Can Green Power Save us from Climate Change?

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The Four Questions

- What does Savings us mean in terms of temperature?
- What would the world look like without Green power?
- How big is the task for Green power?
- Can it be done?

The Sources

- Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millenia. National Research Council, National Academies Press, 2010.
- 2010 The Outlook for Energy: A View to 2030, ExxonMobil.
- BP Statistical Review of World Energy June 2011
- The Green Solow Model, William Brock and M. Scott Taylor, Journal of Economic Growth, June 2010.
- Energy Transitions, Vaclav Smil, 2010 Greenwood Publishing Group.
- The Slow Search for Solution: Lessons from Historical energy transitions, Roger Fouquet, Energy Policy, 2010.

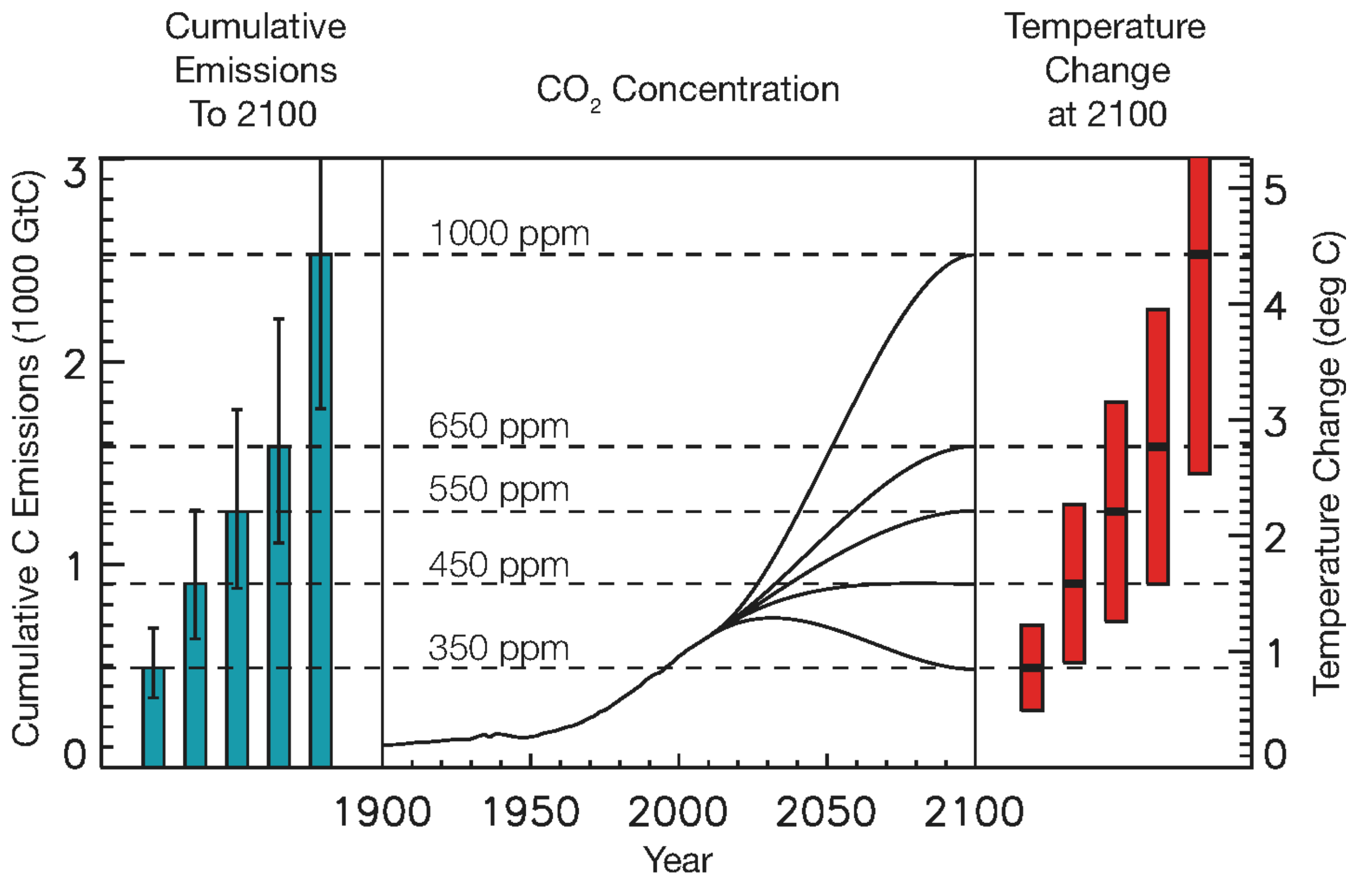
Why do we need Green Power?

- Kyoto is a failure, agreement expires in 2012.
- Emissions of Annex 1 Non-EIT signatory countries are 14.9% above their Kyoto commitments.
- Canada, Japan and some EU countries have effectively ignored their Kyoto commitments.
- India, China, Brazil and the United States account for over 50% of current emissions and are not limited by any international agreement.

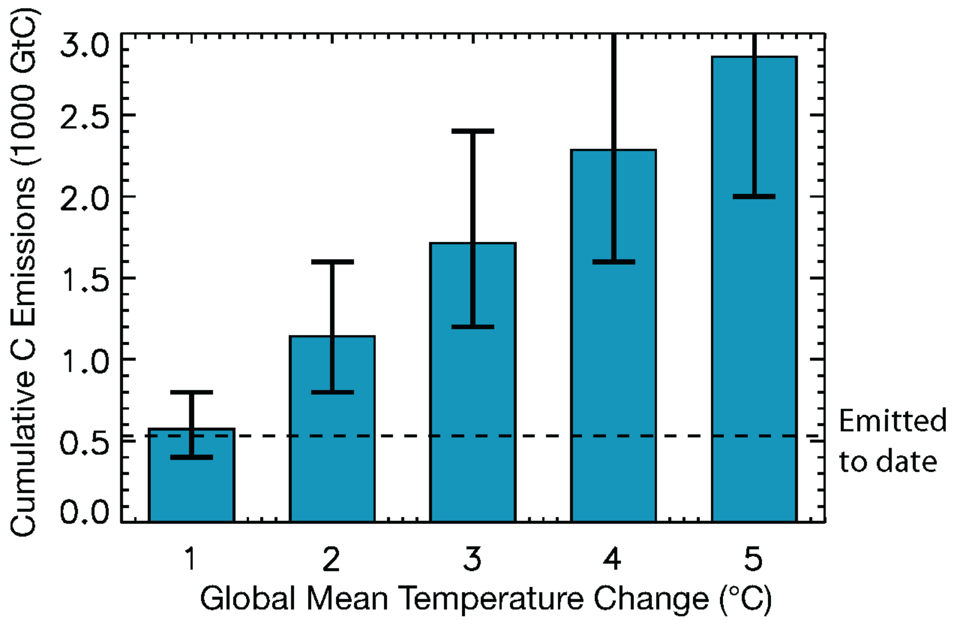
“Saving us” from Climate Change

- What does “saving us” mean in terms of an emissions path?
- Definition: a path producing less than a 2 degree Celsius (3.6 degree Fahrenheit) increase in temperature.
- Cancun agreement was to limit the temperature change to 2° Celsius.

Our Choice Set

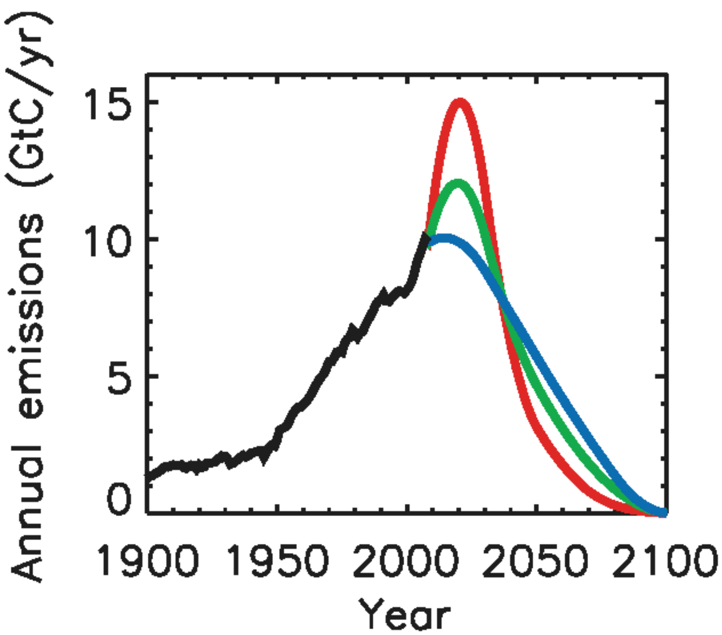


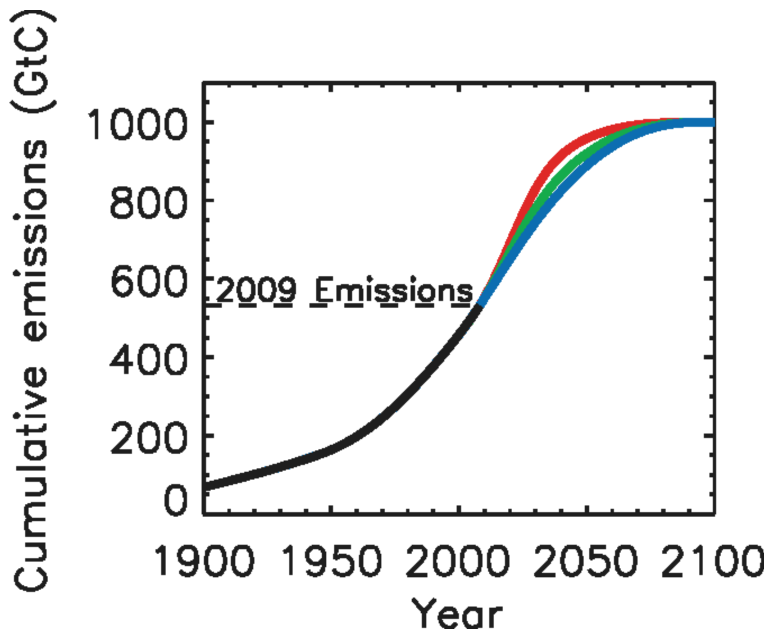
Global Temperature & Cumulative Emissions



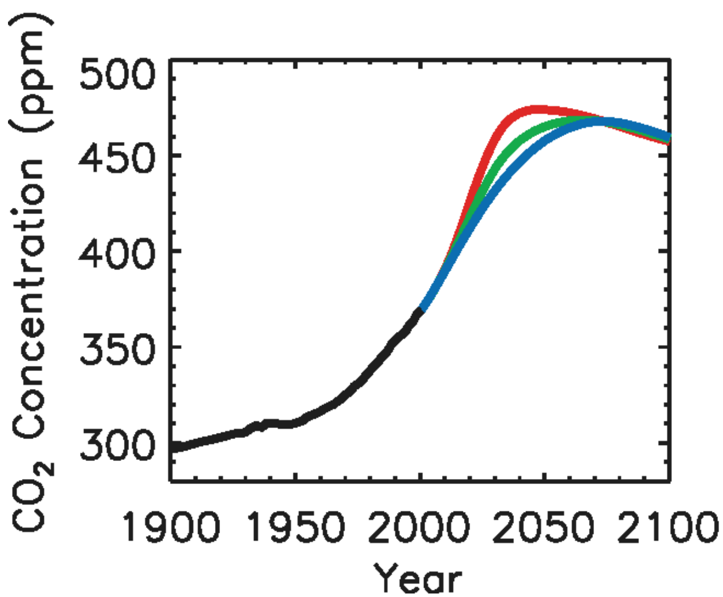
Carbon Budget is 500 Gigatonnes over the next 100 Years.

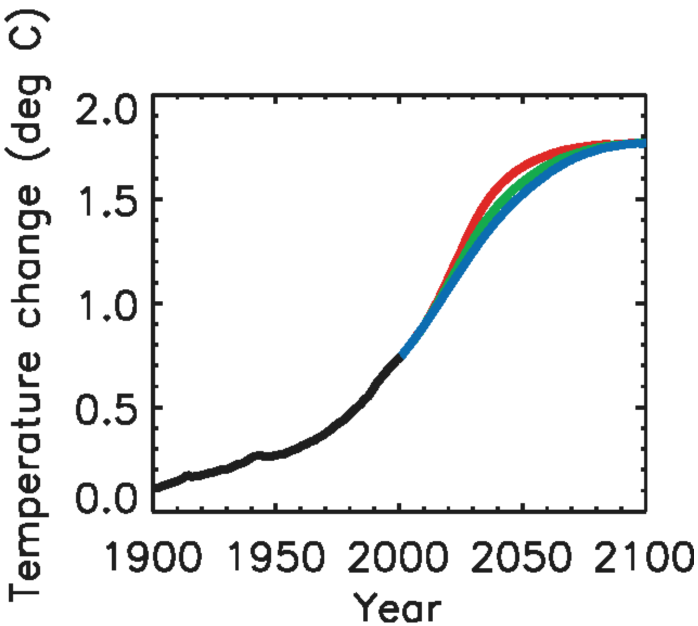
How can we spend it?





It doesn’t really matter





The Climate Change Challenge

- Need to lose 10 Gigatonnes/year of Carbon over the next 90 years.
- Carbon emissions have to go close to ZERO thereafter if temperature is to stabilize.
- Other Greenhouse gases have transitory effects – methane, aerosols – carbon is unique.
- How you get there is irrelevant.

How Big is 500 Gigatonnes of Carbon?

- One tonne is equal to 1000 kilograms
- One Gigatonne is equal to 1,000,000,000 tonnes.
- Burning one gallon of gas creates 8.2 kgs of CO2 or 2.23 kgs of Carbon
- 448 gallons of gas produce 1 tonne of Carbon
- 448 billion gallons create 1 Gigatonne of C
- A bit more than 3 years of U.S. gasoline consumption (138 billion gallons, 2009)
- 1500 years of current U.S. gasoline consumption.

Carbon Liabilities

- Current proven reserves of Natural Gas: 6,609 trillion c.ft.
- Carbon liability of reserves: 109 Gigatonnes of Carbon.
- Current proven reserves of Coal: 813 billion tonnes.
- Carbon liability of reserves: 670 Gigatonnes of Carbon.
- Current reserves of Petroleum: 1,354 billion barrels of oil.
- Carbon liability of reserves: 176 Gigatonnes of Carbon.
- Total Fossil Fuel Liability: 955 Gigatonnes of Carbon.

The World without Green Power

- Create a Business as usual trajectory to develop an expected carbon path.
- Create a Green energy trajectory meeting the carbon constraint.
- Compare the two to solve for the Burden of Green Power.

What will the world look like in 2100?

- Look at forecasts of energy demand with some policy changes expected. \$30ton/CO_2 in 2020; \$60 ton in 2030.
- Adopt forecasts for economic growth, population growth, and emissions from ExxonMobil until 2030.
- Calibrate a simple growth model to fit the forecasts till 2030, but let it run till 2100 to develop a business as almost usual forecast.

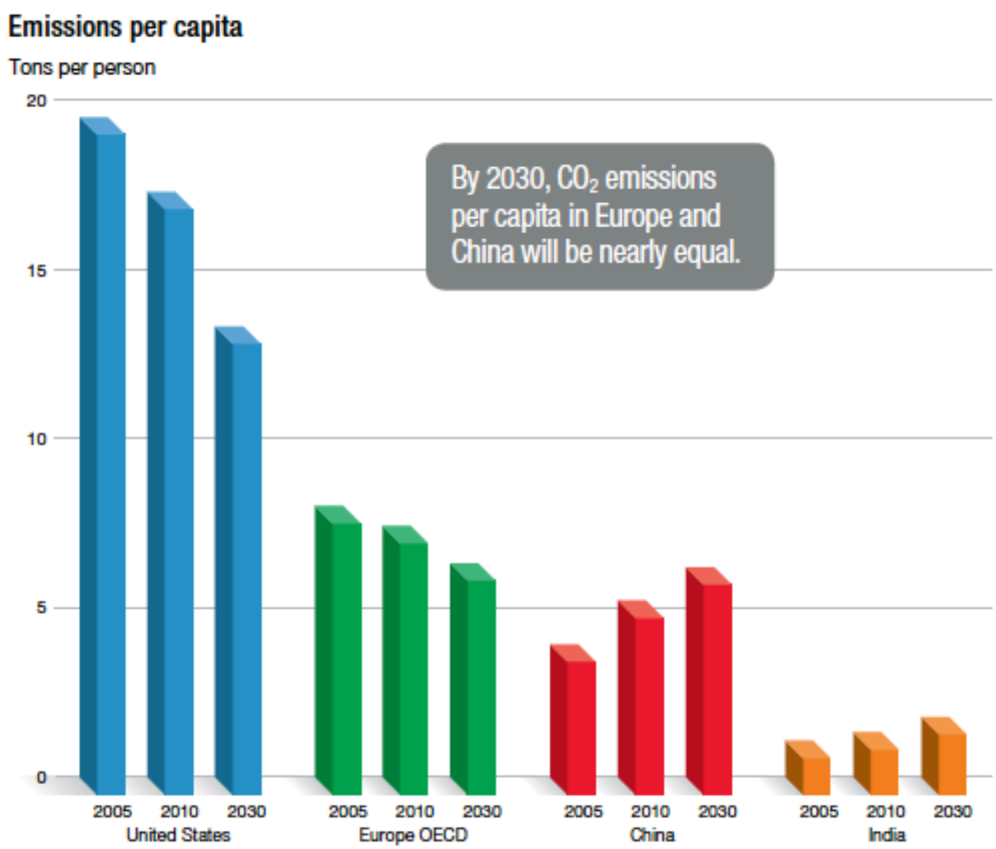
The Green Solow Model

- Capital accumulation plus technological progress drives growth in the short and medium run.
- Technological progress drives growth in the long run.
- Poor countries become Rich and eventually catch up to Rich ones.
- Production requires energy and energy use creates emissions.
- Growth creates emissions, but technological progress drives emissions per unit output downward.

Amendments

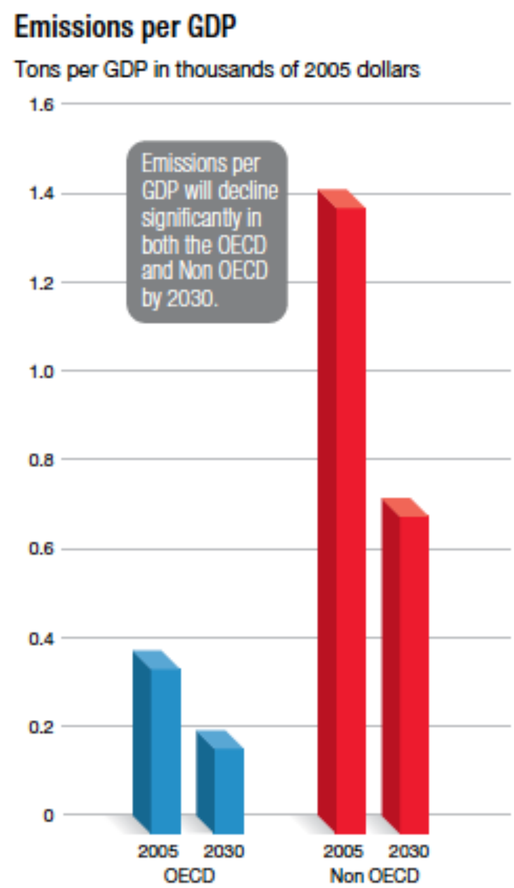
- One unit of GDP requires A units of energy, and one unit of "activity" produced by F(K,L).
- Less energy can be used in more K and L are used.
- One unit of energy creates B units of emissions.
- A falls over time as energy intensity of GDP falls.
- B could fall over time as energy sources change.
- Relative price of Energy/GDP rises over time.

Convergence



ExxonMobil
Economic Outlook
2010

Decarbonization

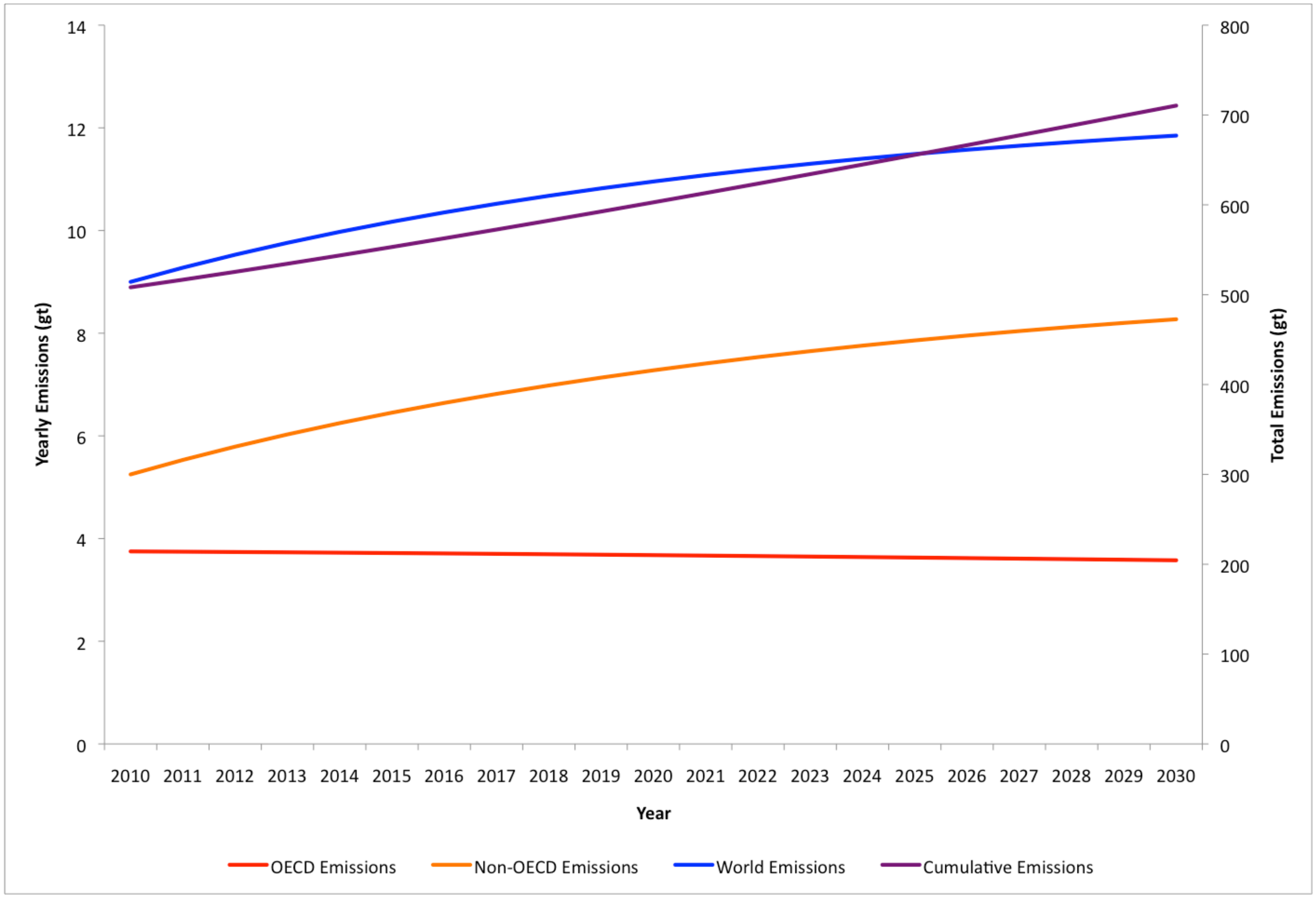


ExxonMobil Economic Outlook 2010

Benchmark Calibration

- Two Region World: OECD, Non-OECD
- World population grows by 1 billion by 2030; majority of growth in Non-OECD.
- OECD GDP grows by 2% per year.
- Non-OECD GDP growth averages 5% year
- Non-OECD emissions exceed OECD emissions by 40% in 2010.
- Decarbonization of 2.5 to 3%/year.

ExxonMobil's World till 2030

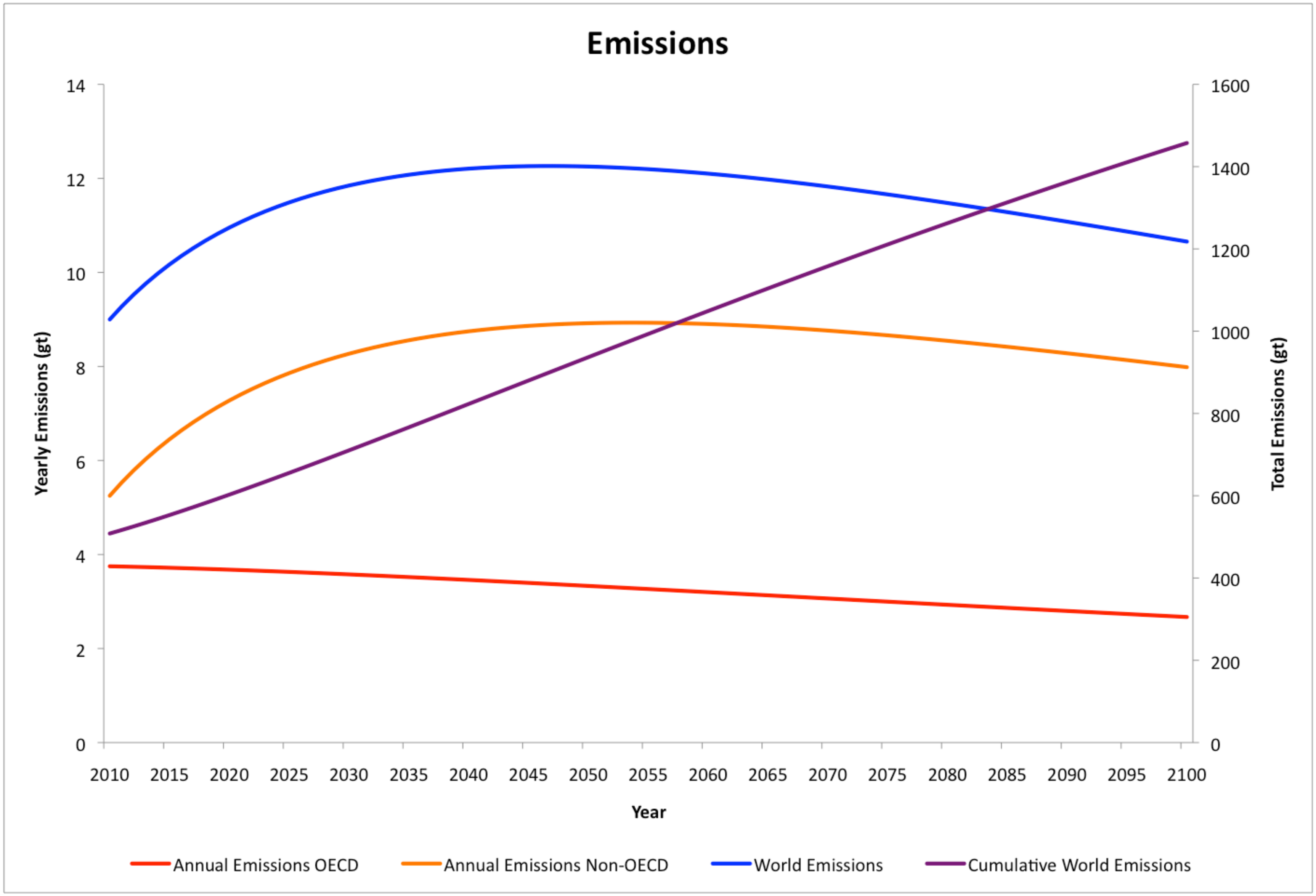


"Results"

- OECD emissions fall by about 15% over the period.
- Non-OECD emissions double OECD by 2030.
- World emissions approach 12 Gigatonnes by 2030.
- Global emissions rise by 1% year over the period.
- Simply extrapolating these results to 2100 implies:
  - A 1% increase per year over 70 years doubles annual carbon emissions to almost 25 Gigatonnes.
  - Cumulative emissions would put us in uncharted waters for temperature: 4-5 Celsius increase.

Extending the ExxonMobil World to 2100

- 3 assumptions worthy of mention.
- Population growth continues at 0.5% year in Developing World; zero in OECD.
- Decarbonization remains slightly faster in Developing World.
- Long run growth in income per capita approaches 2% year everywhere.



Emissions
14
12
10
8
6
4
2
0
1600
1400
1200
1000
800
600
400
200
0
Yearly Emissions (gt)
Total Emissions (gt)
2010 2015 2020 2025 2030 2035 2040 2045 2050 2055 2060 2065 2070 2075 2080 2085 2090 2095 2100
Year
Annual Emissions OECD
Annual Emissions Non-OECD
World Emissions
Cumulative World Emissions

A Much Warmer World

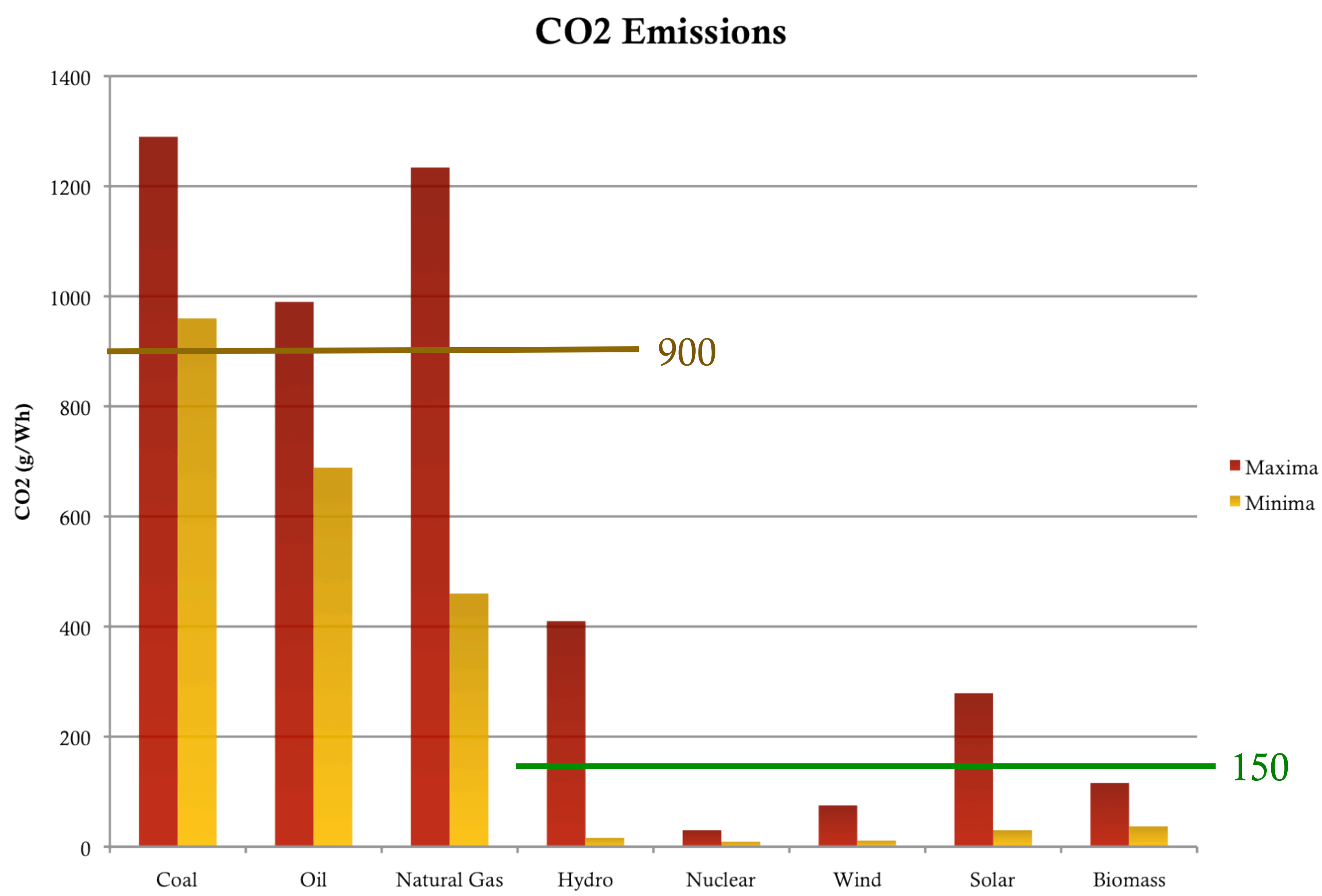
- OECD emissions continue to decline.
- Non-OECD emissions peak in 2050.
- Global emissions peak a little earlier.
- Global emissions in 2100 are over 10 gigatons C
- Cumulative emissions reach 1450 gigatons C
- Temperature implication is perhaps 3 degrees Celsius, with error bands running from 1.75 to 4 Celsius.

What is driving the result?

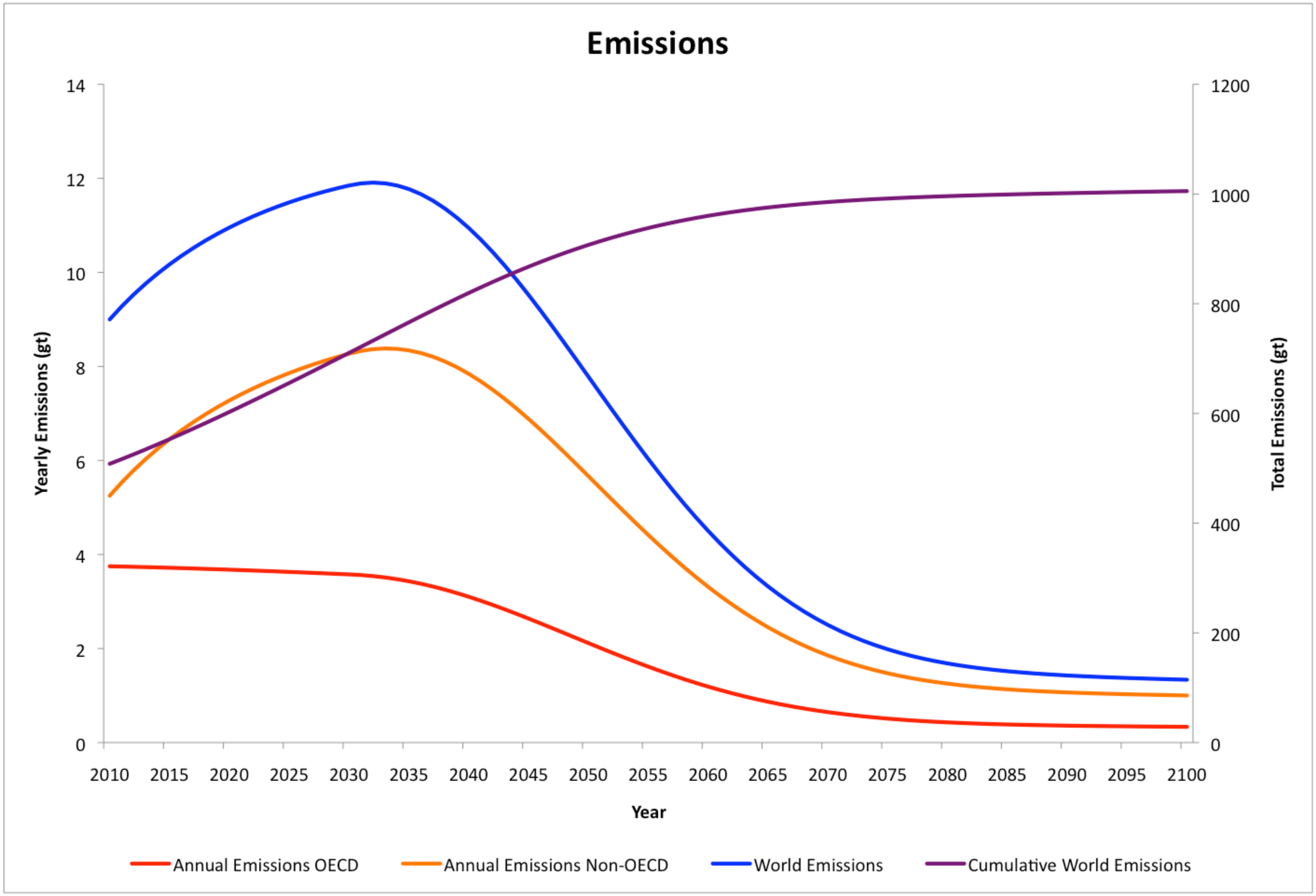
- Long run economic growth at 2% raises emissions.
- Period of transition for Developing World is long, has fast growth, and creates a lot of carbon.
- Decarbonization can offset growth only slightly, and only for mature economies growing slowly.
- High rates of capital accumulation and population growth overwhelm these forces.
- Since cumulative emissions matter, we are cooked!

How big is the task for Green Power?

- Assume Green sources of power are 1/6 as carbon intensive as Brown sources per unit energy delivered.
- Let the rate at which Green Power can replace Brown Power rise over time, starting in 2030.
- Solve for the rate at which Green Power has to be implemented to keep temperatures below 2 Celsius.
- Assume long run economic growth is unaffected by the transition to Green Power.



Source: “Energy Myths and Realities”, Smil, 2008.

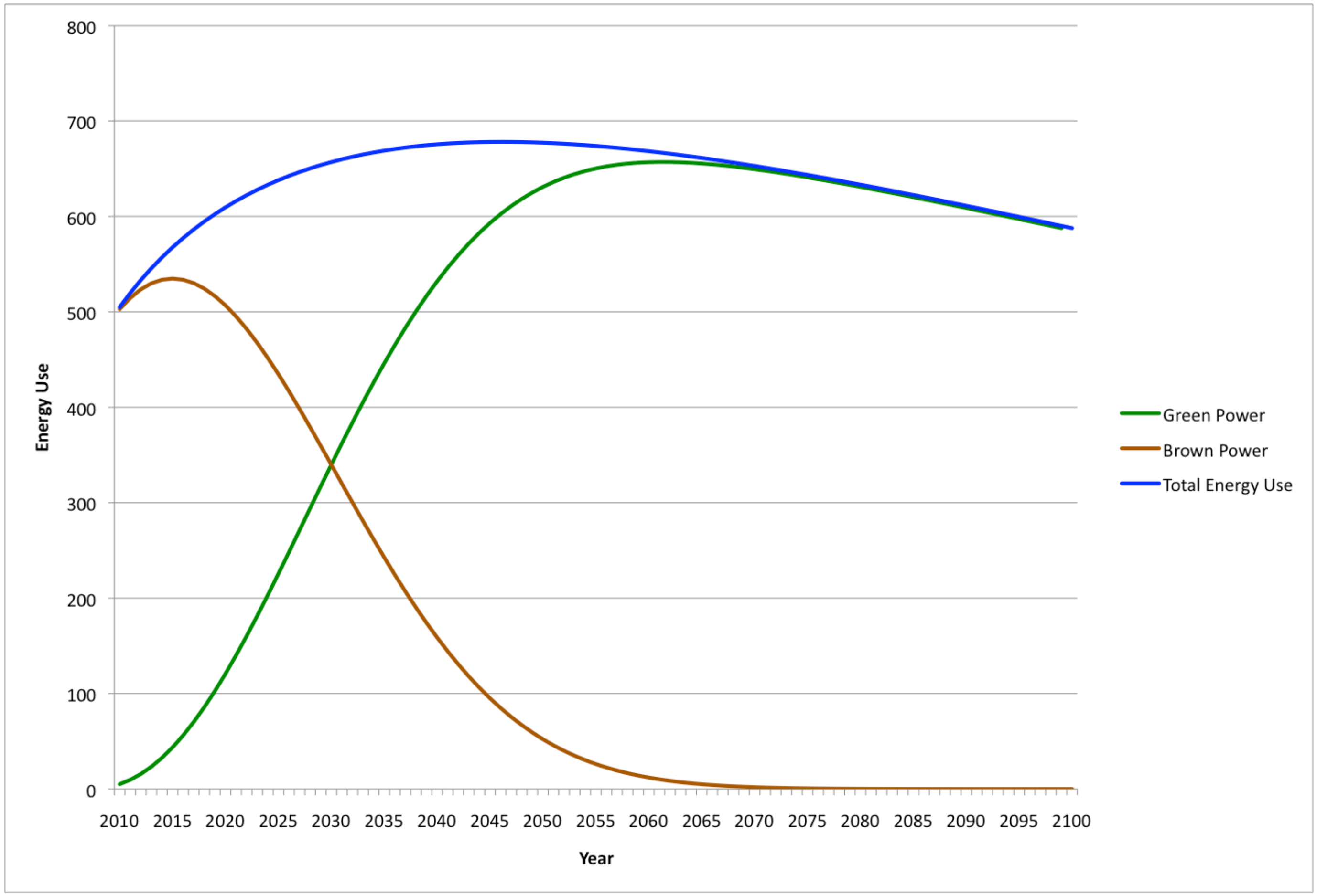


Emissions
14
12
10
8
6
4
2
0
Yearly Emissions (gt)
1200
1000
800
600
400
200
0
Total Emissions (gt)
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
Year
Annual Emissions OECD
Annual Emissions Non-OECD
World Emissions
Cumulative World Emissions

A 2 Degree Celsius World

- OECD emissions decline at a faster rate.
- Non-OECD emissions peak in 2035, then decline quite rapidly.
- Global emissions peak a little earlier.
- Global emissions in 2100 fall to about 1.5 gigatons C
- Cumulative emissions reach 1000 gigatons C
- Temperature implication is perhaps 1.75 Celsius.

The Burden of Green Power



A Summary of the Challenge

- Green Power has to deliver the equivalent of 650 quadrillion BTUs by 2055.
- In 2010 Green Power delivered 65 quadrillion BTU.
- Biomass provided: 47
- Hydro provided: 11
- Solar, wind, and other renewables: 7

Can it be done?

- Engineer a very rapid energy transition from fossil fuels to Green Energy Sources.
- What can history tell us about the constraints we will face?
- What can economics tell us about the incentives, both public and private, to make this transition.

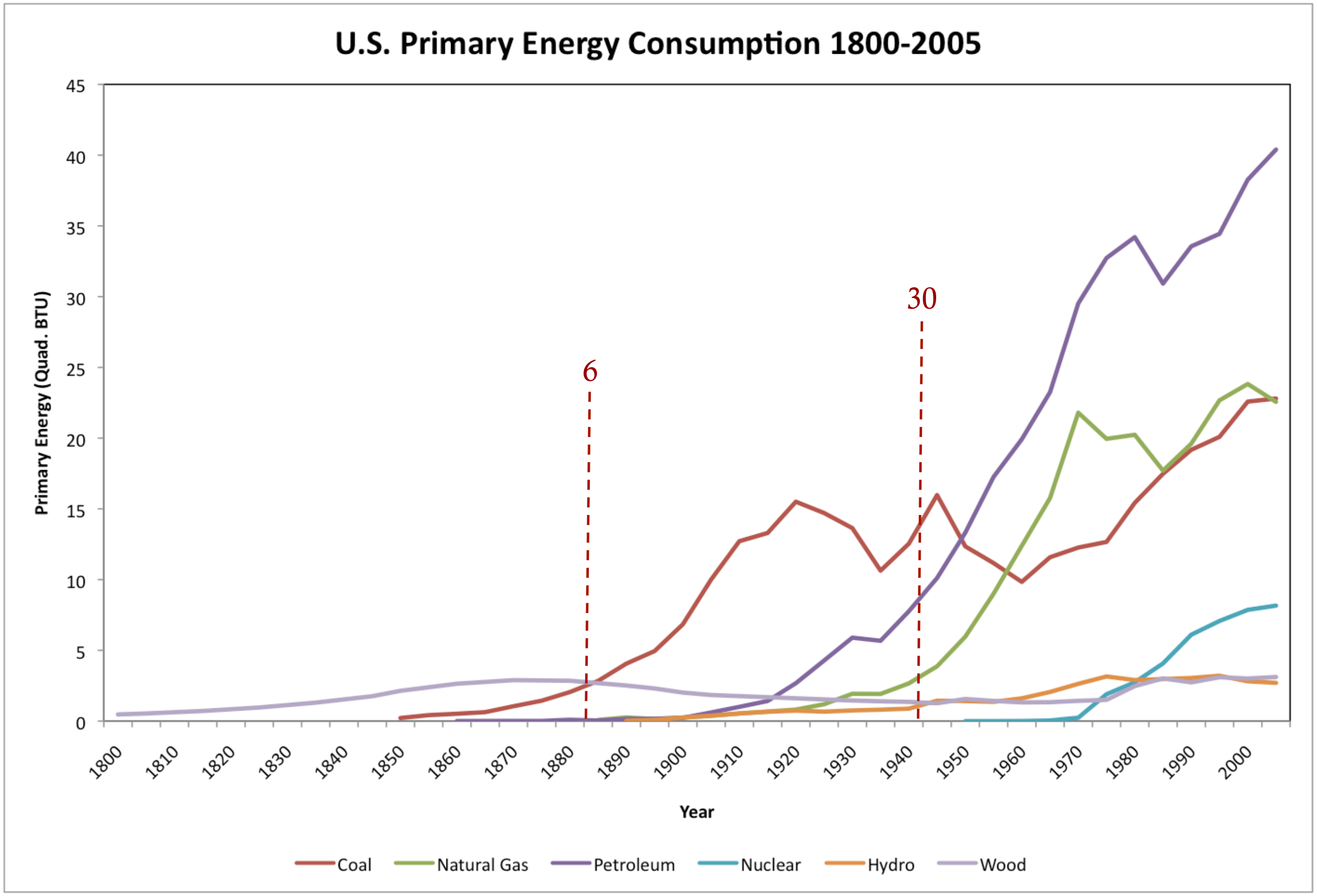
What do we know about Energy Transitions

- Two transitions before
- Biomass to Coal
- Coal to Liquid Fuels – Oil and Natural Gas
- Liquid Fuels – Green Power

The "Stylized Facts" of Energy Transitions

- Past transitions were very slow.
- The transitions were of relatively small magnitude.
- Energy sources don't disappear shares change.
- New energy sources lead to new converters and prime movers.
- Transitions are always to higher density sources, that provided new benefits.

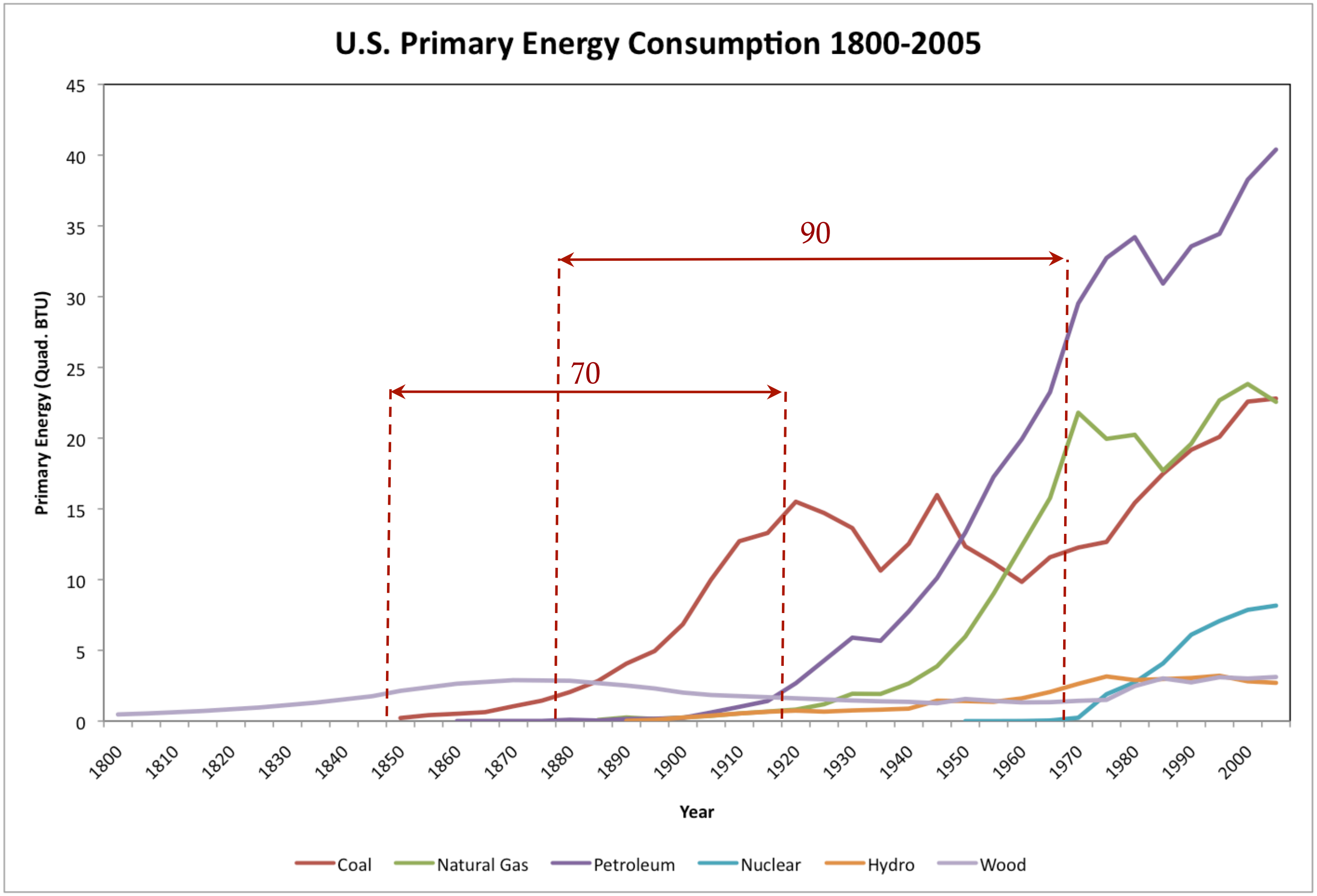
The Past


U.S. Primary Energy Consumption 1800-2005
Primary Energy (Quad. BTU)
45
40
35
30
25
20
15
10
5
0
6
30
1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Year
Coal
Natural Gas
Petroleum
Nuclear
Hydro
Wood

Scale: How big is 600 Quadrillion BTUs

- In 1885, Coal surpassed Wood in the US as the dominant fuel source. Total usage was 6 Quads.
- In 1945, Coal was surpassed by Petroleum and Natural gas as the dominant fuel source. Total usage was perhaps 30 Quads.
- In 2010, Total US consumption was approximately 92 Quads.
- Transition means changing over 6 times current U.S. consumption.

The Past



U.S. Primary Energy Consumption 1800-2005
Primary Energy (Quad. BTU)
0
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1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Year
90
70
Coal
Natural Gas
Petroleum
Nuclear
Hydro
Wood

Speed: How fast have other transitions been?

- From its introduction in 1850 to its complete dominance by 1920, Coal took 70 years.
- From the first U.S. well in 1880 until its point of maximum dominance in 1970, Petroleum and Natural gas took 90 years.
- Green Power must move from a small share today to almost complete dominance in 50 years time.

Direction: Renewables are different

- Energy density: Joules/Kilogram
- Crop residue 17-18 MJ/kg.
- Wood 19 MJ/kg
- Coal 22-24 MJ/kg
- Charcoal 30 MJ/kg
- Petroleum products 40-44 MJ/kg
- Ease of transport, storability, reach.

Renewables are different

- Power density: Watts/square meter
- Solar panels: up to 100 W/M2
- Wind and hydro-generation: 5-15 W/M2
- Biofuels and phytomass: 1 W/M2
- Coal, Natural gas, Oils: 1-10 kW/M2
- Land needed to support, transport costs, city size.

Incentives: Coal

- Coal's first use was heat; coal was cheaper than wood and only after a period of time did it overtake wood in heating.
- Demand for coal, brought us a power source – steam engine –for mining.
- It gave us a power source not tied to rivers, wind or animate power.
- Later still mobile applications arrived powering trains, ships, cars.
- Energy density of coal facilitated its use in transportation.

Incentives: Liquid Fuels

- Petroleum was first a lubricant, until the internal combustion engine was invented in the 1880s.
- Its higher energy density allowed further mobility and miniaturization of engines.
- Liquid form was easier to transport.
- Let to Diesel engines, gasoline engines, jet engines.
- Almost all of international trade is powered by diesel engines; all of air travel by jet turbojets or turbofans.

Incentives: Green Power

- Does not provide any new benefits in terms of energy density for transport applications. Bio-fuels are less dense energy sources.
- Solar, wind generated electricity is just that – electricity.
- Distributed power is a potential benefit, and small scale is useful, but in large scale applications we need to worry about intermittency.
- Without government subsidies or regulations, there would be very little green power generated.

Public Incentives

- Real benefit of Renewable energy is its environmental benefit.
- Local pollution reduction can however be met in a variety of ways – low sulfur coal, scrubbers, electrostatic precipitators, zoning laws.
- These solutions are well known, the technology is available, and the solutions are relatively cheap.
- Cleaner air in the U.S. has been surprisingly cheap.

We are Back to Square One

- Benefits are primarily public and not private; they will be primarily global and not local.
- Massive introduction of Green Power will require active government involvement, and will not be the cheapest energy solution.
- To make these investments worthwhile, Governments will require that they are actual reductions not undone by emission increases in other countries.
- Incentives for Green Power will only be in place if we have an international climate change treaty limiting emissions.

Conclusion

- Current rates of carbon emissions imply large temperature changes in the next 100 years.
- Convergence and decarbonization will help, but business as usual implies a much warmer world.
- Unless the world grows slower, converges faster, and has a smaller population, the challenge for Green Power is daunting.
- The needed scale, speed and direction of change would be unprecedented in human history.

Conclusion

- Unlike earlier transitions there are few private incentives to adopt Green power
- Pubic incentives will remain weak without a global climate agreement.
- Unless the National Academy is wrong, other solutions to Climate Change will need to be found to keep temperature increases below 2 degree Celsius.
- Green Power cannot "save us" from climate change.