Chapter 1

Earth's Climate and Some Basic Principles

1.1 One of the Greatest Crimes of the 20^{th} Century

What was this crime? "...In 1949 a federal jury convicted GM (General Motors), Standard Oil of California, Firestone Tire, and others of conspiring to dismantle trolley lines throughout the country (U.S.A.)."[1]

My father once told me when I was very young, as we sat in a traffic jam, that there used to be electric-powered trolleys (also called streetcars, or light rail) in Los Angeles, before General Motors came in and bought up the trains, tracks and rights of way and did away with them. That comment sat deep in my unaccessed memory until decades later I went to a showing of the movie, "*Taken for a Ride,*" by Jim Klein and Martha Olson[2] held at my public libary.

Discussion of this crime is not yet part of the educational experience of most Americans, while the effects of this crime have been global. That is one of the reasons I bring it to your attention now. The fact itself is important for understanding current transportation and energy troubles, as we shall see; but the lesson in *media literacy* that it begins (more later) is equally important. This crime is also connected to many other important and timely topics to be discussed momentarily, some with strong mathematical content. Thus this section is an illustration of a pattern about which famous conservationist John Muir (1838–1914) said: "When we try to pick out anything by itself, we find that it is bound fast by a thousand invisible cords that cannot be broken to everything in the universe."

Less poetically I enshrine this pattern in the following *assumption*:
Connection Axiom: *Everything is connected to everything else.*

[1]See [416, p. 13]. Although this crime was committed in the U.S.A., it is relevant to the reader for several reasons, irrespective of the country in which the reader resides. This little known fact might have been lost to history had it not been for the work of Bradford Snell, [645].

[2]I highly recommend this video as a scholarly, yet entertaining and accessible, account of "the crime." It is available from NEW DAY FILMS, http://www.newday.com/films/Taken_for_a_Ride.html.

1.2 Feedback

There are two examples of *feedback loops* associated with the elimination of intraurban electric rail transportation systems in the 20^{th} century: one with *positive* growth and one with *negative* growth.

General Motors established the National Highway Users Conference, consisting of over 3,000 businesses associated with cars, to lobby the federal government for highways. One of their legislative triumphs was to get a federal tax on gasoline dedicated exclusively to road construction, without annual review, [416, p. 12]. Thus gas taxes lead to more roads which lead to more driving (as long as oil is sufficiently cheap) which leads to more gas taxes and repeat. In this next exercise we play with some (made-up to be simple) numbers to see how the mathematics works in a feedback loop with *positive* growth.

Exercise 1.1 A Feedback Loop with Positive Growth opar (i) Let's simplify the numbers as follows, until we understand the ideas involved. Suppose that for each 1 mile of road \$100,000 is generated each year in gas and other user taxes. Suppose that it costs \$1,000,000 to build 1 mile of road. In year 0 start with 1 mile of road. After 1 year, this mile has generated \$100,000. Our 1 mile of road can then be extended by how many miles using the \$100,000 generated that first year? (Hint: the answer is a fraction of a mile.)

(ii) How much gas tax will 1.1 miles of road generate in year 2? (For simplicity, we assume that the 1 mile of road instantly becomes 1.1 miles long at the end of the first year. Make a similar assumption at the end of the second year and so on.)

(iii) How much additional road can be built for \$110,000?

(iv) At the end of 10 years how much road will there be and how much gas tax will it generate in the following year?

(v) After 10 years will any money be required to go back and renovate "potholes" or other degradation of the existing roads?

Over \$220 billion was spent on road construction by the U.S. federal government in the last three decades of the last century; with state and local governments spending far more than that on roads. From 1956 to the 70s for every dollar the federal government spent on rail transit it spent over \$88 on highways. This ratio improved in the direction of mass transit in the 70s, never reaching parity, but in the 80s federal highway spending increased by 85% while mass transit spending lost 50%, a trend continuing into the 90s, cf., [416, p. 13]. Consider the following exercises about "percents," cf., Exercise 13.2 (viii).

Exercise 1.2 Percent Change

(i) During the 1980s federal highway spending increased by 85%. Now 85% means $\frac{85}{100}$, a fraction, which can also be written .85; thus given \$1, the increase is \$1 $*$ .85, or \$.85, i.e., 85 cents. What is the sum of the base amount, \$1, and 85% of the base amount? Note that $*$ means multiplication.

(ii) During the 1980s federal spending on mass transit decreased by 50%. So each dollar spent before 1980 is reduced to how much after 1980?

(iii) Suppose the following: in 1980 you spent $1. In 1981 you decreased your spending by 50% over the year 1980. Then in 1982 you increased your spending by 50% over the year 1981. How much did you spend in 1982? Exactly one dollar? More than a dollar? Less than a dollar? How much exactly?

The second feedback loop employed by the GM-led conspiracy was to use a bus company, like National City Lines, which the general public did not know was associated with GM, to go into cities. They would buy up the trolley service, then decrease service thereby diminishing demand, leading to further cuts in service – and then repeat until the trolleys ceased to exist. By 1949 more than 100 electric transit systems in more than 45 cities (90% of the trolley network) had been destroyed, replaced first by buses that were slower and less popular, and then eventually by cars. Let's look at how the math works in such a feedback loop with *negative* growth.

Exercise 1.3 A Feedback Loop with Negative Growth

(i) Suppose you start with 1 unit of demand for an existing 1 unit of trolley service in some city. Suppose National City Lines buys the trolleys and decreases service by 20%. Do you see that now there is .8 units of trolley service?

(ii) The decrease in service makes it more difficult or impossible for some people to use the service so suppose demand drops to .8 units, to meet the amount of available service. Citing the decrease in demand, National City Lines cuts service by 20% again. Do you see that now there are $.8 - .8 * .2 = .8 * (1 - .2) = .8 * .8 = .64$ units of trolley service?

(iii) Suppose that demand drops to meet available service once more, and that service is once more cut by 20%. How many units of trolley service exist now?

(iv) When service drops to less than $\frac{1}{3}$ of a unit, say, the trolleys are discontinued. How many iterations, i.e., repetitions, of the above process does it take for this to happen?

1.3 Edison's Algorithm: Listening to Nature's Feedback.

An *algorithm*, when defined generally, is a step-by-step problem-solving procedure. Thomas Alva Edison (1876–1933) was a famous American inventor with more than a thousand patented inventions, including the incandescent light. Edison reportedly replied to those who commented on the enormous number of "failures" he encountered as he tried one material after another in the search for a functioning filament for his "light bulb:" Those were not 100 failures, for I now know 100 things that do not work.

When you find yourself in a situation with insufficient information to solve some problem (and that's all of us at one time or another), you may be left with no other alternative than to try various things and see what happens. Of course, "insufficient information" rarely equates to "no information at all," if for no other reason than other folks have encountered similar problems before us – tried this or that out – and records of what works and what doesn't were kept.

Humans have been doing lots of things for a long time, and *learning from previous mistakes* might be considered a hallmark of cultural progress. I make explicit this folk wisdom in the following.

Edison's Algorithm. *Given a problem, research what is known about what might work and what might not work, i.e., what might lead to a solution. Using this information attempt solutions (**experiment: observe Nature**), and record the results – to the best of your ability.*

I have found this algorithm surfacing in my own life in organic farming, house building, teaching, and especially in mathematics! Keep it in mind while tackling the homework problems.

A corollary of Edison's Algorithm, or a product thereof, is a *list of rules.* (A corollary of a statement 1 is another statement 2 that logically and easily follows from statement 1.) As mistakes (a mistake by definition leads to undesirable results) are made, investigations are (should be) carried out which isolate the cause(s), and rules are (should be) adopted to avoid making those same mistakes anew.

Corollary: *Lists of rules for solving a particular problem and avoiding previously made mistakes arise from successful implementation of Edison's Algorithm.*

Now Edison's Algorithm and its corollary are so simple and obvious that you might wonder why I take the time to write them down. True, following a set of rules does not guarantee success, but not following "the rules" usually leads to the opposite. Unfortunately, powerful decision-makers all too often ignore the simple wisdom of following rules proven to work. Disasters result. Let's look at some specific examples.

Exercise 1.4 Edison's Algorithm and Lists of Rules

(i) On April 5, 2010 there was an explosion at Massey Energy's Upper Big Branch (Coal) Mine killing 29 miners. According to the Mine Safety and Health Administration (MSHA), see http://www.msha.gov, this mine had 515 citations and orders in 2009, and 124 in 2010 as of May 24, 2010. (See also page 28.) A citation is given for violation of a rule. For example, there are standards for mine ventilation which when followed prevent the buildup of methane gas to dangerous (explosive) levels. Investigate at least two of the violations which were likely proximate causes of the explosion. Discuss the extent to which this is an example of not following Edison's Algorithm and Corollary – even a pattern of such. How much authority does MSHA have? How big are the fines associated with the violations? Is there too much regulation of coal mines, too little? Why? Are whistleblowers fired, see part (viii) below? List all of the causes of system failure you can find in this case and rank them in order of importance.

(ii) On April 20, 2010, the Macondo oil well of BP-Deepwater Horizon in the Gulf of Mexico blew out, 11 workers killed. It took about 100 days to bring the well under control. Find 2 rules (at least) BP violated. (See, for example, *CBS 60 Minutes*: http://www.cbsnews.com/stories/2010/05/16/60minutes/main6490197.shtml, "Blowout: The Deepwater Horizon Disaster." See also "BP's Deep Secrets," by Julia Whitty, *Mother Jones*, Sept/Oct 2010.) Just the year before, the Montera oil rig, operated by PTTEP Australasia in the Timor Sea, blew out on August 21, 2009 and was not capped until November 1, 2009. Previously in the Gulf of Mexico, the Ixtoc 1 (1924' N, 9212' W) oil well being drilled by Pemex blew out on June 3, 1979. It was not capped for 297 days. On January 28, 1969, Union Oil's Platform A off the coast of Santa Barbara, California blew out and went uncontrolled for about 8 to 10 days. Oil disasters are too numerous to list in this book. For example, research the fairly well-known oil pollution in Nigeria and Ecuador, and the not-so-well-known oil disaster in Bolivia, cf., [615, Chapter 2]. Then there was the Exxon-Valdez, cf., page 25, and Exercise 13.12.

Two decades after the Exxon-Valdez serious environmental impacts remain, contrary to some prognotications in 1989–90. (On June 25, 2008, after a long wait, plaintiff's original \$5 billion dollar punitive damage claim, i.e., equal to about one year's Exxon profit at the time of the spill, was reduced by 90%, to about $\$\frac{1}{2}$ billion by the U.S. Supreme Court.) Evaluate each of the above oil-examples for their ecological and economic impacts (so far). For example, regarding the BP blowout in the gulf: How are the Atlantic bluefin tuna, sperm whales, Kemp's Ridley sea turtles, bottlenose dolphins, the Atakapa-Ishak indigenous people, and all others who make their living from the Gulf waters doing when you read this? The Union Oil blowout near Santa Barbara in 1969 is credited by some with inspiring the environmental movement of the 70s. Did the BP Deep Horizon blowout in the Gulf of Mexico inspire American environmentalism to the extent that renewable fuels/energy are taken seriously? How effective was the legal and public relations efforts of BP in blunting response?

While the MSHA inspectors were handing out citations, see part (i), the MMS, Minerals Management Service (agency of the U.S. government managing oil, gas, and other mineral resources on the outer continental shelf, www.mms.gov. Note that in June 2010 the MMS changed its name to the Bureau of Ocean Energy Management, Regulation and Enforcement.) was giving exemptions from comprehensive environmental review to projects such as BP's Deepwater Horizon. Find 2 rules, at least, MMS violated. In the first decade of the 20^{th} century the MMS was saturated with its "sex, drugs, and paintball" scandal. Industry representatives were giving "perks" to, sharing drugs with, and having sex with agents from the MMS. (There are a number of other operations the MMS has given exemptions from review, some operating in the Gulf of Mexico.)

Research each of these oil-examples, find as many instances as you can where those involved did not follow known rules for safety and reliability. Investigate the extent to which censorship of information on the part of participating corporations (and government) was/is practiced. In particular, investigate BP operations, such as Deepwater Horizon, Atlantis, and those in Alaska and Texas, decide if you have found a pattern of BP ignoring known rules. Pick some large ecological disasters caused by humans and compare their impacts to the impacts to the U.S. caused by the terrorists of 9/11/2001.

List all of the causes of system failure you can find in each of these cases above and rank them as best you can in order of importance.

(iii) Research the technique of *hydraulic fracturing* for oil and gas recovery. In particular, study the safety and environmental record of this process. Consider the proposal to drill in the Marcellus Shale, cf., page 466, in the geologic formations that provide water for many New Yorkers. Have the heretofor secret names and amounts of chemicals injected into such wells been released by the industry at the time you read this? Given the rate of known accidents, what do you estimate the chances are of conducting natural gas drilling in the Marcellus Shale without greatly, negatively impacting the drinking water resource?

(iv) Can we move to a fossil fuel free economy, and thus eventually avoid most of the problems associated with fossil-fuel extraction? See Chapter 6.

(v) Read about the January 28, 1986, Challenger disaster, cf., Section 8.4. Find several known essential rules that were not followed by those in charge of making decisions. (Richard Feynman discovered several, see [188].)

(vi) Certain rules for governing the financial industry (rules for avoiding collapse, for example) were learned during the first Great Depression of the 1920s and 30s, see Chapter 2. For example, the Glass-Steagall Act of 1933 was passed, and reasonably enforced until it was repealed in 1999. The financial collapse of 2008 and following years led to a reexamination of "the rules." The financial reforms of 2010 notwithstanding, we have not yet been able to fully return to the "rules" that were learned the hard way in the first Great Depression. Why is this?

(vii) Does a successful following of rules inevitably lead to complacency? Is this an intrinsic human problem? Can complacency be avoided?

(viii) Those who are in the best position to discover new rules, or observe enforcement (or non-enforcement) of known rules are often not in a position of authority. Those who dare speak up in such situations are called *whistleblowers*. Allowing whistleblowers to make their information available in a forum that leads to progress, positive change, would seem advisable. I was told that the safety, such as it was (is?), of the U.S. airline transportation industry, owed its success to a program wherein whistleblowers could reveal information annonymously to the FAA, Federal Aviation Administration, www.faa.gov. Research the fate and impact of at least 3 whistleblowers in any areas of your choice.

(ix) When should a list of rules be revisited for possible revision? Are there rules for this?

(x) Since there are often several causes for a given effect, there arises ample opportunity for "spin" or to play the "blame game." Can you think of a method of listing causes of a given effect and ranking them in order of importance. When arguments arise among parties, for example, one should at least create a list of causes that includes all causes mentioned up to that point. Then one can argue a ranking, and give explicit details of one's reasoning.

(xi) Examples above discuss multiple causes for a given effect. Can you think of examples of circular feedback where A causes B, B causes A, and so on?

(xii) If it is known that violating certain rules increases the accident or death rate in a given situation, then decision-makers so empowered who violate those rules are at least statistically linked to the increased number of accidents or deaths. Said another way, the decision-makers who knowingly violate safety and reliability rules do cause accidents and deaths. It is just not always clear which accidents or deaths. Why is it that such decision-makers are not held accountable in our society, as are, say, murderers in the classical sense?

(xiii) Deciding to intentionally ignore known rules (of safety/reliability and so on) for whatever reason (one is in a hurry, one can make more money if one skips a few safety procedures ...) is grounds for isolating that decision-maker from the rest of us – to a degree and for a duration – commensurate with the extent that person's actions have been an unnecessary contributory cause of pain, death, dismemberment, or discombobulation (ecological, economic, social, or otherwise). Comment.

(xiv) Is it a rule (or observable pattern) that in any system run by humans that known rules set in place to avoid mistakes and achieve success will eventually be violated due to incompetence, complaceny, impatience, greed, laziness, or stupidity? What system(s) do you envision can be put in place to avoid this type of meta-mistake? Besides making sure that our educational system includes teaching a respect for the rules that Nature/reality has taught humans over time (with examples), consider Part VIII.

I will now return to our discussion of one of the greatest crimes/mistakes of the last century.

1.4 Fuzzy Logic, Filters, the Bigger Picture Principle.

My experience has been that the following claim is generally accepted as true by most people, including experts in history with whom I have communicated. None of the folks with whom I have discussed this subject and who believed the following claim were aware of "the crime" mentioned above.

The Claim: Buses replaced trolleys, and were in turn replaced by cars because the public wanted it that way.

Now it is possible that there was at least one person in 1920, say, that had a car and wished that the trolleys would get out of the way. (For example, in 1918 only 1 family in 13 had a car, by 1929 4 out of 5 families had one.) So "The Claim" is probably not completely false. On the other hand, trolleys were quite popular. In fact, we have the following observation from [430, p. 26]: "*Electric trolleys were born in the USA. They chalked up their first commercial successes in America and they gave Americans a first-class system at a time when public transport in London, Berlin and Tokyo was still mired in horse manure. Trolleys are as indigenous to America as jazz, baseball and abstract expressionism. Why then were they killed off in the United States while they and their latter-day incarnations were viewed throughout most of the world as both winsome and essential?*"

It is quite likely, then, that "The Claim" is not completely true; recall the findings of federal court that begin this chapter.

Mathematicians can handle a situation like this with *fuzzy*,[3] or more precisely, *measured logic*. Thus a truth value of 1 for our claim corresponds to the claim being completely, i.e., 100%, true. A truth value of 0 corresponds to the claim being completely false, i.e., 0% true. Any truth value between 0 and 1, e.g., $\frac{1}{2}$ or $\frac{3}{11}$, is possible.

I have not seen a great many well-documented writings on the claim. However, the following references suggest that the truth value of the claim is near 0, [39, 430, 142, 416, 679].[4]

What I have just done is *filter* the information presented to you. See Figure 32.1 in the final chapter (on Media Literacy) and duplicated below.

This happens to all of us all of the time. I have not included all references to the claim that exist, in fact this is not possible. There are probably references I do not know of. I did not include references without documentation. Some references might pop up after this book is published. Statements have been made in support of the claim – or else the claim likely would not even exist.[5] I have just indirectly referenced some of these statements, but have not found supporting evidence for the claim that holds up under thorough examination. In fact, I claim that we would have both a robust electric rail system and a system of roads and cars had "the crime" not been committed. Thus there are at least two competing views of the claim, quite a common situation.

What is one to do? In a word "triangulate." If an issue is important to you it is necessary to expend the time and energy to find as many references as you can, at least two or three which are as mutually independent as possible. Direct experience certainly counts as "a reference," but more often than not we must rely on the experiences and reporting of others. Do not fall into the trap

[3]Lotfi Zadeh introduced the term "fuzzy sets" in 1965 in order to *more precisely* model certain phenomena. Fuzzy does not mean muddleheaded in this context.

[4]Other references are *Car Trouble* by Steve Nadis, James J. MacKenzie; an article in the February 1981 *Harper's* by Jonathan Kwitny; an article by Morton Mintz in the May 1974 *Washington Post*; and *Corporate Crime and Violence* by Russel Mokhiber, 1988.

[5]For example, see the movie: "Taken for a Ride," cf., page 3.

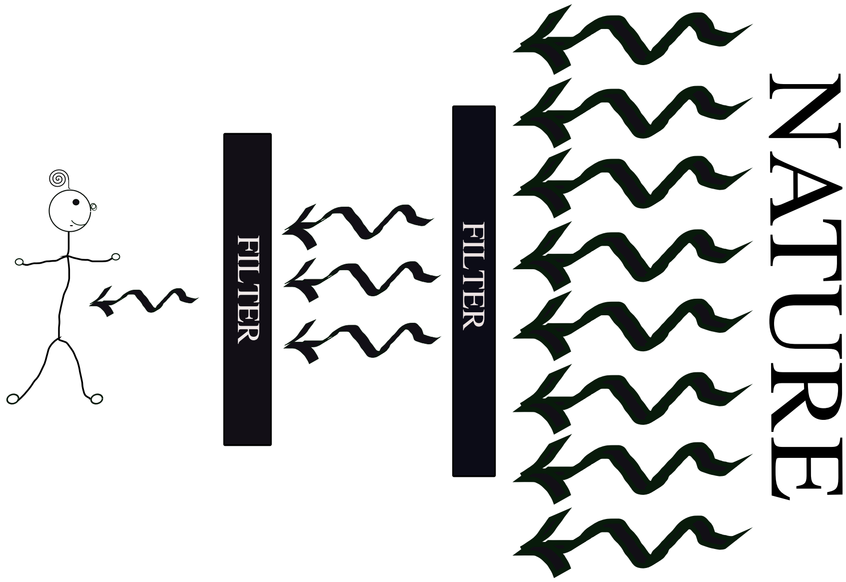

FIGURE 1.1: Filters Between You and Nature

of only finding references you agree with. Find contrary sources, arguments; compare them with yours. Which argument is most rigorous? Most convincing? To whom? *Can you find a "Picture" big enough to explain all arguments in contention?* Always document, but realize you can "document" anything; how many references, e.g., Web sites, can you find asserting ("proving") that the earth is flat? Do not fall into the trap of always relying on information that is most easily available. Be *critical*! To paraphrase Upton Sinclair: *it is difficult to get a man to understand* (or be *honest* about)[6] *something when his job* (finances, friendships, or social status) *depends on* **not** *understanding* (or being honest about) *it.* Always check sources for a *conflict of interest*! For example, ask: Who pays the source? How much and why? If possible, repeatedly return to an issue for as long an interval of time as possible. Does new information surface? Do new connections, new patterns emerge? While searching for information keep in mind that as early as 1995 the number of professional propagandists, known as PR (public relations) personnel, 150,000, was larger than the number of (news) reporters, 130,000; by 2008 there were almost 4 PR persons for every 1 employed as a journalist, editor, reporter, or announcer in the newspaper, radio, or TV industries. Often what is presented as "objective news" is just PR disguised as news, [560, p. 2], [181], [424, p. 49].

[6]Note that I define *honest* to mean *being one with what is.* Nature is what "is," and I suggest that Nature is the ultimate arbiter.

If you go through the process of the previous paragraph, I say that you have applied the *Bigger Picture Principle*. Is your picture big enough to contain, explain, understand all of the information, arguments on the subject under scrutiny? There are whole industries, cf., advertising, public relations/propaganda, lobbyists, and more, devoted to presenting smaller pictures leading to preordained conclusions. It is somewhat surprising to me that such industries can sometimes lead people (sometimes yours truly) into clearly behaving against their own self interest. But humans fooling other humans is quite common. When humans are dealing with Nature, however, honesty is imperative; for *Nature cannot be fooled*. By the way, I am making the tacit assumption that there is one all encompassing reality, which includes all of us;[7] and I call it Nature.

Exercise 1.5 Bigger Pictures are Models

(i) Why do I talk about Bigger Pictures but not the Biggest Picture?

(ii) Exercises 1.1 and 1.3 are examples of simple *models* (of small parts of Nature). I refer to the (entire) picture of Nature that you have in your mind as your *mental model*. Estimate how much of your mental model of Nature, i.e., reality, has been put there by others, and how much you have had a direct, dominant role in creating. How much of your mental model comes from your direct observations of Nature, without intervening (human) filters? How much of your mental model is the product of your imagination? Pick someone else and ask (and try to answer) these same questions about their mental model.

(iii) I have heard the following claim: Anything I really need to know will be presented at or before the time I need to know it in the "mainstream news," e.g., television, newspapers, news magazines, or will have been presented in textbooks and such materials during my educational experience. I assert that "the crime" of section 1.1 is a *counterexample* to this claim. Thus the truth value of this claim is not 1. What is your estimate of the truth value of this claim? Can you think of very important examples, e.g., involving life and death, nations going to war, where the claim is mostly false? Can you think of cases where the claim is mostly true?

(iv) You probably have heard of *spin*. Is spin, to the extent that it does not contain outright falsehoods, just the process of presenting a smaller picture favorable to pre-ordained conclusions?

Many generations ago people believed that eating liver cured night blindness and eating citrus cured scurvy. People were led to this model by direct observation of Nature, and this model *worked* long before the discovery of vitamins A in liver and C in citrus.[8]

Since ancient times the Warlpiri Aborigines of Australia, cf., III, have believed that when harvesting yams, only a fraction (say one-third) of any particular yam should be taken at a time. To take more would anger the Yam God, and the plant would die. Although their mental model of the situation may be considered a *myth*, this mythic mental model passes an important test: it works for them – it contributed/contributes positively to their sur-

[7]As in *Not Man Apart; Lines from Robinson Jeffers*, author David Brower, Sierra Club Book, January 1, 1965.

[8]See [53] for the history of finding the cure for scurvy, and, much later, vitamin C.

vival and enjoyment of life. I propose that their model works because it is based on direct, *honest* observations of Nature.

Thus I suggest that one simple way to judge a model is to ask: "Does the model *work*?" When something stops working for you, it is time to ask "why?" and make the necessary changes. One of the results of "an education" should be the ability to analyze a model and make changes to prevent complete collapse *before* it happens. You are *responsible* for your mental model and its consequences. The choices you make of what to read, watch, listen to; of what experiences you have, what you chose to think about – all these and more go into shaping your mental model. Your mental model becomes a fundamental part of you and largely determines with whom and with what you are in harmony or conflict, how you interact with Nature and what you believe is true. Reality acts on you, and you act on reality. This is another example of a feedback loop. Nature will likely, eventually, take care of models that are not honest – maybe sooner than later.

1.5 Consequences of the Crime: Suburbia's Topology

There is an axiom of city planners, [496]:

Land Use Axiom: *Transportation determines land use.*

From [496, p. xvii]: *"Until about 1945, the focus of design for American communities was people – pedestrians, bicyclists, kids. Neighborhood streets were places where people walked, socialized, greeted neighbors sitting on their front porches, places where kids played kick the can and rode their bikes. Compared to most of our neighborhoods today, streets were narrower and connected to each other at almost every block, blocks were shorter, street surfaces were often rougher. Cars parked along the roadside, trees shaded streets and sidewalks – and there* were *sidewalks. In city streets, people ran into friends, exchanged greetings with strangers, conducted business, window shopped, waved to acquaintances through shop and restaurant windows."*

If you have ever visited a city that was designed and built for people (before the automobile), such as an old part of a European city or Boston, U.S.A., you see it right away, it is tough to get around in a car. Today's cities and suburbs are designed for the automobile. If you live in the suburbs, since everything you need in life except your house is too far to walk to, you drive – a lot. You want to get there quickly, so streets are wider, traffic faster. To keep children safe, to keep traffic noise away, you don't live on a main road, you live on a cul-de-sac, which connects to a network of a few main arteries which become jammed with traffic periodically or constantly. Over half of the urban space in America, on average, is devoted to cars; in Los Angeles the figure is two-thirds. Some 40,000 to 50,000 people die in traffic accidents every year in the U.S., many of these deaths could be prevented, cf., [525];

and a comparable number die from air pollution, largely because of cars, cf., section 1.6. Parking downtown, if it exists, is expensive, so you shop at a mall surrounded by an ocean of asphalt, i.e., free parking. Life is busy, there is no time to cook, so many of us pick up a quick meal[9] at a drive-through. Less walking means more obesity, less meaningful interaction with others. Many Americans do not know or socialize with their neighbors, driving from home to work, to home with a TV. This model does not apply to all of us, but it applies to many of us.

In the following exercise we look at some mathematical differences between an "Old Town" built on a grid of roads versus a typical suburban development.

Exercise 1.6 The Topology of Suburbia versus Old Town

The following helps explain the relatively higher rates of traffic congestion and lower rates of social interaction in suburbia as opposed to an old town with a grid road system.[10]

(i) Imagine a square with lower left vertex labeled A and the diagonally opposite upper right vertex labeled B. You can draw the square so that its top and bottom are horizontal and its sides are vertical, cf., Figure 1.2 below. How many ways, i.e., paths, are there from A to B, subject to the following rule: From any vertex you can only move to the next vertex to the right or the next vertex above (straight up).

(ii) Add a line segment to the square in (i) that connects the midpoint of one side of the square to the midpoint of the opposite side of the square. Now how many paths are there from A to B, subject to the same rule as in (i)? See Figure 1.2 below.

(iii) Add another line segment to the figure in (ii), perpendicular to the segment you just added, which joins the midpoint of one side of the square to the midpoint of the opposite side. Your original square should now be subdivided into 4 smaller squares. How many paths are there from A to B now, still subject to same rule as in (i)? See Figure 1.2 below.

(iv) Keep this process up until you have subdivided your original square into $9^2 = 81$ equally sized subsquares with an array that has 10 "roads" connecting the top of your square to the bottom and 10 more "roads" connecting the one side of the square to the other. How many paths are there from A to B now, subject to the rule in (i)? See Figure 1.2 below. Hint: Each path can be uniquely labeled with a sequence of 18 letters, 9 of which are R, for move to right, and 9 of which are U, for move up. Each such word uniquely represents a path (that satisfies the rule). Thus from Chapter 17, apply the formula $\frac{18!}{9!9!}$.

(v) Now assume that three sides of the original square are declared "main roads." Erase parts of line segments within the grid of part (iv) until you have everyone inside the square "living on a cul-de-sac, i.e., a dead-end road." How many paths there are from A to B now.

(vi) Suppose two houses are very close to each other but on different cul-de-sacs in suburbia in (v). What is the distance along roads between them? What was the distance along roads, in (iv), before you erased some?

(vii) Describe the differences in the traffic patterns and modes of transportation you would expect in parts (iv) and (v).

(viii) If walking and streetcars were the main mode of transportation, which design do you think would be most popular, (iv) or (v)?

(ix) In general, which road system, (iv) or (v), offers the quickest response time for an emergency vehicle?

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[9] Possible health effects of an exclusive "fast-food" diet are explored in the DVD, *Super Size Me* (2003), starring John Banzhaf and Bridget Bennet (II), et al.

[10] This exercise is adapted from [496, pp. 30-4]. If you look up the formula therein, be careful in how you use it, there is a small misprint. In Chapter 17 we will take a more systematic look at how to solve problems like this one.

(x) From the Dec. 13, 2009 issue of *The New York Times Magazine*, p. 34, "Cul-de-Sac Ban, The," we read that in the fall of 2009 the state of Virginia became the first state to severely limit cul-de-sacs from future housing developments. All new subdivisions need to attain a level of "connectivity" with sufficiently many through-streets connecting to other neighborhoods and commercial areas. At the time you read this has any other city, county, or state adopted similar regulations?

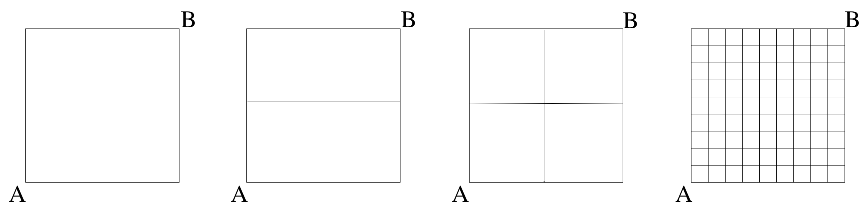

FIGURE 1.2: Street Grids

1.6 A Toxic Consequence of the Crime.

In [679] the former head of the California Environmental Protection Agency draws a close parallel between the behavior of the tobacco industry and the behavior of the automobile and fossil fuel energy industries, including their (toxic) contribution to the synthetic soup we all live in.

The research paper [140] reports[11] on one of longest most in-depth studies of the correlation between air pollution and disease/mortality. Of particular concern are pollution air particles, pm 10 or smaller, i.e., particles 10 microns[12] or less in diameter. Of these those of 2.5 microns or smaller were most tightly correlated to increased mortality and disease – the more air pollution particles the more disease and mortality. This study is not the only one which correlates air pollution and disease/mortality,[13] and these studies have survived criticism as have many scientific results with economic implications. This body of science is analogous to the science establishing links between

[11] Note http://content.nejm.org/cgi/content/abstract/329/24/1753 is the Web address of the original paper. Note http://www.healtheffects.org/Pubs/Rean-ExecSumm.pdf is the Web address of a later reanalysis of the original data.

[12] A micron is one-millionth of a meter.

[13] A National Academy of Sciences report released Oct. 19, 2009, claimed that nearly 20,000 people die prematurely each year as a result of air pollutants from power plants and vehicles (that is the burning of coal and oil products), cf., "Fossil Fuel's Hidden Cost Is in Billions, Study Says," by Matthew L. Wald, *The New York Times*, Oct. 20, 2009.

illness and smoking, both in its implications and its being a focus of attack. I might add that before the mandatory introduction of unleaded gasoline, lead and its negative health effects were part of the toxic legacy of automobile exhaust cf., Section 4.5 . Is any of that lead still around? Note that the Clean Air Act of 1970 gave the first administrator of the Environmental Protection Agency the power to remove lead from gasoline in 1973. The auto industry and its allies vigorously opposed the Clean Air Act, [142, p. 68].

I must confess that I learned very early that I am often not sufficiently critical. On many days when I walked home from Dahlia Heights elementary school in east Los Angeles my lungs/chest hurt when I took a deep breath. I asked my dad why. He said it was the smog. In one of the first television programs I saw in my life some official people explained that L.A. smog was produced by dirty industrial plants. No autos were mentioned. Later, while breathing air far away from L.A., I read that it had been discovered that L.A. smog was primarily due to auto exhaust. I never regained the trust in television (or officials) that I had in elementary school.

Exercise 1.7 Meters and Correlations

(i) We will deal with the metric system and conversions to and from the American/English system in section 3.4. For the moment try to understand how big an air pollution particle which is 2.5 microns in diameter is by comparing it with the size of something you know, say various diameters that a human hair might have. I have seen numbers ranging from 181 microns to 17 microns given for the diameter of various human hairs, with 100 microns as "typical." Could you see a pollution particle which was 2.5 microns in diameter?

(ii) The thinnest paper I have seen is .001″, i.e., one one-thousandth of an inch, thick. How many microns is this? Hint: Use 1 meter = 39.37 inches, or cf., section 3.4.

(iii) It has been stated that a piece of paper, say the one in part (ii) above, cannot be folded in half 12 times by hand. Mathematics can help you understand possible difficulties, for example, how thick would the resulting 12-times-folded-in-half paper be? How thick would be the result if you did this 15 times? 20 times?

(iv) We will discuss correlations very lightly in Section 5.11. For now, a *correlation coefficient* is a number between 1 and -1. If two phenomena have a correlation of $+1$, they are observed to always happen together (if -1, they never happen together). For a small project investigate what is meant by "pollution particles of 2.5 microns or smaller are most tightly correlated to mortality and disease."

(v) Some air pollution particles are small enough to pass from the air through lung tissue into the blood stream, affecting other organs. What are the sizes of such particles?

1.7 Hubbert's Peak and the End of Cheap Oil

In 1956 Marion King Hubbert, an American geophysicist,[14] predicted that in the early 1970s oil production in the United States would reach a peak,

[14]M. King Hubbert (1903–89) was working at the Shell Oil research lab in Houston when he made his original predictions/estimates of future U.S. oil production. He later worked for the USGS, United States Geological Survey.

i.e., oil production (actually extraction) would rise each year until reaching a high point and then decline each year thereafter. His prediction came true between 1970 and the Spring of 1971. In the 1950s almost everyone in and out of the oil industry rejected Hubbert's work; just as those who use the same methods to predict a peak in world oil production have been, if not rejected, ignored today. Admittedly, there is a bit of magic involved, in addition to some brilliant mathematics.

Hubbert's Mathematics. Briefly, Hubbert hypothesized that production data for the unconstrained exploitation of a nonrenewable resource, like oil, would follow a "bell-shaped curve." The peak of the curve would be attained when half of the resource was exhausted. He also assumed that the *discovery curve* would look very much like the *production/exploitation curve*, except that the discovery curve would occur some fixed number of years earlier than the production curve. Since, according to Hubbert's hypothesis, the peak occurs when half the oil is gone, one key to a successful prediction is knowing/guessing/estimating what the total petroleum reserves are. Using the best estimates available, in the 1950s Hubbert fit the known data for the United States with a curve, a logistic curve, using some of the same math used to analyze population growth.[15] What was Hubbert's prediction long ago is (for the U.S.) now an actual set of data, cf., Figure 1.3 from http://en.wikipedia.or/wiki/Peak_oil, which is a graphical illustration of data from the Energy Information Administration of the U.S. Department of Energy. With 50 years of hindsight, another curve, a *Gaussian*, is used because it apparently gives a better fit to historical data; and presumably it will do a more accurate job of predicting Hubbert's peak for world oil production. As for discovery curves, discovery of oil in the lower 48 states of the U.S. peaked in 1930, cf. [726, p. 312]. Also see [131, pp. 137–3], where it is stated that "More oil was found in the United States during the 1930s than in any decade before or since." Graphs of oil production that include Alaska and deepwater sources can be found in [726, p. 314]. These new sources did not dramatically alter general trends. As for the world, global oil discovery peaked in about 1964, [70] and [726, Appendix 9]. I encourage you to do your own literature search and see what numbers you come up with; beware, however, that not everyone uses the same definitions of "discovery," "reserves" and "hits."

So When Will the World's Oil Production Peak? The biggest argument comes in estimating total world oil which equals all the oil ever extracted plus what remains in the ground, i.e., estimated reserves. One estimate of $1.8(10^{12})$ *barrels*,[16] when using a Gaussian curve to fit known data, yields

[15] If you want to look at some of the math, including rate plot techniques, see [130, Chapter 8]. The logistic curve usually encountered in population growth, of Pierre Verhulst, is "S" shaped. But the graph of the rate of growth, i.e., the derivative, rises to a peak then declines. Note we study populations in V.

[16] Note that 10^{12} is 1 trillion, i.e., 1 followed by 12 zeroes. For a complete discussion of this notation see Section 3.4, and Exercise 3.11 in particular.

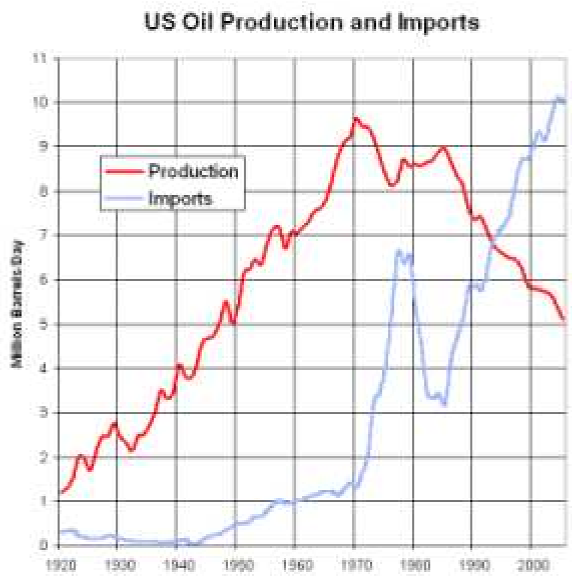

FIGURE 1.3: Hubbert's Peak for U.S.A.

2003 as the peak year. A colleague of mine in the physics department got 2004. Other published estimates range from 2004 to 2009, assuming a little over $2(10^{12})$ *barrels* total world oil. The USGS estimates world oil reserves to be $3.012(10^{12})$ *barrels*; which requires the discovery of an additional amount of oil equivalent to the entire Middle East. Some will say that the peak in world oil production is decades away. The chances of this happening are not zero, but low. Estimating remaining oil reserves, and to a much lesser extent researching past world oil production, gets you involved in guessing which country is fudging its numbers for political purposes, filling in numbers that are held secret by some governments, and guessing what has not been discovered yet. One sobering exercise is to look at a picture of the world with pins stuck wherever a hole has been drilled for oil. There have been a tremendous number of such holes drilled, and the more holes the less chance that future holes will come up with significant oil. The mathematics and data assign probabilities to each estimate of Hubbert's peak for the world, none are known with absolute precision – as should be clear; and we will not be sure of the peak's date until about 10 years after the fact. What is clear, at least to me, is that Hubbert's peak for world oil will occur within the lifetime of a typical 18 year old reader of this book, and it is likely to occur well before such a reader reaches middle age, and quite likely much sooner than that – in fact, it may have already occurred.[17] Other references are [69, 70, 221, 243, 293, 294, 221, 218, 472] and www.dieoff.org; there are many more.

In the following exercise we will introduce some topics that we do not have room to pursue in this book.

Exercise 1.8 Energy Return on Investment (E.R.O.I.), Self-Organizing Systems, Electric Cars and Trains, How Might It Have Been?

(i) Why are the graphs in Figure 1.3 not smoother?

(ii) Can you sketch the discovery curve of oil in the U.S. based on Figure 1.3 and Hubbert's analysis discussed in the text?

(iii) Did Standard Oil of California simple disappear, or is it still around under a different name? If so what is that name?

(iv) Hubbert's Peak analysis applies to *all* non-renewable energy resources: oil, coal, gas, uranium; and to other non-renewable resources that are not recycled. This is somewhat obvious. If you have piles of stuff of variable quality, buried in lots of different places, at various depths, with variable accessibility, one will probably extract the easiest, most valuable piles first, proceeding on to extract piles involving increasing effort/cost until forced to stop due to cost or lack of resource. Trying to predict how long the piles will last requires more sophistication, like Hubbert's analysis. Figuring out how cheap/expensive a resource is at any given time also requires more sophistication. A fundamental way to understand the cost of a resource, like oil for example, is to calculate the Energy Return on Investment – the number of units of energy you get in return for each unit of energy expended in getting said energy. (See VII for a discussion of units of energy.) Why is this method more meaningful/fundamental than calculating the cost of extraction of a resource in dollars, euros, yuan or yen? For a discussion of E.R.O.I. in several contexts see [270]. As an example, Cutler Cleveland, one of the authors of [270], an energy scientist at Boston University who helped develop the concept of E.R.O.I., calculates that from the early 1970s to the early 1990s the E.R.O.I. for oil and natural gas in the United States fell from 25 to 1 to about 15 to 1. Do you think this result is reasonable? Why has this happened? What is oil's E.R.O.I. the year you read this?

(v) Research and/or estimate the E.R.O.I. of every energy source you can think of: coal, tar sands (E.R.O.I estimate of 4 to 1), renewable energy sources, ... For example, is the following statement true? "In 1950, spending the energy equivalent of one barrel of oil in searching for more oil yielded 100 barrels in discovered oil. In 2004, the world's five largest energy companies found less oil energy than they expended in looking for that energy." (This is a quote from Chris Stolz's review on Amazon of [677].)

(vi) What is the relationship of the E.R.O.I. of a fossil fuel resource to climate change? Hint: See Section 1.9.

(vii) Another method of evaluating a resource is to look at the environmental and social impacts/damages due to the extraction of the resource and due to the disposal of waste after the resource is spent. Investigate such impacts for all non-renewable sources of energy, e.g. coal ash disaster, Kingston, Tennessee. Will renewable energy sources have environmental and social impacts? How do you think they (will?) compare to the impacts of non-renewable sources?

[17] A summary of all the predictions of Hubbert's peak for global oil production can be found in [726, Appendix 9]. Reference [130] is written by a colleague of M. King Hubbert, is readable and gives a great deal more detailed information than can be provided here. Natural gas will soon have a peak of its own, cf., [127]. For technical reasons having to do with restrictions on output of gas wells created by gas pipeline capacity, the Hubbert peak for natural gas is "flattened" and longer in duration, followed by a more precipitous decline, sometimes called the "gas cliff," cf., [127, pp. 94-6].

(viii) The fine that was imposed for the crime of dismantling (90% of) the trolley system was $5,000 in 1949. If that money were put in the bank and earned 7% simple interest per year for 60 years, how much money would there be?[18] How much light rail could you build for that amount? A lot? Almost nothing? We will deal with the mathematics of this calculation in more detail in V and VII.

(ix) I propose the following "*democratic, decision-making principle*:" Except in the rarest and most urgent of circumstances,[19] decisions that effect a majority or most of the people in a given unit should be put to a direct vote of the people in that unit.[20] Was "the crime" an example of too few people making a decision for all of us, i.e., a violation of this principle? Was the feedback experienced by the conspirators very strong?

(x) If electric-powered rail transportation had been allowed to evolve, both intercity and intracity, along with an evolving automobile mode of transportation, what are the possible outcomes you imagine could exist today? What would the differences in outcomes be? Mathematically speaking this would have been an example of a (freely) *self-organizing* social system. This is a somewhat new branch of mathematics: self-organizing systems.

(xi) Research the history of the electric car. It was killed twice, once at the beginning of the 20^{th} century and a second time at the beginning of the 21^{st} century. In response to California's passage of a law requiring certain fractions of auto sales to be zero emissions cars by certain dates, General Motors[21] produced the EV1 electric car with Stanford R. Ovshinsky batteries. There was an eager waiting list for these well performing and very popular cars, but under pressure from auto/oil/federal government the California Air Resources Board voted on April 24, 2003 to kill the zero emissions requirements. Within a year GM had reclaimed all EV1s and had them destroyed (only one is in a museum). See the movie (DVD) "Who Killed the Electric Car?" (released 2006), then discuss if General Motors would have been better prepared for the future if California had followed the above democratic decision-making principle?

(xii) One of the technical problems with solar and wind power is storage. If a majority of cars were electric and there were an electric rail system both within and between cities, would this provide a large reservoir into which solar and wind energy could be dumped in real time? (If all the electricity for this alternative transportation scenario were provided by burning coal, would the environment be better/worse or the same as it is today with oil-powered transportation?)

(xiii) The people of Iceland are making a serious effort to create a hydrogen economy for themselves. Research the problems and promise of a hydrogen economy, including fuel cell technology, cf., [155, 575, 679].

(xiv) How much of your life is built upon the assumption that petroleum products will remain cheap or at least affordable – or at least available?

(xv) When will the peak of coal production occur? How many years of coal used for energy, assuming no shift to renewables, remain? (The answer may not be nearly as far off in the future as you have been led to believe!)

(xvi) Discuss additional impacts on America of the killing of trolleys. Discuss solutions as we go over Hubbert's peak. Where do we go from here? A few among many references include [674, 341, 492, 266, 84, 683, 377, 470, 193].

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[18] Do not try this, since bank accounts are declared inactive if left unattended for 5 years.

[19] Such as an invasion by aliens, perhaps certain epidemics – a list of exceptions decided on by use of the democratic decision-making principle!

[20] As we will discuss a bit more in VI there is no mathematically "perfect" method of "voting" that always reflects the "will of the population." Nevertheless, if one believes in democracy as a form of government, one must strive to implement voting processes that reflect the bottom up self-organizing wisdom of the population, even if it is not perfect.

[21] Other auto corporations produced electric cars as well, but GM was first. GM also simultaneously fought California's zero emissions standards.

1.8 Resource Wars: Oil and Water

We will delve more deeply into conflict over resources in VII; however, due to its importance I will briefly mention it here, together with its connection to "the crime." In Figure 1.3 is reflected the fact that the U.S. went from being an oil exporter nation, to one that was barely self-sufficient, to a major oil importer nation during the 20^{th} century. Since our military, transportation network, chemical industry – even our food supply, cf., Chapter 5, are seriously dependent on reliable oil supplies, maintaining access to such has been a national priority.

In Section 1.6 I very briefly mentioned the impacts of the crime on our air, but there are impacts on water, both salty and fresh, as well. Potable water is becoming an ever more valuable and contentious resource, cf., Chapter 5. Mention oil spill pollution of our oceans and many major accidents around the globe can be cited: Santa Barbara (Union Oil Company) and Prince William Sound (Exxon Valdez, cf., Exercise 13.12), cf., II, and the BP gusher of 2010 immediately come to mind for me. However, an immense amount of oil is released (often deliberately dumped) into the U.S. environment every year, polluting among other things, fresh water.[22]

One-half to one-third of our urban areas are paved. Although there exist paving materials that are partially porous to water, most paving is impenetrable – leading to water runoff, which contains an assortment of pollutants. One example: pesticides/herbicides and fertilizers stacked up in parking lots at various big-box stores contribute to the toxic mix of pollutants deposited on these surfaces by cars and trucks. Rain then quickly delivers this brew to our waterways, often violating the Clean Water Act, [461, p. 118]. In heavy rains paving increases the chances of flooding. Paving interferes with the natural cycle during which water would percolate through the earth, replenishing ground water, being partially filtered and cleansed in the process.

Exercise 1.9 What Have We Done for Oil, What Have We Done to Water?

(i) Assess the truth value of the following statements: America invaded and has occupied Iraq (2003–?) because: (A) Saddam Hussein had links to the 9–11 terrorists and/or was a malevolent dictator. (B) Iraq had weapons of mass destruction. (C) Iraq has/had the second largest oil reserves on earth. (Hint: Your picture should be big enough to explain/understand the National Security Council documents aired during the January 11, 2004 *60 Minutes* interview with former Treasury Secretary Paul O'Neill, cf., http://www.cbsnews.com/stories/2004/01/09/60minutes/main592330.shtml and page 96 of [675].) Note that in 2010 the end of combat/war by American's in Iraq was declared by the U.S. President. How many U.S. troops remained at that time (and when you read this)? How many employees of private military contractors remained at that time (and when you read this)? For example, see the 9/3/10 interview with Phyllis Bennis, www.fair.org.

[22] Pick a year, like 1997; it was estimated that 240 million gallons of the 10.8 billion barrels of oil used in U.S. transportation that year were released, cf., [341, p. 95]. Much of this oil ends up in storm sewers, waterways and ground water.

(ii) What changes would you expect in the past 100 years of Iraq's political history if its principal resource were not oil but, say, broccoli?

(iii) Do your answers to the above questions depend on how carefully you checked the documentation/accuracy of the pronouncements of government officials and the mainstream media during the invasion of Iraq and the years afterward? Discuss with your friends and/or classmates, especially if they do not agree with you. Have any of those government officials or mainstream media changed their story in the interim?

(iv) Estimate how much less dependent America could have been on oil, had electric rail and car transportation been allowed to co-evolve with fossil-fuel powered transport.

(v) Big-box stores and shopping centers alone are responsible for about 900 million cubic feet of runoff each year in the Cleveland metropolitan area, [461, p. 106-7]. Assume Cleveland is roughly 80 square miles (the metro area is bigger, but we ignore this for simplicity) with a shape of a semicircle bounded on its diameter by Lake Erie. Consider two scenarios: the 900 million cubic feet of water ran off into the lake, or the 900 million cubic feet of water went into the ground and is sitting a few feet from the surface, at roughly the same elevation as the surface of the lake. (This latter scenario is possible if porous paving materials are used.) Estimate the difference in energy it would take for 100,000 uniformly distributed wells to pump this water to the surface in one year, versus the energy to transport this water from the lake to the 100,000 pump sites in a year. You can give a qualitative answer in English, or a more quantitative answer using VII.

(vi) Measured in terms of the amount of oil released as a pollutant into the environment, how does the year in which you read this compare to 1997?

(vii) Can you identify at least two indigenous populations in the world who have suffered greatly in terms of health, social, and environmental degradation due to the extraction of oil from their lands? Are there more than two such cases? Do the same exercise for coal, natural gas, and again for uranium, if you have time.

(viii) To what extent is there/has there been armed conflict over resources such as oil, cf., [354, 355]? Have the costs of these conflicts been directly reflected in the price of such resources?

1.9 The CO_2 Greenhouse Law of Svante Arrhenius

In 1824 the French mathematician, Jean Baptiste Joseph Fourier (1768–1830), in order to describe certain observations, created the term "greenhouse effect," [199, 200]. Thus the term greenhhouse effect has a long history! In modern language this effect occurs when visible spectrum sunlight passes through an enclosure-creating barrier, like glass or an atmosphere, and the enclosure heats up because the barrier absorbs/emits infrared spectrum radiation or otherwise traps heat.

In 1860, scientist John Tyndall experimentally determined that gases such as CO_2, carbon dioxide, and water vapor were major contributors to the greenhouse effect.[23] He observed that these gases, not the massively more

[23]Some have argued that increased water vapor in the atmosphere leads to more clouds which reflect some sunlight, hence global warming may not be as big a problem as once thought. It is not that simple. A more detailed analysis than we can go into here indicates that the global warming effect of water vapor is greater than the cooling effects of clouds (besides cloud cover at night slows the escape of heat at ground level, for example). I

abundant oxygen and nitrogen, were the most effective in trapping thermal energy.

In 1896, Swedish scientist, Svante August Arrhenius (February 19, 1859–October 2, 1927), 1903 Nobel Prize winner in chemistry, studied effects of atmospheric concentrations of CO_2 on ground level temperatures. Motivating Arrhenius was his desire to explain ice ages. His careful calculations were based in part on certain experimental data available at the time. Details in the work of Arrhenius, [16], may easily be criticized from the vantage point of the 21^{st} century. For example, some of the numerical values of constants carefully calculated by Arrhenius are not in agreement with numerical values used now. Also, he likely believed that global warming would be an unalloyed blessing, averting ice ages, an understandable position in 1896. Finally he thought, based on anthropogenic CO_2 emissions at the time he was working, that it would take humans about 3000 years to double atmospheric CO_2 concentrations.

These days the role of atmospheric CO_2 concentrations in the science of ice ages is still considered nontrivial, but other mechanisms are believed to precipitate "ice age events." Also, the time it is taking humans to double the CO_2 concentration in the air is of the order of 100 years, not 1000. But as for his major thesis, which he was the first to articulate, namely: *increasing emissions of CO_2 leads to global warming* – Arrhenius's work remains intact. Although some of the numerical values used or calculated by Arrhenius can be called into question, the basic *form* of his "greenhouse law" remains the same; and he derived this law from basic scientific and mathematical principles. Using this law and the numerical values he calculated for various constants, Arrhenius predicted that doubling CO_2 concentrations would result in a global average temperature[24] rise of 5 to 6 $\deg C$. The Intergovernmental Panel on Climate Change (IPCC) calculated in 2007 a 2 to 4.5 $\deg C$ rise; fairly good agreement given that over a century separates the two sets of numbers – which rely on the accuracy of certain experimentally determined constants.[25]

From a reference published about 102 years after [16], namely, page 2718 of [476], we see Arrhenius's greenhouse law for CO_2 stated as:[26]

$$\Delta F = \alpha\ ln(C/C_0), \qquad \text{(Greenhouse Law for } CO_2\text{)}$$

invite the interested reader to research this and many other related topics, for example, cf., http://www.realclimate.org.

[24] Note that C denotes degrees Centigrade, where $F = \frac{9}{5}$ C + 32, is the formula connecting Fahrenheit temperature, i.e., F, to Centigrade temperature, C.

[25] It should be emphasized that these numbers are global averages. The temperature in the Arctic, for example, is increasing much faster than the global average. From the Toolik field station in Alaska I learned that in parts of the Alaskan arctic temperatures are up 4 degrees Fahrenheit or more since the 1950s, compared to a global average increase of about 1 degree over the last century.

[26] Do not be alarmed just yet if you do not understand every detail of Arrhenius's law. It will be easier after we study ln, the natural logarithm function, in V.

where C is CO_2 concentration measured in parts per million by volume (ppmv); C_0 denotes a baseline or "unperturbed concentration" of CO_2; α is a constant (IPCC gives $\alpha = 6.3$, [476] gives 5.35); and ΔF is the radiative forcing, measured in Watts per square meter, $\frac{W}{m^2}$, due to the increased (or decreased) value for C, the independent variable. Radiative forcing is directly related to a corresponding (global average) temperature; because by definition radiative forcing is the change in the balance between radiation coming into the atmosphere and radiation going out. A positive radiative forcing tends on average to warm the surface of the Earth, and negative forcing tends on average to cool the surface.. (We will not go into the details of the quantitative relationship between radiative forcing and global average temperature.)

For the record, cf., [15], preindustrial concentrations of CO_2 are estimated to have been about 275 ppmv. Also see Figure 1.4, where CO_2 concentrations of the past are measured in ice cores taken at Siple station in Antarctica. We could take $C_0 = 275$ ppmv in Arrhenius's law. From Figure 1.4 (or from [15], p. 43) we see a graph (or table) of global, average annual CO_2 concentrations measured at Mauna Loa, Hawaii from 1960 when it was 316.91 ppmv to 2006 when it was approximately 381.84 ppmv. In this graph/table the function of CO_2 concentration versus time is essentially an increasing function from 1960 to the present (neglecting the annual fluctuation). We note that in 2008 CO_2 concentrations of 387 ppmv were measured in Svalbard, Norway.

So What's the Point? Arrhenius's CO_2 Greenhouse Law, like the law of gravity, has never been repealed since discovered. Though we may not be able to discuss every detail of the math/physics/chemistry involved here, the approximate quantitative increase in global temperature experienced on the ground corresponding to any particular rise in CO_2 concentrations is understood. Now some comments. Do you think humans burning carbon-based fuels like crazy since the beginning of the Industrial Revolution has had anything to do with the fact that CO_2 concentrations are rising? (See Exercise 1.10 part (xix).) Also, CO_2 is not the only greenhouse gas whose concentrations are going up due to human activities, cf., methane, for example.[27] In [476] a few other greenhouse gases are discussed along with the corresponding laws from science telling us how much warming we can expect from an increase in their atmospheric concentrations.

Thus those who would deny that global warming is occuring have a prodigious task. They have to (quantitatively) show that some other factors compensate for, i.e., cancel out, the warming predicted by Arrehenius's law. (This warming is significant, cf., Exercise 1.10 part (xvii).) They have to explain why mounting data indicating that warming is going on, [217, 218, 51], to name only three of many references, (not to mention what polar bears and

[27]As I write there are news stories about methane being released from formerly stable regions – sea beds, frozen tundra, and the like. Methane is more than 20 times more potent a greenhouse gas than is CO_2. What is the status of methane release at the time you read this?

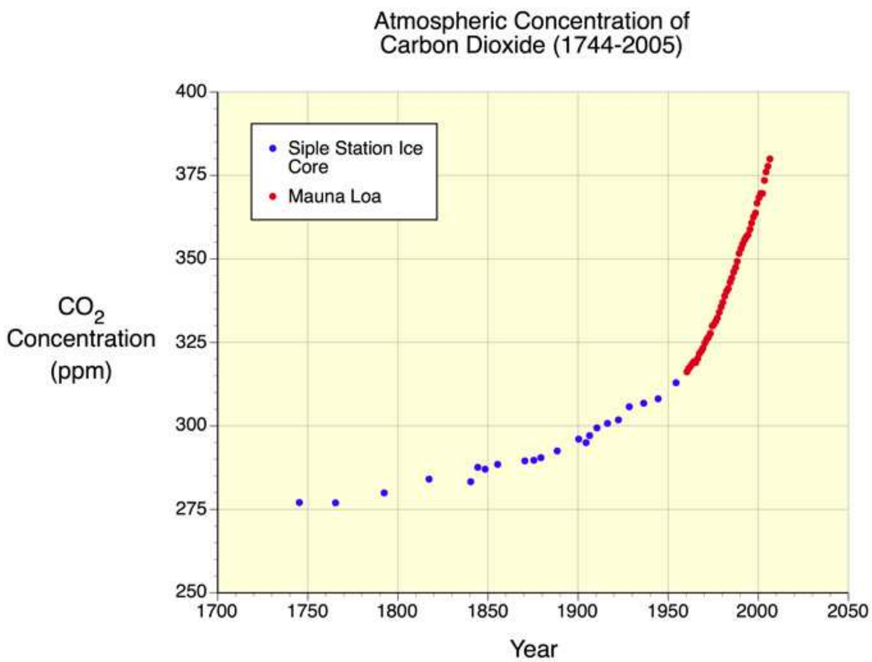

FIGURE 1.4: Carbon Dioxide Concentration in the Atmosphere (1744–2005)

some indigenous arctic folks have to say) is not persuasive. Doubters will no doubt always be with us, as might be expected in any diverse self-organizing system. For example, in late 2009 a number of pundits concluded after "eyeballing" temperature data that the globe was cooling. The Associated Press responded by doing the following experiment. They gave global temperature data to four independent statisticians without telling them what the numbers represented. (This is an example of a "blind test"). The mathematicians found no actual temperature declines over time, despite the fact that 1998 was a record temperature year. So why do I have to even discuss these things? For decades the fossil fuel industries and some of their associates have financed the disinforming of the public about this science, [217, 218]. This disinformation campaign finally, rather late, made the front page of *The New York Times* on Friday, April 24, 2009.[28] As noted in the article, a group, the Global Climate Coalition, ignored its own scientists's findings (that global warming is a fact) as it sowed seeds of doubt in the media, legislative bodies, and among the public about the science of climate change (much of which was understood by

[28] Andrew C. Revkin, "On Climate Issue, Industry Ignored Its Scientists," *The New York Times*, April 24, 2009.

Arrhenius in 1896!) and the need to reduce carbon dioxide emissions. The mainstream media gave this effort "equal time" to show "balance," without making it clear who exactly was arguing on each side of the issue. When it comes to science and mathematics, all a PR effort has to do is confuse the public to induce inaction, cf., [317] for a book length critique by a PR professional of the PR effort to challenge climate science on the subject of global warming. Confusion was well funded as we read, again a bit after the fact, in 2009 in [247, p. 366] that Exxon-Mobil was giving millions of dollars to 39 groups "which misinformed the public about climate change ...." The disinformation continues in various forms as I write.[29]

On April 1, 2008, during a congressional hearing, Exxon-Mobil Senior Vice President, Stephen Simon, had this to say in reply to Representative Jay Inslee's discussing America's energy portfolio in 2050 and questioning Exxon-Mobil's investing less than one percent of their profits in renewable energy: "..., but the fact is that we are going to have oil and gas and coal, and its going to constitute about 80 percent of the energy equation. With that as a given, ..."[30]

Future generations might be able to use the complex organic molecules in what fossil fuels might remain for them in fantastic ways we have yet to imagine. Burning oil for energy is like burning the Mona Lisa for heat. If the current world's human population succeeds, however, in burning most of the remaining coal, oil, natural gas, tar sands and oil shale, following the vision put forth just above, the journey begun with the destruction of the trolleys in America will likely end in distress. The climate science seems quite clear: stop burning fossil (carbon) fuels.

Exercise 1.10 Global Warming Exercises

(i) A 3 degree rise in temperature centigrade corresponds to how many degrees rise Fahrenheit?

(ii) Can you find a ln button on your calculator? If so what is $ln\,2$?

(iii) Would you estimate that relatively very few people were able to confuse the global warming debate? Is this number more, less, or about the same as the number of people it took to destroy the trolley systems in America?

(iv) Take a close look at Figure 1.4. Extrapolate, i.e., extend into the future, where you think the graph is going, given present trends. In what year do you predict we hit 400 ppmv? 450 ppmv? 500 ppmv? Are there any circumstances you are aware of that might speed up (or slow down) your predicted arrival dates at each of the above? How might other gases like methane behave as the planet warms?

(v) I claim that James Hansen is one of the most highly regarded climate scientists in the world, cf., [52]; investigate the truth value of my claim. I also claim that Freeman Dyson is one of the most highly regarded mathematicians/physicists in the world; investigate this claim as well. Dr. Hansen has said that we must get the global CO_2 concentrations below 350 ppmv as soon as possible to avoid a "tipping point" in world climate that humans

[29]Research the role in disinforming the public about climate change of Koch industries and the various groups it funds, such as AFP, Americans for Prosperity. Charles and David Koch are owners of the the largest privately held oil corporation. See, for example, "Covert Operations: The billionaire brothers who are waging a war against Obama," by Jane Mayer, *The New Yorker*, Aug. 30, 2010, pp. 44 - 55.

[30]See http://www.democracynow.org, April 2, 2008.

might likely find highly undesirable, cf., www.350.org. Dr. Freeman Dyson does not agree, cf., Nicholas Dawidoff, "The Global-Warming Heretic: How did Freeman Dyson – REVERED SCIENTIST, LIBERAL INTELLECTUAL, PROBLEM-SOLVER – wind up infuriating the environmentalists?", *New York Times Magazine*, March 29, 2009. (I mention Dyson because I have found no evidence that his views were "purchased" by the disinformation campaign discussed in this section.) Whose mental model do you think is closer to reality and why? If we follow the advice of Dr. Hansen and he is wrong, what are the consequences, to whom? If we follow Dr. Dyson and he is wrong, what are the consequences, to whom?

(vi) Investigate the truth value of the following claims. The extraction process associated to any non-renewable fuel has negative environmental impacts that get larger the longer the extraction process continues. The disposal of waste products associated to every non-renewable fuel has environmental impacts that also increase with time. Every non-renewable fuel "runs out" eventually, in the sense that it takes more energy to extract it than what you get, i.e., its E.R.O.I. (see Exercise 1.8) is less than 1; and/or it becomes too expensive to extract. Conclusion: we must eventually rely on renewable energy sources, the only question is when do we start, and why?

(vii) I once heard a media pundit mock climate change scientists with approximately the following argument: "2 degree temperature rise, 4 degree temperature rise, who cares, that can hardly be really noticeable, at least in my lifetime." I wrote a paper, [697], that quite possibly calls this argument into question. Under a very tenable assumption, it follows that a modest increase in average global temperature leads to an immodest increase in extreme weather events, such as tornados, hurricanes, floods, blizzards and so on. What is this assumption? Are we already experiencing this phenomena? Is the data conclusive? Is there a qualitative, intuitive argument for this phenomena? Should we take no action until there is no doubt?

(viii) For at least approximately 10,000 years humans have enjoyed a global climate that has been relatively stable. Research where climate scientists think precipitation will increase/decrease, and what instabilities we can expect with global warming. Make an estimate or at least discuss qualitatively what effects these changes will have on human agriculture.

(ix) Not everyone agrees with my last sentence before this exercise. They say that we can continue to burn fossil fuels, we just need to sequester the carbon dioxide thus produced. Investigate proposed methods of sequestration such as pumping the CO_2 into underground formations, or liquifying it in pools in the deep ocean and so on. At the time you read this are there any successful/commercial CO_2 sequestration operations? What are the negative environmental consequences of CO_2 sequestration? One interesting fact is that for every 14 tons of pure carbon that is completely burned, about $14 + 16 + 16 = 46$ tons of CO_2, cf., Figure 11.1, is produced and needs to be sequestered.

(x) **Global Warming: A National Security and Economic Threat?** Trillons of dollars have been spent on military activities. Trillions have been spent in attempts to "fix" the financial crisis of 2008 and beyond. How much money has been spent in response to the quite possibly devastating effects on humans of global warming? What does this say, if anything, about humans as a species?

(xi) **Geoengineering?** Suppose some massive engineering project, like putting mirrors in space to reflect sunlight, managed to compensate for the greenhouse effect of CO_2. If humans could then continue with increased CO_2 emissions without worrying about warming, what other catastophe, possibly greater than global warming, would take place? Hint: see Chapter 5. Projects such as these are called *geoengineering*. Another proposes to put sulfur dioxide into the atmosphere, year after year, mimicking volcanic eruptions. Discuss.

(xii) **Other Reasons for Not Burning Fossil Fuels.** Assume for the sake of argument that burning coal and other fossil fuels did not cause global warming or ocean acidification. Give at least two additional important reasons for switching to renewable energy sources.

(xiii) **Probabilities of Adaptation or Extinction.** It is quie possible (likely?) that humans will not be able to control their greenhouse gas emissions in time to prevent the global climate from passing through a tipping point, which will bring irreversible dramatic changes lasting thousands, perhaps millions, of years. Do you think it will be possible for humans to adapt, or will they go extinct? What sort of adaptations do you envision?

(xiv) **Tax Policy and Global Warming.** Discuss the relative merits of a (revenue neutral) *carbon tax* and a *cap and trade* program of carbon emissions with regard to curbing CO_2 emissions. Briefly, cap and trade is analogous to the system that (partially) mitigated the acid rain effects from SO_2 emissions. It involves putting "caps" on emissions by law, hopefully *declining over time*, and allowing those whose emissions are below their cap a "credit" or "allowance" which becomes a financial instrument that can be sold or traded. If one exceeds their cap, they must buy sufficiently many "credits" to compensate or be fined. (One method is to buy "offsets" in the developing world; but enforcement is difficult and loop holes exist so that net carbon emissions do not necessary decrease.) A revenue neutral carbon tax is a tax on every source (mine or port of entry), say $x per ton of C. The tax is revenue neutral if, say, income taxes are reduced by the amount the carbon tax brings in. Cap and trade is complicated, possibly hard to enforce, especially internationally, but it has the political advantage of creating new securities, including likely unregulated derivatives that Wall Street can profit from. (See Chapter 2. Is a "carbon bubble" possible? What would be its consequences when it "pops?") The carbon tax is simpler, enforceable, and would reduce emissions, but likely difficult politically. See [247, pp. 342-5], which advocates using both. See James Hansen, "Cap and Fade," *The New York Times*, Dec. 7, 2009, p. A27, who argues for a revenue neutral carbon tax. Hansen also has a book, [272], urgently calling for action to stem global warming. (Note Hansen believes nuclear power is an essential part of the energy mix of the future and that "renewables" cannot completely fill the bill. See our Chapter 6 and www.rmi.org for arguments that "renewables" can indeed fulfill humanities energy requirements.) See also http://www.storyofstuff.com/capandtrade/. In addition to putting a price on carbon, by whatever mechanism, what needs to be done to actually start reducing carbon emissions?

(xv) **Agriculture and Global Warming.** The figures at the climate change Web site, www.ipcc.ch, state that at least 60 percent of all nitrous oxide, N_2O emissions, the most potent greenhouse gas, are caused by industrial agriculture, primarily from the use of synthetic nitrogen fertilizer. Nearly 50 percent of methane, CH_4, the second strongest greenhouse gas, is due to industrial farming practices, much of this from intensive livestock operations. The IPCC then estimates that industrial agriculture contributes at least 14% of greenhouse gas emissions. The Center for Food Safety estimates that if one looks at a "Big Picture" which includes: all energy inputs into industrial agriculture (such as production and use of pesticides, herbicides, fertilizers); food transport; factory farming impacts; water useage; and displacement of carbon sequestering biodiverse ecosystems; then the IPCC estimate could be revised upward to 25% to 30%. If this is true then industrial agricultural practices would need to be addressed for a complete solution to our climate change challenge. Do your own estimates of the Center for Food Safety estimates and see if you agree.

The Center for Food Safety offers the following solution: *"The potential for rapid change is exciting. For example, studies by the Rodale Institute project [coolfoodscountdown.org] (Scroll down to Regenerative Organic Farming: A Solution to Global Warming) that the planet's 3.5 billion tillable acres could sequester nearly 40 percent of current* CO_2 *emissions if converted to 'regenerative' organic agriculture practices. The same 10-year research project concluded that if U.S. cropland (based on 434 million acres) were converted to organic farming methods, we could reduce nearly 25 percent of our total GHG emissions.*

"Many other studies have drawn similar conclusions. In India, research shows that organic farming practices increase carbon absorption in soils by up to 55 percent (even higher when agro-forestry is added into the mix), and water holding capacity is increased by 10 percent. A study [www.cnr.berkeley.edu] of 20 commercial farms in California found that organic fields had 28 percent more carbon in the soil than industrial farms."

They also compare productivity of organic versus industrial agriculture: *"A comprehensive study [www.ns.umich.edu] of 293 crop comparisons of industrial and organic agriculture demonstrates that organic farm yields are roughly comparable to industrial farm yields in developed countries and result in much higher yields in developing countries (the full study is available for purchase [journals.cambridge.org]).*

"The World Bank and United Nations International Assessment of Agricultural Knowl-

edge, Science and Technology for Development [coolfoodscountdown.org] concluded that a fundamental overhaul of the current food and farming system is needed to get us out of the growing food (and fuel) crisis. They recommend that small-scale farmers and agro-ecological methods 'not industrialization' are the keys to a viable food security. Additionally, numerous studies [coolfoodscountdown.org] unequivocally state that our survival depends on the resiliency and biodiversity of organic farm systems free of fossil fuels and chemical dependency."

For a project give a critique of the IPCC and Center for Food Safety statements. We discuss some of these issues in Chapter 5.

(xvi) The United States has come to rely ever increasingly on the Alberta tar sands of Canada for oil. What are the impacts on global CO_2 emissions, on water, on the health of indigenous peoples living downstream? See [494] for an up-close perspective.

(xvii) **The Law of Arrhenius.** Given the numbers relevant to the Greenhouse gas law of Arrhenius, viz., $\frac{390}{275}$ as the ratio $\frac{C}{C_0}$ in 2010, calculate the Watts per square meter increase due to carbon dioxide increases in the atmosphere. Compare this to the natural solar radiation, also measured in Watts per square meter, from the sun, see Exercise 6.6.

(xviii) The U.S. military has considered climate change seriously as a matter of national security. If Americans actually took the potential impacts of climate change seriously how do you think their behavior and, say, the U.S. national budget, would change? For example, would a revenue-neutral carbon tax be possible? (A tax would be levied on carbon fuels at their source, either mine, well, or port of entry, for example; and the money would then be distributed to the population at large in, say, the form of a tax credit.) Would we be spending some defense money in the form of solar energy research and installation of existing technologies? Would we be treating climate change as seriously as, say, the danger of an explosive device or weapon being carried on an airplane?

(xix) The late John Firor, an environmental scholar and former director of the National Center of Atmospheric Research (NCAR), in a lecture given on November 18, 1998, said that there are about 6 billion tonnes of C, i.e., carbon, put into the atmosphere in the form of CO_2 every year. At that time there were about 6 billion people on earth. So the human contribution of C to the atmosphere is easy to remember, about 1 tonne per person per year – on average. However, Firor estimated that the typical American's contribution is 6 to 10 tonnes per person per year while, say, the typical Indian contributes $\frac{1}{5}$ tonne. The exercise is this: verify the accuracy of these statements – either now, or later when you have read more of the book and have hopefully picked up sufficiently many skills to do this verification. In fact, in the intervening years (decade), the amount of C put into the atmosphere per person per year has been increasing somewhat. Is it less than 1 tonne per person per year on average at the time you read this?

(xx) It is fair to say that the fossil fuel industry would disagree with most if not all of this chapter, e.g., the official position being that global warming is a "scam," a "lie," or a "mistake," or "misinformation," or similar sentiment. On page 25 I gave a quote from an Exxon representative. Look up quotes of other representatives of the fossil fuel industry, especially in regard to their position on global warming and/or climate change. Check to the best of your ability the references from which they get the information on which they base their disbelief. For example, the following can be found at www.democracynow.org, April 7, 2010, regarding Massey Energy, the fourth largest coal company in the U.S. (The video clip of the Massey Energy CEO runs from the 32:25 to the 34:25 minute marks of the 41:15 minute piece.)

AMY GOODMAN: I want to play some of the past comments of Massey Energy CEO Don Blankenship. He's the director of the US Chamber of Commerce. He's strongly opposed any legislation around climate change. These are highlights from the speech Don Blankenship delivered at the Tug Valley Mining Institute in West Virginia in November of 2008.

DON BLANKENSHIP: I don't believe climate change is real. I do believe that the Arctic is melting and the Antarctic is getting colder. I believe it's a normal cycle. This is the first speech in twenty-two years at the Tug Valley Institute that I've made in November while it was snowing outside. So it's not my greatest concern.

Let me be clear about it: Al Gore, Nancy Pelosi, Harry Reid, they don't know what they're talking about. They're totally wrong. What they do is nonsense. And until we begin to call it what it is, people are going to misunderstand, because when we talk about it in more articulate, educated ways, the American public doesn't get it. Pretty simple, they're all crazy. I mean, it is absolutely crazy. How can anybody run for office and say they're going to bankrupt the coal companies and be energy-independent and get elected? I mean, how do you do that? How do you stop us from mining coal while we look for Indiana bats and put up windmills to kill them all? I mean, if they go ahead with the windmills, we wouldn't have a problem. You know, it is absolutely crazy.

It is a great – it is as great a pleasure to me to be criticized by the communists and the atheists of the Gazette as it is to be applauded by my best friends, because I know that they're wrong. I mean, when you have an editor that's, you know, an admitted atheist and when you have people who are clearly of the far-left communist persuasion, would you want them to speak highly of you? You know, its really crazy when you look at it – and I reuse that word over and over, because what weve got is people cowering away from being criticized by people that are our enemies. I mean, are we going – would we be upset if Osama bin Laden were to be critical of us? I don't think so.

(xxi) Research the global flow of dust. For example, dust from the Sahara in Africa has landed in the Western Hemisphere, as has dust from Asian deserts. Dust from Arizona and Utah have ended up at my home. Why is this becoming a more frequent occurrence?