We've been asked to address the question: "Are we on the right track to meeting the climate change imperatives?"

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No!
What do we need to do to get on the right track to meeting the climate change imperatives?

But first, a few slides to remind us all why we have a climate problem.
The climate system…

About 30% of the energy that comes from the sun is reflected right back to space (the fraction that is reflected is called the albedo).

While the atmosphere is transparent to light, it is opaque to heat (i.e. infrared) because of water vapor, CO₂ and other "greenhouse gases." So the energy gets trapped. This warms the planet (by about 60°F) to the point that it is warm enough so that the same amount of energy is radiated back to space as infrared.

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A useful analogy is to think of a bathtub with a very large faucet and a very small drain.

Unless we really close down on the faucet (i.e., reduce CO₂ emissions by a large amount) the bathtub keeps filling (i.e., the concentration of CO₂ in the atmosphere keeps rising).

How much warming is uncertain…

…both because we don't know how much CO₂ humans will emit in the future, and because there is some uncertainty about exactly how much warming will result.

Source: IPCC
How much warming is uncertain

What warming will do is also uncertain

Electric power generation...

...is a major source of CO₂. Here is the EPA's breakdown of US sources:
Electric power generation... 

...is a major source of CO$_2$. Here is the EPA’s breakdown of US sources:

Despite lots of talk, the world still makes most of its electricity from coal, natural gas and other fossil fuels.

For example, consider the Bruce Mansfield power plant (2460 Mw) located on the Ohio River, just west of where I live in Pittsburgh, PA. A plant this size burns the equivalent of about 200 100T hopper cars of coal every day.

If coal were pure carbon, that would be the same as taking 150 such cars, converting them into invisible CO$_2$ gas, and releasing them into the atmosphere every day.

Many hundreds of such plants are operating all over the world.

Sources: www.firstenergycorp.com and www.battelle.org.
So, back now to the question:

"What do we need to do to get on the right track to meeting the climate change imperatives?"

ANSWER:

We need regulation that, over the next several decades will reduce emissions of CO₂ by roughly 80%.

We also need sustained investment in research, development and deployment of new technology.

Regulation…

…could take the form of some direct or indirect price on CO₂ emissions via a carbon tax or a cap-and-trade system.

However, as I'll elaborate in the next two slides, neither will be effective unless the associated price is high enough and will get higher over time in some clearly articulate way.

For many emission sources (especially if the price on CO₂ emissions stays below $20/ton for some years) we are going to need performance standards.
Costs

6¢/kWh plus

Premium for low-carbon electricity above a base of 6¢/kWh (2008 $/kWh)

Source: C. Samaras.
Strategies to decarbonize our energy system

1. Make dramatic improvements in the efficiency with which we use energy.

2. Switch to fuels that are less carbon intensive (with the exception of H₂ and fuels from biomass, this is only a short term strategy - i.e. works for a decade or two).

3. Retire technologies that emit large amounts of CO₂ and adopt energy technologies that emit little or no CO₂.

1. Dramatic improvements in efficiency of use

The opportunities here are enormous.

While the McKenzie supply curve has problems, transparent work by others such as Inês Azevedo demonstrate great potential.

The recent NRC study chaired by my colleague Lester Lave concludes that we could achieve a 60% reduction in energy use by buildings.
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**IMPLICATION FOR PUCs:** If you have not already done so, find a way in which utilities can make money by promoting efficiency.

2. Switch to low(er) carbon fuels

For the utility industry this primarily means moving from coal to natural gas. Gas has half the CO₂ emissions of coal so does not get us to 80% reduction. Prices are highly volatile. Despite US shale gas there are issues of foreign dependency.

Hydrogen is just an energy carrier. Today it is largely made by cracking hydrocarbon fuel. Making it from water is very energy intensive. The H₂ economy, while worthy of research, is still a mirage on the distant horizon and will not become reality for decades, if then.

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**IMPLICATION FOR PUCs:** Be really careful not to get locked in to an all-gas future.

3. Adopt (almost) zero CO₂ generation

This means nuclear, coal and gas with CCS, wind, and perhaps in some places solar thermal.

Some argue "doing this will wreck the economy." Many made the same argument about the Clean Air Act. The CAA ended up costing about 0.5% of GDP and did not wreck the economy. We've estimated that decarbonizing the energy system in a systematic way over the next 50 years would have costs of roughly the same magnitude.
3. Adopt (almost) zero CO$_2$ generation

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BUT…if we stall and stall and then have to do it in a hurry, the cost could be much higher.

We don't have time…

…for games of my technology is more virtuous than yours.

Achieving an 80% reduction in CO$_2$ will take a portfolio of everything we have got – and even then there is a very good chance we will not make it.

Photo sources: The Economist, CNN, Greenpeace, FERC.
A few words on coal and gas with CCS

All the technology to do this exists today at commercial scale. We need to put the piece together and start moving down the learning curve. Learning curves for such technology often go up before they go down.

For details on the SOx and NOx controls see Rubin et al., *IJGGC*, 2007.

Federal money is beginning to show up in larger amounts, and some pilots are getting built. BUT, we need to get started on several >100Mw plants NOW.

*The AEP Alstom Mountaineer plant is one great start but it is just a few percent of the size we’ll need.* (Photo: AEP)
CCS also presents important regulatory challenges. See: www.CCSReg.org

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A final thought on CCS…(Cont.)

There has been lots of talk about possible technology transfer:

Tech transfer

US’s Futuregen
A final thought on CCS…(Cont.)

There has been lots of talk about possible technology transfer:

If we talk much longer without serious action, I have growing doubts about the direction of the transfer!


A word about wind and gas

When the wind does not blow, many utilities fill the gap with gas.

Photo source: Power plants around the world
A word about wind and gas

When the wind does not blow, many utilities fill the gap with gas.

Today’s turbines have not been optimized to be ramped up and down quickly. Let’s compare:

![Emissions comparison diagram]

Photo source: Power plants around the world

Net NOx emissions may actually go up:

![Graphs of CO2 and NOx emissions]

Sources: Katzenstein and Apt; www.summitvineyardllc.com; www.sealegacy.com
This does not mean that wind is a bad idea!

It does mean that systems that do not have hydro, have large renewable portfolio standards and are in violation of the NOx standard, will need to be careful.

This is just one example of the many issues that arise when one sets out to integrate large amounts of wind into a power system.

Jay Apt who directs Carnegie Mellon's Electricity Industry Center is about to kick off a big project called **RenewElec** that will examine all the issues involved in facilitating the adoption of large amounts of variable and intermittent power sources in real power systems. Project web site coming soon at www.RenewElec.org
Finally, a very important word on making "prudent" investments

**IMPLICATION FOR PUCs:** Be careful to define "prudent" in a way that considers not just today or next year, but also thinks ahead to likely future controls on CO₂.

In many cases, it is not prudent to build new generation today that emits large amounts of CO₂ if there is a high probability that it will have to retire it long before its useful life has ended.