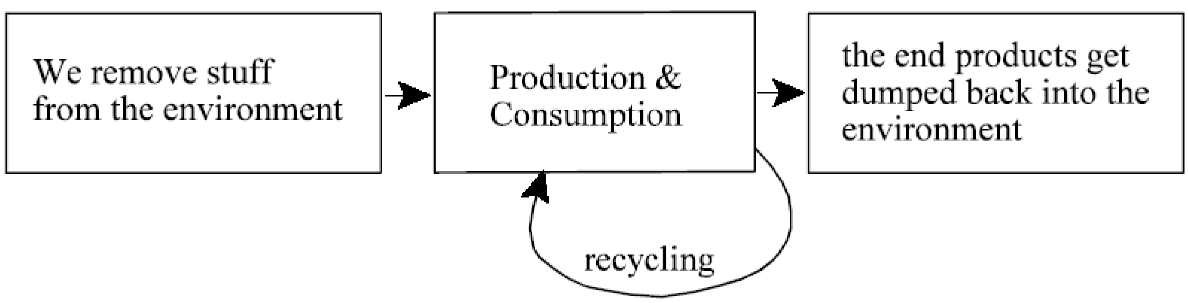
Environmental economists think of

(Production and consumption)

And

(Emissions, waste, and pollution)

As two sides of the same coin – what goes in must come out.



The total amount (weight) of what goes in must equal the total weight of what comes out—why it is called *Materials Balance*: in the long-run the environmental teeter-totter must balance.

Why must it balance? With the exception of nuclear reactions, matter is neither created nor destroyed.[1] (We need to learn a bit about the First and Second Laws of Thermodynamics.)

And,

If it doesn't come out in one form it must come out in some other form. Nothing is lost: production and consumption just change the form of things.

Everything that is produced and consumed has its origins in the environment. Think trees, plants, water, air, and minerals.

I think of production as simply a rearranging of stuff.

Energy is what drives the rearrangement.

Factories take inputs, rearranging them to produce an array of commodities.[2] Some of these commodities are valued by consumers, or other producers, so can be sold for a positive price. Producing these "market" commodities is why the firm is in business. But other less-desirable commodities are produced as well. The other commodities produced are called *emissions*, or more precisely, *non-market emissions* – one could think of goods as one type of emissions, the good type.

---

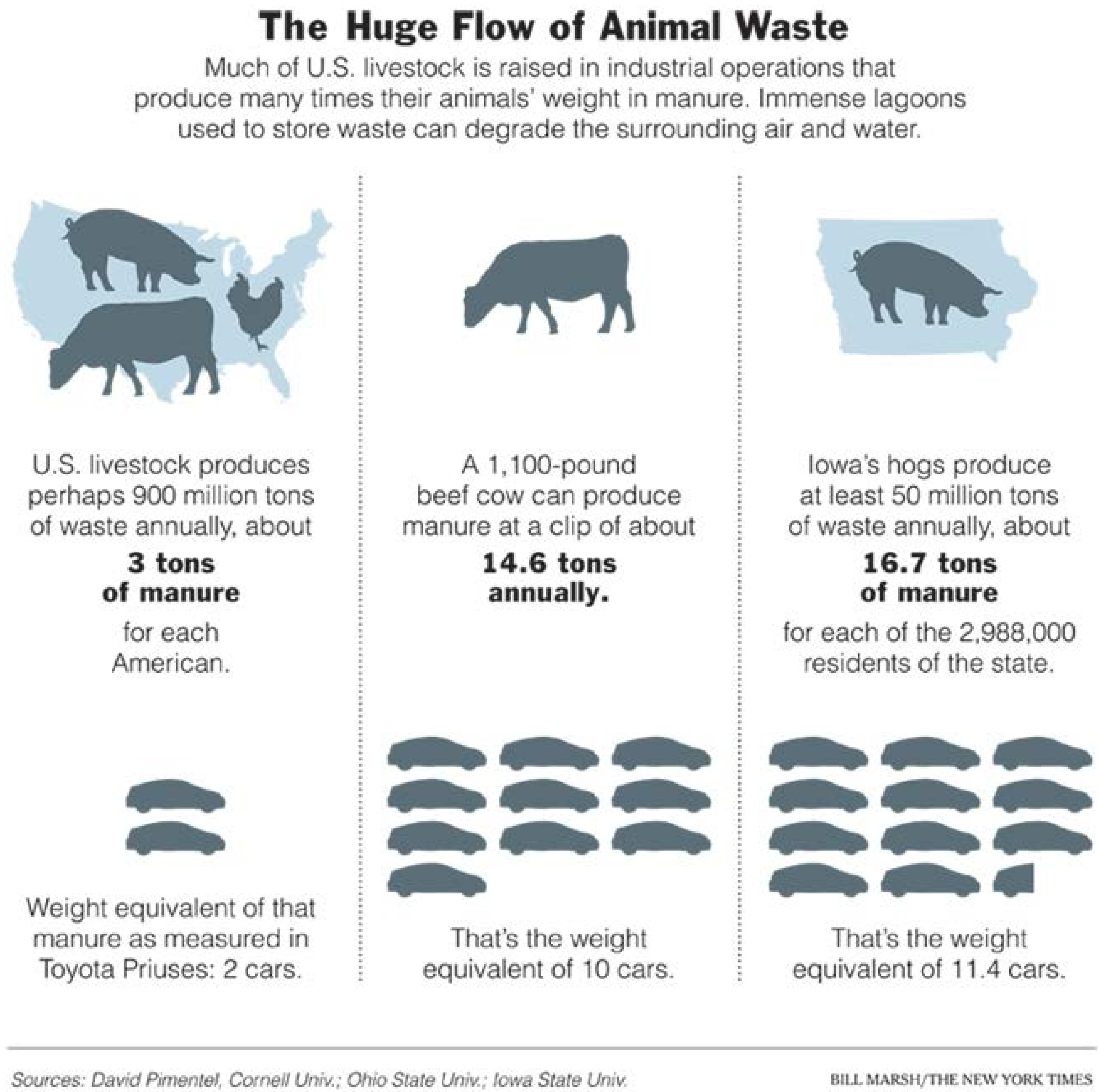
1 The same is true of energy. Google the "First Law of Thermodynamics."

2 In principles of economics courses, firms are presented as entities that produce a single product, a good. This is too simplistic. The "single product" firm produces a vector of outputs, but only sells one of them. Many firms produce many products, and sell a subset of what they produce.

The total weight of the inputs used by the producer must equal the total weight of the market goods and other emissions generated by the production process.

In many production processes, the weight of the other emissions is much greater than the weight of the market goods produced. Think of how much of the material in a tree actually ends up in products consumed by individuals. The weight of the marble waste that was generated in the production of Michelangelo's David probably weighed more than the David weighs, and don't forget to include in the emissions Michelangelo's sweat and all of the worn out chisels.

A lot of paper and cardboard ends up on your car floor after you have finished the Big Mac.



Copied from [M. Bittman, Rethinking the Meat-Guzzler, NYT, Jan 27, 2008]

So, if you an average U.S. meat-eater who goes vegetation there will be 6000 fewer pounds of shit a year. (Note that I am not saying you should do this: bacon tastes wonderful)

Some emissions take up space but, other than that, cause little injury or harm. Other emissions cause injury. The injury can be as mundane as the unsightliness of a junk pile or couch in the front yard after the students have moved out, or life changing, such as toxic chemicals that cause birth defects.

The term *consumption* is also a misnomer. Consider the plight of Big Macs – you don't have an anti-matter machine in your stomach. Consumption is, like production, just another rearranging of stuff. Consumers break down/rearrange the products they buy by expending energy, chewing, swallowing, and digesting.

In the case of Big Macs and bananas, the process is quick and obvious, less quick for marble statues.[3] Cars and stereos break down faster than marble statues but slower than Big Macs. Energy is what drives the process.[4] The total weight of the materials you consume is not "consumed;" it just ends up in another form: respiration, fat, poop, couches in the front yard, trash.

It would be interesting to weigh everything you buy in a week (or month) and also everything you throw away or discard. Don't forget to weigh yourself as well, and all the stuff that goes down the toilet. This could be the topic of an essay for the course.

---

3 I recently learned through reading, not experimentation, that it takes, on average, about 50 hours to move stuff from mouth to butt, but there is wide variation across individuals. Alcohol speeds up the process. It also depends on whether something happens that "scares you shitless." See C.S.J. Probert, et al., Some determinants of whole-gut transit time: a population-based study, *Quarterly Journal of Medicine* 88, 311-315 (1995). And R. Bowen at http://www.vivo.colostate.edu/hbooks/pathphys/digestion/basics/transit.html

4 E.g. the energy from the sun causes a lot of things to break down.

The process of consumption makes me think of something written by the noted philosopher Harry G. Frankfurt, a famous philosopher, writing on *bullshit*.

When we characterize talk as hot air, we mean that what comes out of the speaker's mouth is only that. It is mere vapor. …..

There are similarities between hot air and excrement, incidentally, which make hot air seem an especially suitable equivalent for bullshit. Just as hot air is speech that has been emptied of all of its informative content, so excrement is matter from which everything nutritive has been removed. Excrement may be regarded as the corpse of nourishment, what remains when the vital elements in food have been exhausted. In this respect, excrement is a representation of death that we ourselves produce and that, indeed, we cannot help producing in the very process of maintaining our lives. (*On Bullshit* by Harry G. Frankfurt, Princeton University Press, 2005.)

His article/book on bullshit got him on The Daily Show.

Recycling is another is another type of rearrangement of stuff: we take emissions that have no or little market value, and using energy, combine them with other stuff to produce commodities that have value to producers or consumers. The more we recycle the more time it takes for the weight of the stuff we remove from the environment to equal the weight of the stuff that ends up back in the environment.

Keep in mind that recycling is not free: it requires additional resources and energy to turn waste into a valuable commodity.

Eventually, all the stuff that was taken from the environment for our needs ends up back there as our waste.

Why aren't we buried up to our necks in the waste of our ancestors: Julius Caesar's flip-flops, Benjamin Franklin's poop, and a whole lot of dead bodies?

The *assimilative capacity* of the environment

The environment has the ability, within limits, to break down and clean our waste, producing enew environmental commodities that will be become inputs into production and consumption. This process of breaking down and renewing is driven by energy, typically from the sun (stuff rots in the hot sun). Some types of emissions are easier to break down than others; food and human waste break down rapidly, toxic chemicals and nuclear waste can take thousands or millions of years to break down.

You paint or stain your house to decrease the rate at which its siding breaks down.

If too much biological pollution is put in an environmental sink such as a river, the sink will be overwhelmed and lose it ability to assimilate the stuff. In the case of a river, it will atrophy (die).

This holistic (materials balance) view of production and consumption has some important implications for environmental policy:

1. It is important to distinguish between emissions and pollution. Some emissions are neutral, and some are bad, and some are "badder" than others. We call the bad stuff "pollution". Are any emissions good?

2. The only way to have zero emissions is to have zero production and consumption. Zero emissions are neither efficient nor equitable.

3. What is *pollution abatement*/reduction? Labor, capital, and energy allocated to pollution abatement does not make the material disappear. The process converts the pollution into a different, hopefully less harmful, form—we can't make matter disappear. Pollution abatement is a process of transformation, not a process of elimination.

> (Consider a refinery smoke stack with and without scrubbers. What happens to the waste? With scrubbers, it gets converted from air pollution into wet/dry solid waste.
>
> 
>
> Scrubber waste
>
> http://pittsburgh.cbslocal.com/2013/03/15/residents-taking-operators-of-fly-ash-disposal-site-to-court/
>
> http://www.wvillustrated.com/story/20660566/firstenergy-may-ship-mansfield-scrubber-waste-to-pa-mine
>
> http://ens-newswire.com/2013/01/12/tva-permit-to-dump-liquid-waste-from-air-scrubbers-appealed/

Materials Balance: An introduction. Edward Morey, August 29, 2018

4. Recycling waste into useful stuff requires that energy and scarce resources be allocated to recycling. E.g. paper waste does not magically convert itself to recycled paper. If we could costlessly convert bads into goods, we always would.[5]

5. Society can reduce emissions, and pollution, by reducing production and consumption.

6. Society can reduce emissions, and pollution, by increasing recycling, but this requires additional inputs and energy.

7. Society can reduce pollution by converting bad emissions into less bad emissions. Again, this takes energy and other resources.

8. Given the state of technical knowledge, and assuming efficiency in production and full employment of resources, can society hold production, consumption and recycling constant and reduce overall emissions?

NO. Possibly yes if current production processes are inefficient.

9. Given the state of technical knowledge and assuming efficiency in production, can society hold production, consumption, and recycling constant and reduce pollution?

---

5 I worked for years on a legal case about PCB pollution in the Bay of Green Bay, a large bay on Lake Michigan. The PCB pollution was the result of recycling: PCBs were used to remove the ink from newsprint.

> Maybe? It requires that there is unemployed labor, capital, and energy, and that some of it be allocated to converting pollution to less damaging forms. That is, total emissions would remain constant, but we would change their composition.

What are the implications of materials balance for environmental policy?

Think about how we dispose of our wastes; it must be emitted either into the air, the water, or dumped on the land. We could also shoot it into outer space, but that would require a great deal of energy.

What will happen if we decrease air pollution holding production, consumption and recycling at their current levels?

> We will most likely increase water pollution, solid-waste pollution, or both.

Environmental policy should not consider different types of pollution in isolation. They are all different forms of the same thing, so cannot be correctly managed in isolation of one another.

If we pass a law that requires firms to reduce air pollution they will likely respond by producing more water pollution and solid-waste pollution: it has to go somewhere.

The environmental issue is often not so much one of reducing emissions but rather deciding on the mix of pollution/emissions that is efficient and equitable. There is also the question of where the emissions occur, and the question of how and where the wastes are stored. In poor neighborhoods?[6]

---

6 Is it more efficient to store them in poor rather than rich neighborhoods?

So, some physics about the conservations of matter and energy:

There is the *law of conservation of mass*

It implies that matter can neither created nor destroyed.

But the matter can change form.

Materials balance follows.

For example, in a chemical reaction (e.g. burning gasoline) the mass of the chemical components after the reaction must equal the mass of the initial chemical components.

Note that the law is not always true: there are violations when it comes to nuclear reactions, quantum mechanics, and special relativity, but for our purposes it's a law.

For example, burning coal and wood does not affect the mass: the total weight of the stuff burned just goes up in smoke (gases and particulates) except for the charred stuff that remains in the fireplace

The same is true when your car burns a gallon of gasoline: a gallon of gas weighs 6.2 pounds, and so does the exhaust.

Parallel to the conservations of matter is the law of the conservations of energy (the **first** law of thermodynamics)

Put simply, the total amount of energy in an isolated system is a constant

Energy can be stored in different ways: the energy stored in logs and gas is *chemical energy*.

https://en.wikipedia.org/wiki/Energy
Jump to Forms - Common forms of energy include the *kinetic energy* of a moving object, the *potential energy* stored by an object's position in a force field (*gravitational*, electric or magnetic), the *elastic* energy stored by stretching solid objects, the *chemical energy* released when a fuel burns, the *radiant energy* carried by light, ...

Sound is another way to store energy.

Chemical energy, according to Wiki is "the potential of a chemical substance to undergo a transformation through a chemical reaction to transform other chemical substances. Examples include batteries, **food**, **gasoline**, and more. Breaking or making of chemical bonds involves energy, which may be either absorbed or evolved from a chemical system….

Chemical potential energy is a form of potential energy related to the structural arrangement of atoms or molecules. This arrangement may be the result of chemical bonds within a molecule or otherwise. Chemical energy of a chemical substance can be transformed to other forms of energy by a chemical reaction. As an example, **when a fuel is burned** the chemical energy of molecular oxygen is converted to heat,[1] and the same is the case with **digestion of food** metabolized in a biological organism.

So, when you burn a log in the fire place or a gallon of gas in your car, the matter is conserved, and so is the energy. Burning stuff is a chemical reaction that converts chemical energy into heat energy. The matter changes form (the liquid is converted into gases and particulates) but the amount stays the same. The total amount of energy in the system also remains the same: some of it directly heats the air without making your car go faster, the rest first powers your car and then dissipates in the environment.

Unfortunately, there is the *second law of thermodynamics*.

It says that in an isolated system, while the total amount of energy remains constant, entropy cannot increase (it will remain constant or increase over time).

Entropy is a measure of the amount of work (moving your car, heating your house) the energy can produce: increased entropy means a fixed amount of energy is capable of less work.

If energy is converted from one form to another, it entropy increases.

This is sad? It means no perpetual-motion machines.

Picture an electric water-heater that heats the pool in your backyard by circulating pool water through the heater. You heat your pool to 70 degrees and then turn off the heater. Assume the air temperature is less than 70 (otherwise the air would have eventually heated the water). What happens to the energy stored in the water in terms of heat? It dissipates into the air until both the water and air are the same temperature. And, now it is more difficult to use that energy. It’s the law, the second law.

Think of the earth, which is not a closed system: energy is lost to space and energy is absorbed from the sun. If more is absorbed from the sun than is lost to space, earth increases in temperature. That is called global warming.

While the earth is effectively a closed system with respect to materials (at least until we start mining the moon), it is not closed with respect to energy. The sun is an outside source. Dissipated energy can be pollution; think noise and unwanted heat.

Can we recycle energy?

Yes, but every time we recycle the same energy, we get less useful energy (the recycled energy is not as a productive from our perspective; it is more difficult to harness)