

# Energy, the Environment, and What Mathematicians Can Do

John Baez

<http://math.ucr.edu/home/baez/what/>

August 1, 2011

Shǒudū Shīfàn Dàxué

We use more and more energy. We get most of it by burning fossil fuels.

We use more and more energy. We get most of it by burning fossil fuels.

In 2007, the average human burnt 1.2 tonnes of carbon.

We use more and more energy. We get most of it by burning fossil fuels.

In 2007, the average human burnt 1.2 tonnes of carbon.

The average person in China burnt 4.9 tonnes.

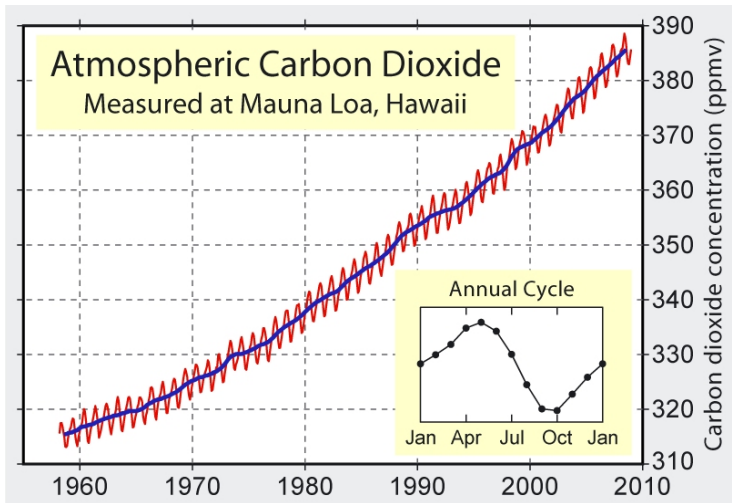
We use more and more energy. We get most of it by burning fossil fuels.

In 2007, the average human burnt 1.2 tonnes of carbon.

The average person in China burnt 4.9 tonnes.

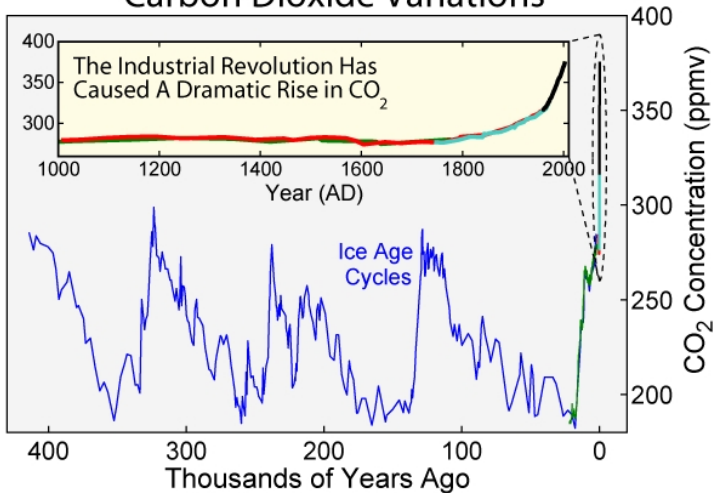
Worldwide, we burnt 8 gigatonnes of carbon in 2007.

So, the amount of carbon dioxide in the air is soaring:

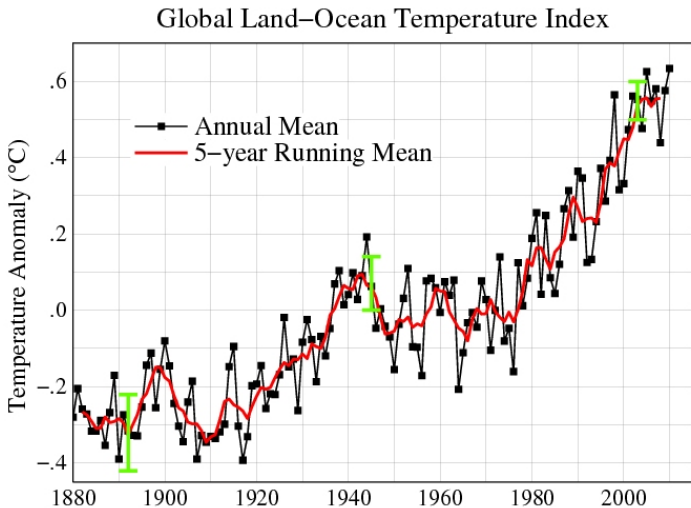


To understand just how much, we need to take the long view:

## Carbon Dioxide Variations

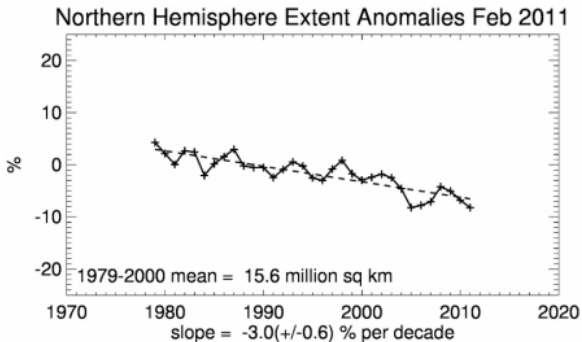


As you'd expect, the temperatures have gone up — about  $0.8^{\circ}\text{C}$  since 1880:

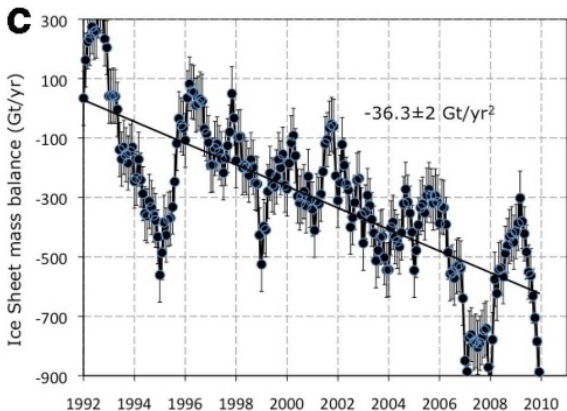




Arctic sea ice is shrinking in extent:



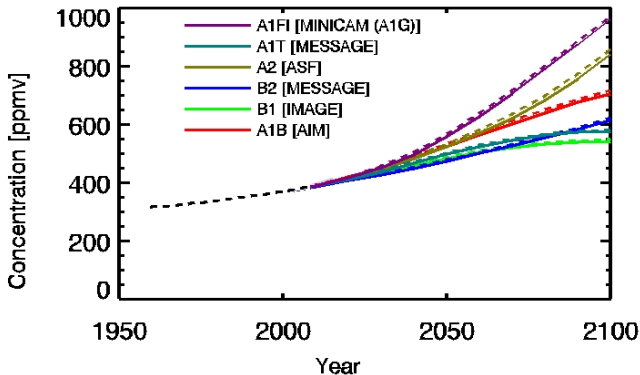
According to Rignot *et al*, the melting of Antarctica and Greenland is accelerating:



So far: *no projections or climate models*. But what do we expect to happen?

So far: *no projections or climate models*. But what do we expect to happen?

Before the industrial revolution, the CO<sub>2</sub> concentration was 290 parts per million. Now it's 390. What next?



Many different arguments say that doubling the carbon dioxide (CO<sub>2</sub>) concentration will increase average temperatures by 2 – 4.5°C.

Many different arguments say that doubling the carbon dioxide (CO<sub>2</sub>) concentration will increase average temperatures by 2 – 4.5°C.

With high economic growth and continued reliance on fossil fuels, the atmosphere could contain 950 parts per million of carbon dioxide by 2100.

Many different arguments say that doubling the carbon dioxide (CO<sub>2</sub>) concentration will increase average temperatures by 2 – 4.5°C.

With high economic growth and continued reliance on fossil fuels, the atmosphere could contain 950 parts per million of carbon dioxide by 2100.

This could cause temperatures roughly 2.4 – 6.4°C higher than today.

What effects might that have? With just 3°C of warming, the US National Academy of Sciences expects that:



What effects might that have? With just 3°C of warming, the US National Academy of Sciences expects that:

- 9 out of 10 northern hemisphere summers will be “exceptionally warm”: warmer than 1 out of 10 in 1980-2000.

What effects might that have? With just 3°C of warming, the US National Academy of Sciences expects that:

- 9 out of 10 northern hemisphere summers will be “exceptionally warm”: warmer than 1 out of 10 in 1980-2000.
- Much more land will be burned by wildfires in parts of Australia, Eurasia and North America.

What effects might that have? With just 3°C of warming, the US National Academy of Sciences expects that:

- 9 out of 10 northern hemisphere summers will be “exceptionally warm”: warmer than 1 out of 10 in 1980-2000.
- Much more land will be burned by wildfires in parts of Australia, Eurasia and North America.
- Extreme precipitation events will increase by 9-30%.

What effects might that have? With just 3°C of warming, the US National Academy of Sciences expects that:

- 9 out of 10 northern hemisphere summers will be “exceptionally warm”: warmer than 1 out of 10 in 1980-2000.
- Much more land will be burned by wildfires in parts of Australia, Eurasia and North America.
- Extreme precipitation events will increase by 9-30%.
- Rainfall in some dry regions will drop by 15-30%

Rignot *et al* expect a sea level rise of 32 centimeters by 2050.

Rignot *et al* expect a sea level rise of 32 centimeters by 2050.

Even *not including* Greenland and Antarctica, we expect a 60 centimeter rise by 2100. This would increase the number of people at risk of coastal flooding by 5 to 200 million, with up to 4 million displaced permanently.

Rignot *et al* expect a sea level rise of 32 centimeters by 2050.

Even *not including* Greenland and Antarctica, we expect a 60 centimeter rise by 2100. This would increase the number of people at risk of coastal flooding by 5 to 200 million, with up to 4 million displaced permanently.

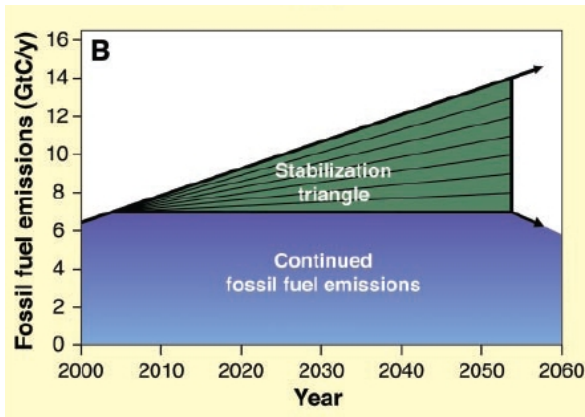
And it's not just people in trouble: species are already moving 6 kilometers closer to the poles each decade. The rate of extinction will increase.

What can we do? Slowing the rate of carbon burning is not enough: most CO<sub>2</sub> stays in the air a *very long time*, though individual molecules come and go. We need to:

- leave fossil fuels unburnt,
- live with a hotter climate,
- sequester carbon, and/or
- actively cool the Earth.



In 2004, Pacala and Socolow looked for ways to hold carbon emissions constant until 2054 — *not a solution, just a start!*



They said it would require 7 'wedges'. Each wedge is a way to reduce carbon emissions by 1 gigatonne/year by 2054.

Some examples of wedges (using numbers from 2004):

Some examples of wedges (using numbers from 2004):

**Wind:** Replace 700 gigawatts of coal-fired power plants by wind power.

Some examples of wedges (using numbers from 2004):

**Wind:** Replace 700 gigawatts of coal-fired power plants by wind power. This requires *multiplying existing wind power by 50!*

Some examples of wedges (using numbers from 2004):

**Wind:** Replace 700 gigawatts of coal-fired power plants by wind power. This requires *multiplying existing wind power by 50!*

**Solar:** Replace 700 gigawatts of coal power by solar power.

Some examples of wedges (using numbers from 2004):

**Wind:** Replace 700 gigawatts of coal-fired power plants by wind power. This requires *multiplying existing wind power by 50!*

**Solar:** Replace 700 gigawatts of coal power by solar power. This requires *multiplying existing solar power by 700!*

Some examples of wedges (using numbers from 2004):

**Wind:** Replace 700 gigawatts of coal-fired power plants by wind power. This requires *multiplying existing wind power by 50!*

**Solar:** Replace 700 gigawatts of coal power by solar power. This requires *multiplying existing solar power by 700!*

**Nuclear:** Replace 700 gigawatts of coal power by nuclear power.

Some examples of wedges (using numbers from 2004):

**Wind:** Replace 700 gigawatts of coal-fired power plants by wind power. This requires *multiplying existing wind power by 50!*

**Solar:** Replace 700 gigawatts of coal power by solar power. This requires *multiplying existing solar power by 700!*

**Nuclear:** Replace 700 gigawatts of coal power by nuclear power. This requires *doubling existing nuclear power!*



Some examples of wedges (using numbers from 2004):

**Wind:** Replace 700 gigawatts of coal-fired power plants by wind power. This requires *multiplying existing wind power by 50!*

**Solar:** Replace 700 gigawatts of coal power by solar power. This requires *multiplying existing solar power by 700!*

**Nuclear:** Replace 700 gigawatts of coal power by nuclear power. This requires *doubling existing nuclear power!*

**Biofuels:** Making 5.4 giga liters of bioethanol to replace gasoline.

Some examples of wedges (using numbers from 2004):

**Wind:** Replace 700 gigawatts of coal-fired power plants by wind power. This requires *multiplying existing wind power by 50!*

**Solar:** Replace 700 gigawatts of coal power by solar power. This requires *multiplying existing solar power by 700!*

**Nuclear:** Replace 700 gigawatts of coal power by nuclear power. This requires *doubling existing nuclear power!*

**Biofuels:** Making 5.4 giga-liters of bioethanol to replace gasoline. This requires *multiplying existing bioethanol production by 50!*

**Conservation:** Assuming the number of cars goes up from 500 million to 4 times that, *make everyone in the world drive half as much!*

**Conservation:** Assuming the number of cars goes up from 500 million to 4 times that, *make everyone in the world drive half as much!*

**Efficiency:** Under the same assumptions, make all cars twice as efficient *without people driving more!*

**Conservation:** Assuming the number of cars goes up from 500 million to 4 times that, *make everyone in the world drive half as much!*

**Efficiency:** Under the same assumptions, make all cars twice as efficient *without people driving more!*

**Conservation/efficiency:** Cut carbon emissions by 25% in buildings and appliances.

**My personal thoughts, right now:**

## **My personal thoughts, right now:**

Each wedge is a massive undertaking, and we need to do *seven* of them just to hold carbon emissions constant.

## **My personal thoughts, right now:**

Each wedge is a massive undertaking, and we need to do *seven* of them just to hold carbon emissions constant.

We probably won't bother unless conditions get worse *in a fairly dramatic way*.



## My personal thoughts, right now:

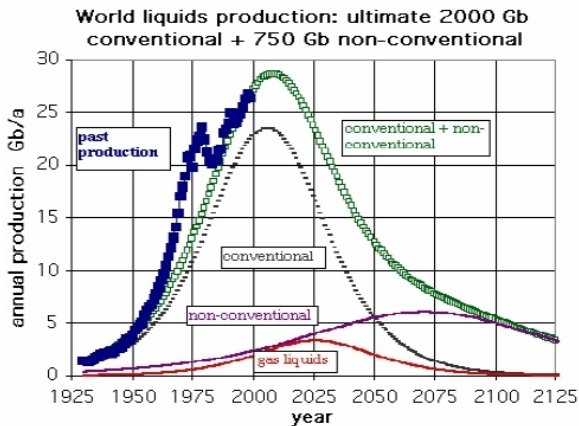
Each wedge is a massive undertaking, and we need to do *seven* of them just to hold carbon emissions constant.

We probably won't bother unless conditions get worse *in a fairly dramatic way*.

The floods in Pakistan covered 800,000 square kilometers, affecting 20 million people. Suppose events like this become more common. How many will it take before we:

- 1) decide global warming is to blame and
- 2) decide to do something very difficult to stop it?

If we wait 20 years, weather disasters and crop failures will combine with *declining oil supplies* to make us change our ways:



At that point, if we're not too busy *fighting wars*, governments will push scientists — and even mathematicians — to do something about energy and the environment.

At that point, if we're not too busy *fighting wars*, governments will push scientists — and even mathematicians — to do something about energy and the environment.

I decided to start now.

At that point, if we're not too busy *fighting wars*, governments will push scientists — and even mathematicians — to do something about energy and the environment.

I decided to start now.

But what can someone like me do? I'm not a politician, an inventor, or a climate scientist.

I'm just a mathematician!

At that point, if we're not too busy *fighting wars*, governments will push scientists — and even mathematicians — to do something about energy and the environment.

I decided to start now.

But what can someone like me do? I'm not a politician, an inventor, or a climate scientist.

I'm just a mathematician!

# 1. Fly less.

## 1. Fly less.

The easiest way to burn less carbon is to fly less.



## 1. Fly less.

The easiest way to burn less carbon is to fly less.

One round-trip flight from Beijing to San Francisco burns 0.6 tonnes of carbon. This is 50% of an average human's yearly amount, and 12% of an average Chinese person's.

## 1. Fly less.

The easiest way to burn less carbon is to fly less.

One round-trip flight from Beijing to San Francisco burns 0.6 tonnes of carbon. This is 50% of an average human's yearly amount, and 12% of an average Chinese person's.

My visit here will burn 0.15 tonnes. I can only justify this if some of you decide to fly less!



## 1. Fly less.

The easiest way to burn less carbon is to fly less.

One round-trip flight from Beijing to San Francisco burns 0.6 tonnes of carbon. This is 50% of an average human's yearly amount, and 12% of an average Chinese person's.

My visit here will burn 0.15 tonnes. I can only justify this if some of you decide to fly less!



But I've cut back immensely... and I'm happier.

## 2. Make conferences local, or virtual.

## **2. Make conferences local, or virtual.**

We should not subsidize air travel. We should make it easier for people to give talks online and watch them online.

## 2. Make conferences local, or virtual.

We should not subsidize air travel. We should make it easier for people to give talks online and watch them online.

Let's invent better ways for people to socialize *online* at conferences.

## 2. Make conferences local, or virtual.

We should not subsidize air travel. We should make it easier for people to give talks online and watch them online.

Let's invent better ways for people to socialize *online* at conferences.

It seems unthinkable... just like every other new thing we ever did.

### 3. End innumeracy and illogic.



### **3. End innumeracy and illogic.**

We need clear thinking now more than ever. Mathematics is the art of precise thinking.

### 3. End innumeracy and illogic.

We need clear thinking now more than ever. Mathematics is the art of precise thinking.

Most mathematicians teach for a living: *this is our big chance to do something that matters.*

### 3. End innumeracy and illogic.

We need clear thinking now more than ever. Mathematics is the art of precise thinking.

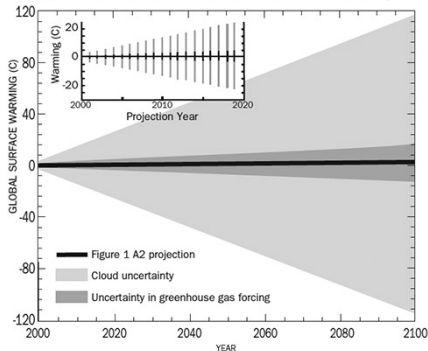
Most mathematicians teach for a living: *this is our big chance to do something that matters.*

Innumeracy and illogic can be found on both sides of almost every argument about climate change and energy policy. I will unfairly single out one example!

Patrick Frank, in *Skeptic Magazine*, said: uncertainty in estimates of cloud cover causes a  $1.1^{\circ}\text{C}$  uncertainty *per year* in temperature predictions. So:

*"By 50 years, the uncertainty in projected temperature is  $\pm 55^{\circ}$ . At 100 years, the accumulated physical cloud uncertainty in temperature is  $\pm 111$  degrees."*

Accumulation of Projection Uncertainty in the Climate Impact of Clouds or of Greenhouse Gas Forcing



## 4. Work with nonmathematicians.

#### **4. Work with nonmathematicians.**

Talk to people who work on energy technology, climate prediction, ecology, biology. They all need help with math!

#### **4. Work with nonmathematicians.**

Talk to people who work on energy technology, climate prediction, ecology, biology. They all need help with math!

You'll need to learn new things... but you'll get great new ideas!

#### **4. Work with nonmathematicians.**

Talk to people who work on energy technology, climate prediction, ecology, biology. They all need help with math!

You'll need to learn new things... but you'll get great new ideas!

The impact of math is often indirect, but that's okay.



## 4. Work with nonmathematicians.

Talk to people who work on energy technology, climate prediction, ecology, biology. They all need help with math!

You'll need to learn new things... but you'll get great new ideas!

The impact of math is often indirect, but that's okay.

The work of Hilbert underlies quantum mechanics...

#### **4. Work with nonmathematicians.**

Talk to people who work on energy technology, climate prediction, ecology, biology. They all need help with math!

You'll need to learn new things... but you'll get great new ideas!

The impact of math is often indirect, but that's okay.

The work of Hilbert underlies quantum mechanics...  
which underlies lasers and semiconductors...

#### **4. Work with nonmathematicians.**

Talk to people who work on energy technology, climate prediction, ecology, biology. They all need help with math!

You'll need to learn new things... but you'll get great new ideas!

The impact of math is often indirect, but that's okay.

The work of Hilbert underlies quantum mechanics...  
which underlies lasers and semiconductors...  
which underlie bar code scanners, computers, and more.

#### **4. Work with nonmathematicians.**

Talk to people who work on energy technology, climate prediction, ecology, biology. They all need help with math!

You'll need to learn new things... but you'll get great new ideas!

The impact of math is often indirect, but that's okay.

The work of Hilbert underlies quantum mechanics...  
which underlies lasers and semiconductors...  
which underlie bar code scanners, computers, and more.

## 5. Join the Azimuth Project

The **Azimuth Project** is a group of mathematicians, scientists, and engineers trying to help save the planet. We are studying:

## 5. Join the Azimuth Project

The **Azimuth Project** is a group of mathematicians, scientists, and engineers trying to help save the planet. We are studying:

**Plans of action:** the best plans people have made to slow global warming and move to sustainable technology.

## 5. Join the Azimuth Project

The **Azimuth Project** is a group of mathematicians, scientists, and engineers trying to help save the planet. We are studying:

**Plans of action:** the best plans people have made to slow global warming and move to sustainable technology.

**Network theory:** electrical circuits, chemical reactions, ecosystems and other complex systems made of interacting parts.

## 5. Join the Azimuth Project

The **Azimuth Project** is a group of mathematicians, scientists, and engineers trying to help save the planet. We are studying:

**Plans of action:** the best plans people have made to slow global warming and move to sustainable technology.

**Network theory:** electrical circuits, chemical reactions, ecosystems and other complex systems made of interacting parts.

**Climate cycles:** what causes the ice ages? How important are changes in the Earth's' orbit, perhaps made stronger by stochastic resonance?



On the **Azimuth Wiki**, we are explaining the main environmental and energy problems the world faces today:

- Global warming - human caused climate change.
- Extinction - mass die-offs caused by global warming and habitat changes.
- Deforestation - loss of primary and secondary forests.
- Ocean acidification - rise in ocean acidity due to rising CO<sub>2</sub>.
- Dead zones - large areas of the ocean that can't support life.
- Water crisis - the decline of aquifers and freshwater supplies.
- Peak oil - the decline in the availability of oil as an energy source.

Will this work stop global warming?

Will this work stop global warming? **No.**

Will this work stop global warming? **No.**

Not by itself, anyway. But it's a way for mathematicians to help.

Will this work stop global warming? **No.**

Not by itself, anyway. But it's a way for mathematicians to help.

For more details, go here:

<http://math.ucr.edu/home/baez/what/>