Innovations in Materials Technology for a Sustainable World

Gary L. Messing
Department of Materials Science and Engineering
Materials Research Institute
Pennsylvania State University

Innovation for Sustainable Production 2008
April 22-25, 2008
Brugge, Belgium

"Limits of Growth" Meadows et al., (1974)

- Systems analysis study at MIT
- Commissioned by the Club of Rome
- Conclusions were doomsday-ish
  - Study sees disaster by 2100
  - Scientists warn of global catastrophe

Brundtland Commission Report. “Our Common Future” (1987)

- Humanity has the ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of the future generations to meet their own needs”
- Must not damage or destroy basic life support system; air, water, soil and biological systems
- Must be economically sustainable to provide continuous flow of goods and services
- Requires sustainable social systems at international, national, local and family levels

Sustainable Development Is:

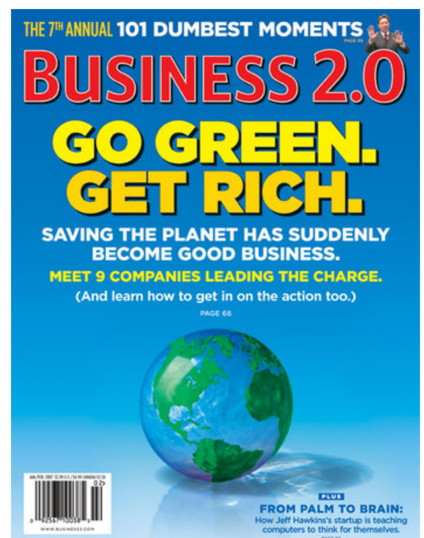
A globally accepted approach to sustaining economic growth without harming our planet or exhausting its resources while improving the quality of life for its current and future inhabitants.

- **Economic Responsibility**
- **Environmental/Ecological Performance**
- **Social Responsibilities**

Bayer MaterialScience

What’s driving the ‘Sustainability’ movement?

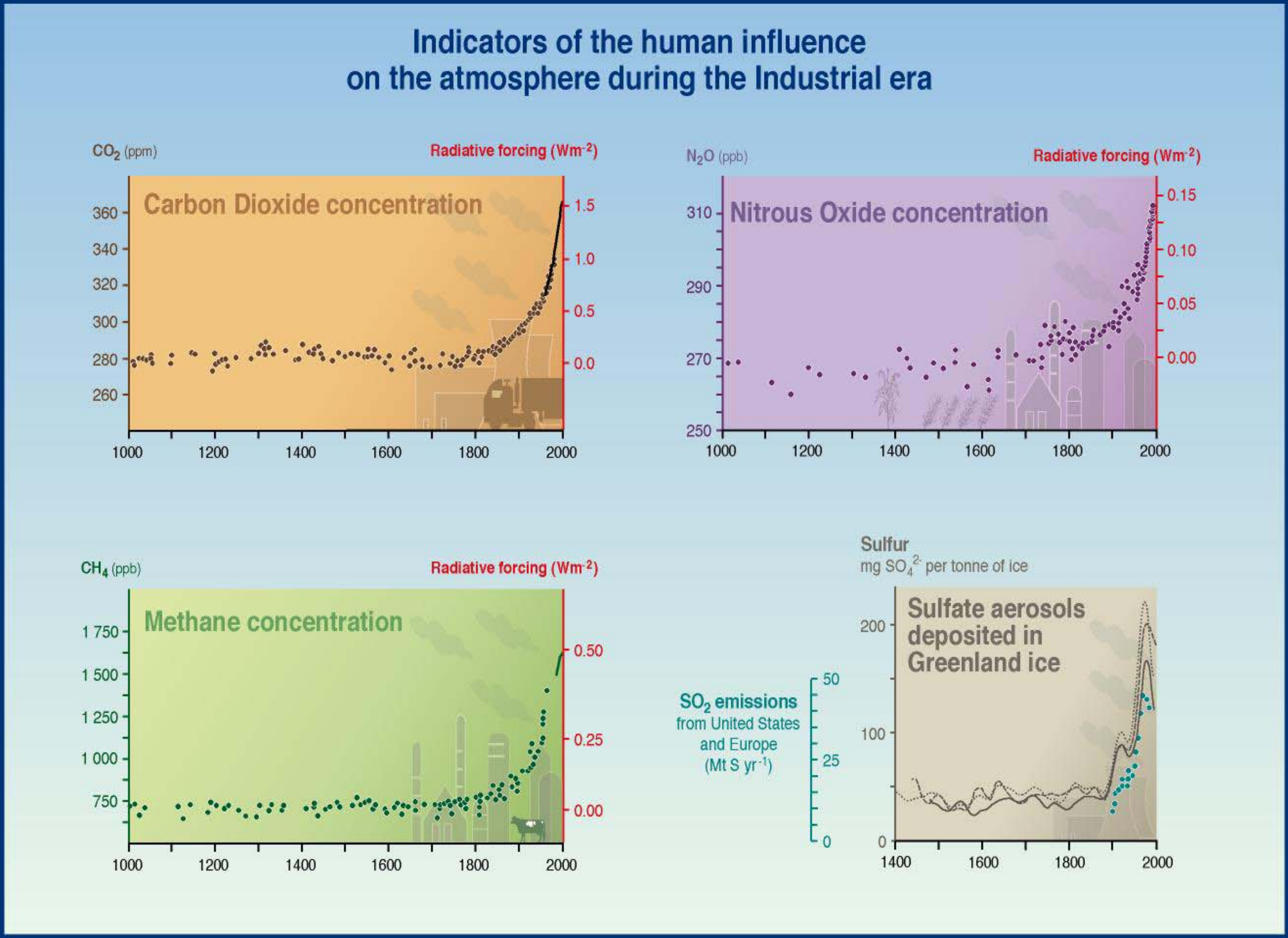
- Society and growing public concern in U.S.
- Rapidly emerging state regulatory plans
- Recent U.S. elections
- Equity markets considering sustainability in valuations



Bayer MaterialScience

The scale of the problem grows

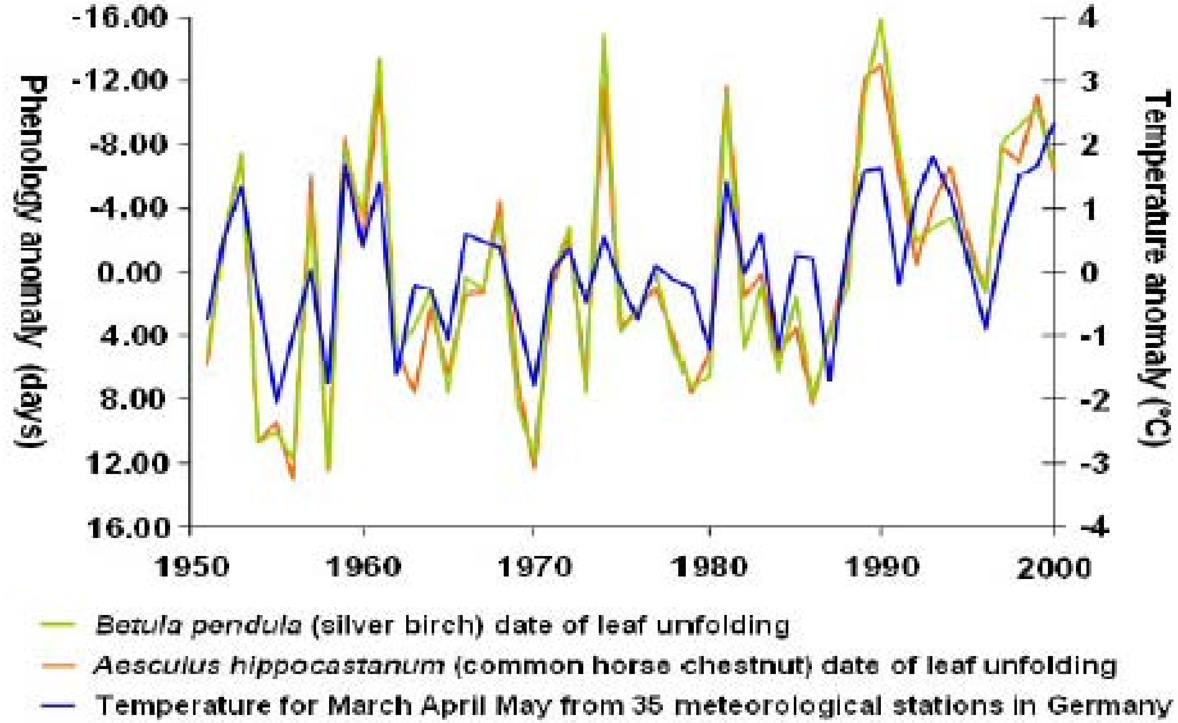
- Global warming is real
- Stratospheric ozone depletion
- Forest, wetland and habitat destruction
- Loss of biodiversity
- Encroaching desertification
- Contamination of ground and surface water resources
- Growing population, and subsequent energy and resource use



SYR - FIGURE 2-1
WG1 FIGURE SPM-2

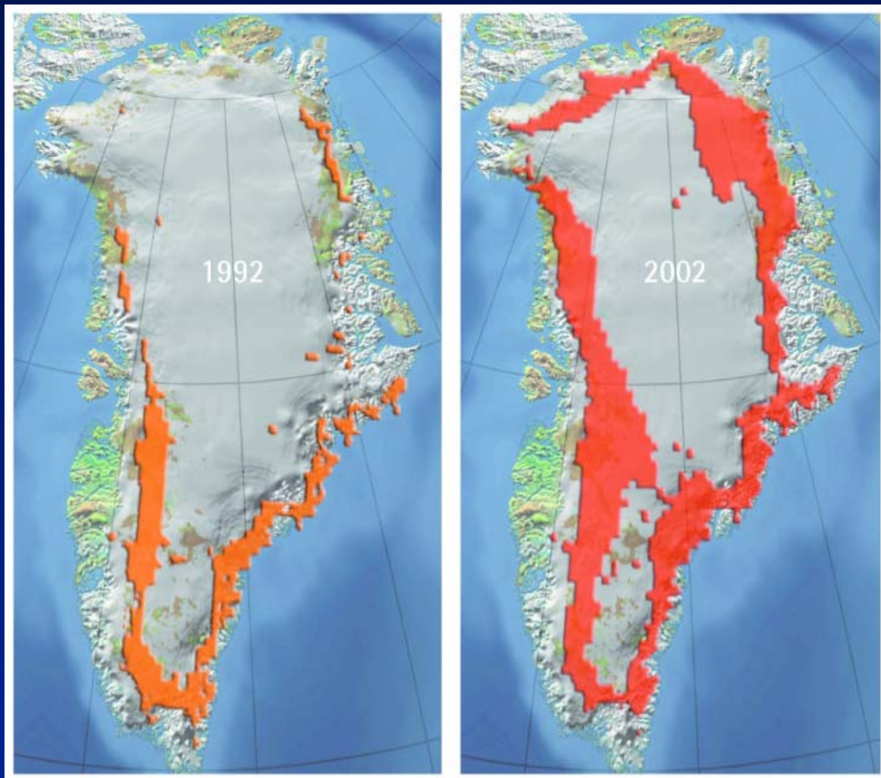
From the Intergovernmental Panel on Climate Change (IPCC); Climate Change 2001 Synthesis Report

Leaf unfolding dates in Europe



Greenland Ice Sheet

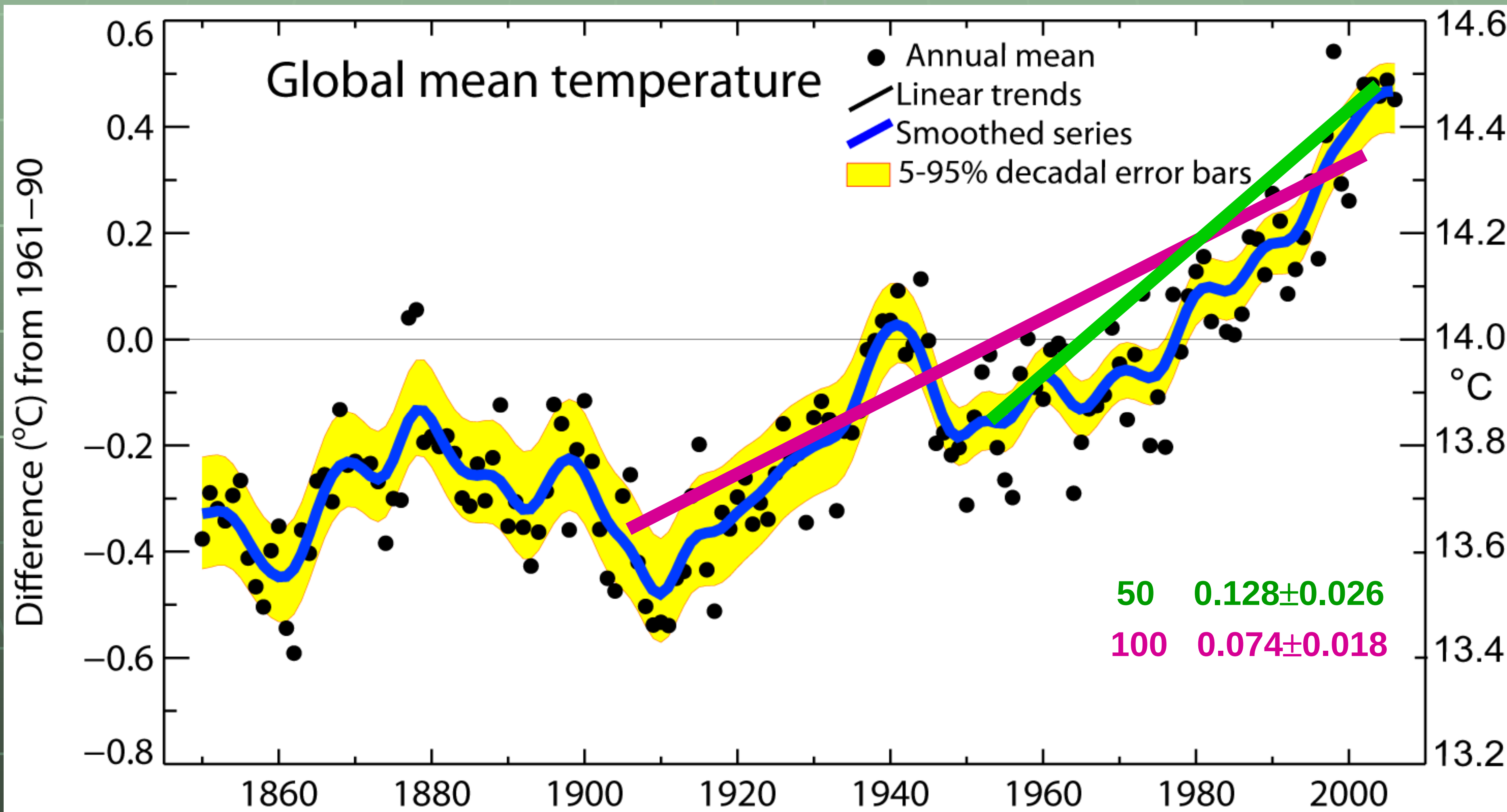
Permafrost



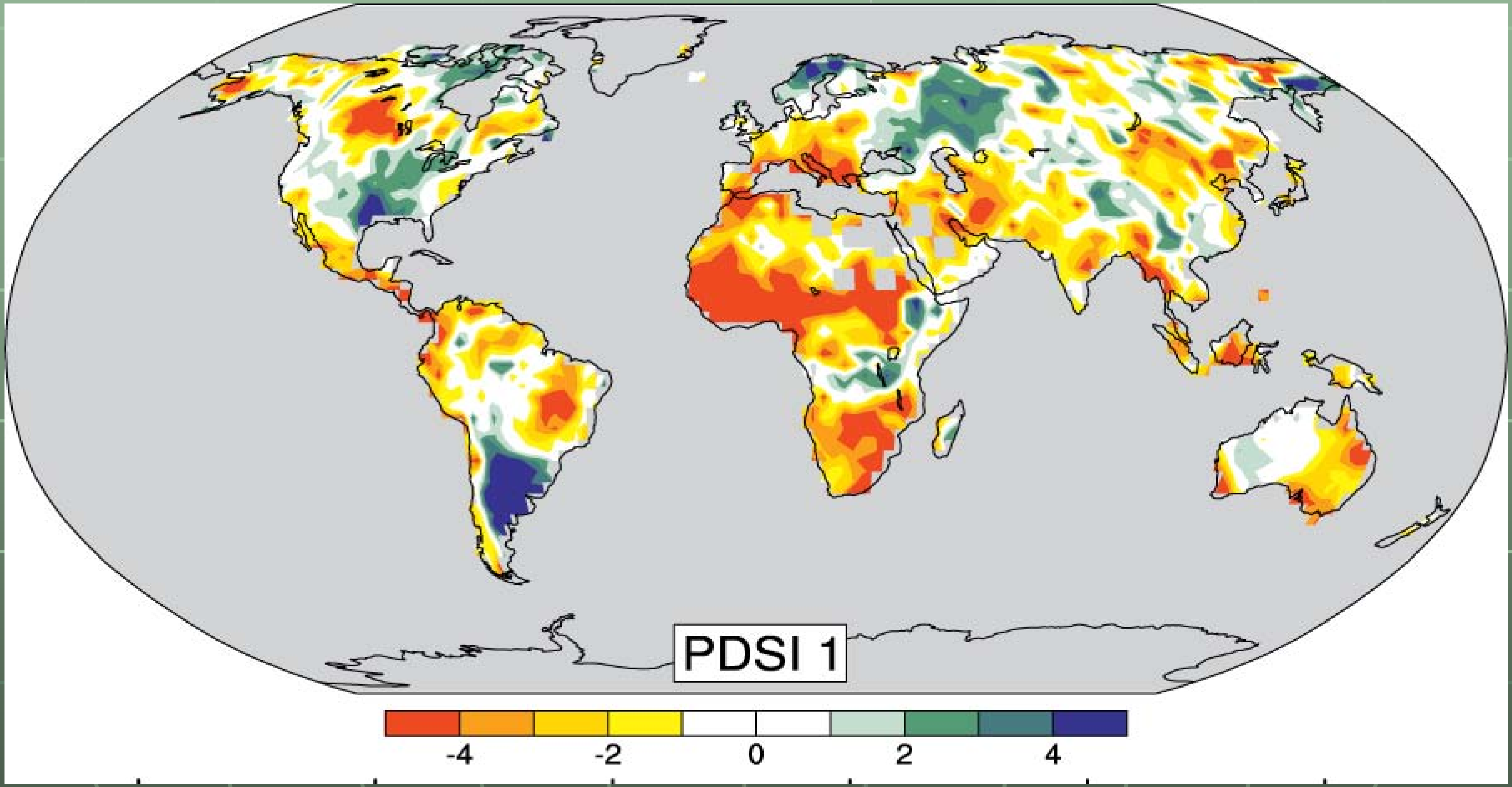
Coral Bleaching

QuickTime™ and a
TIFF (Uncompressed) decompress
are needed to see this picture.

Global mean temperatures are rising faster with time



Over the longer term drought is increasing most places

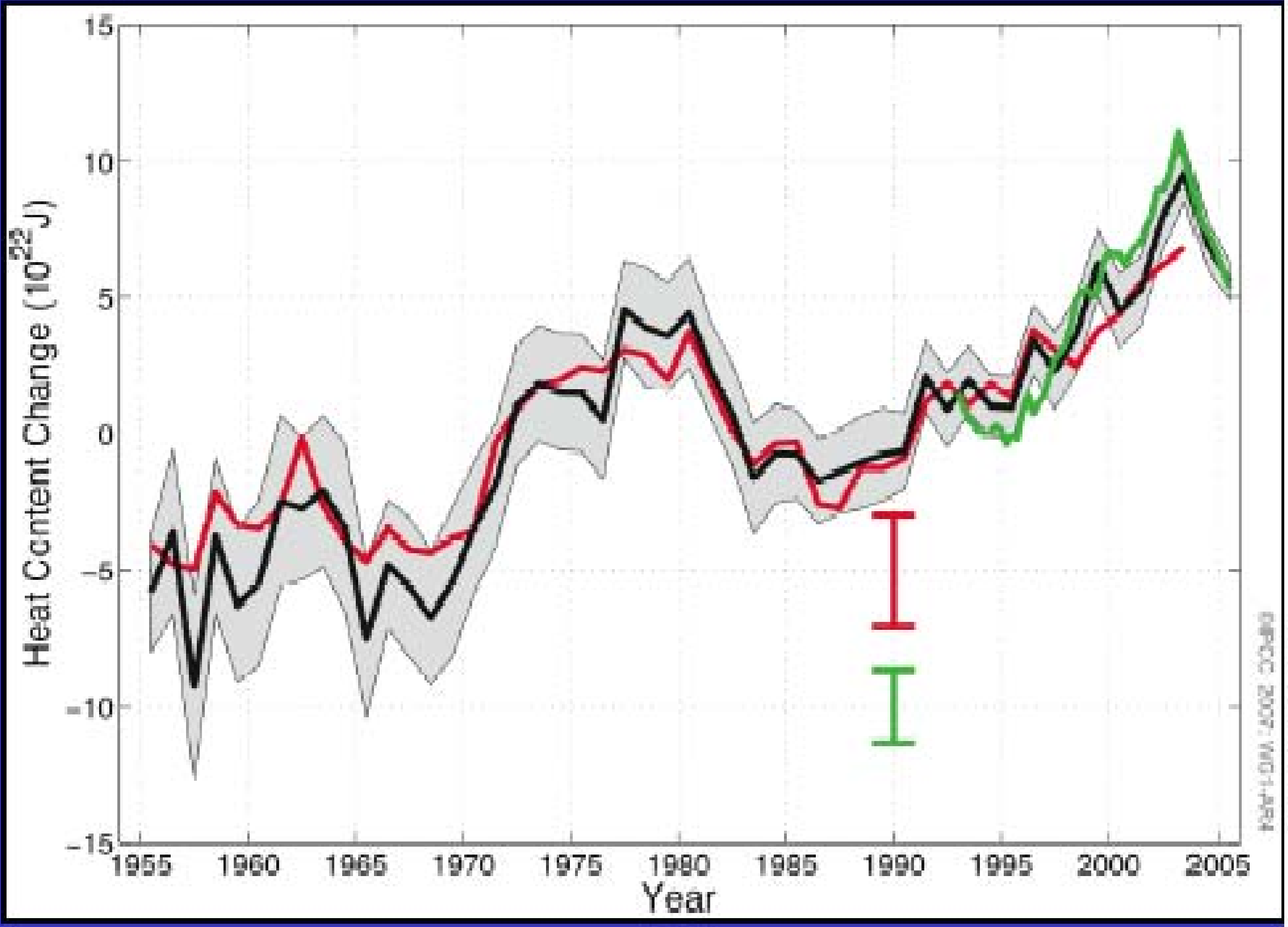


Change in Palmer Drought Severity Index, 1900 - 2002

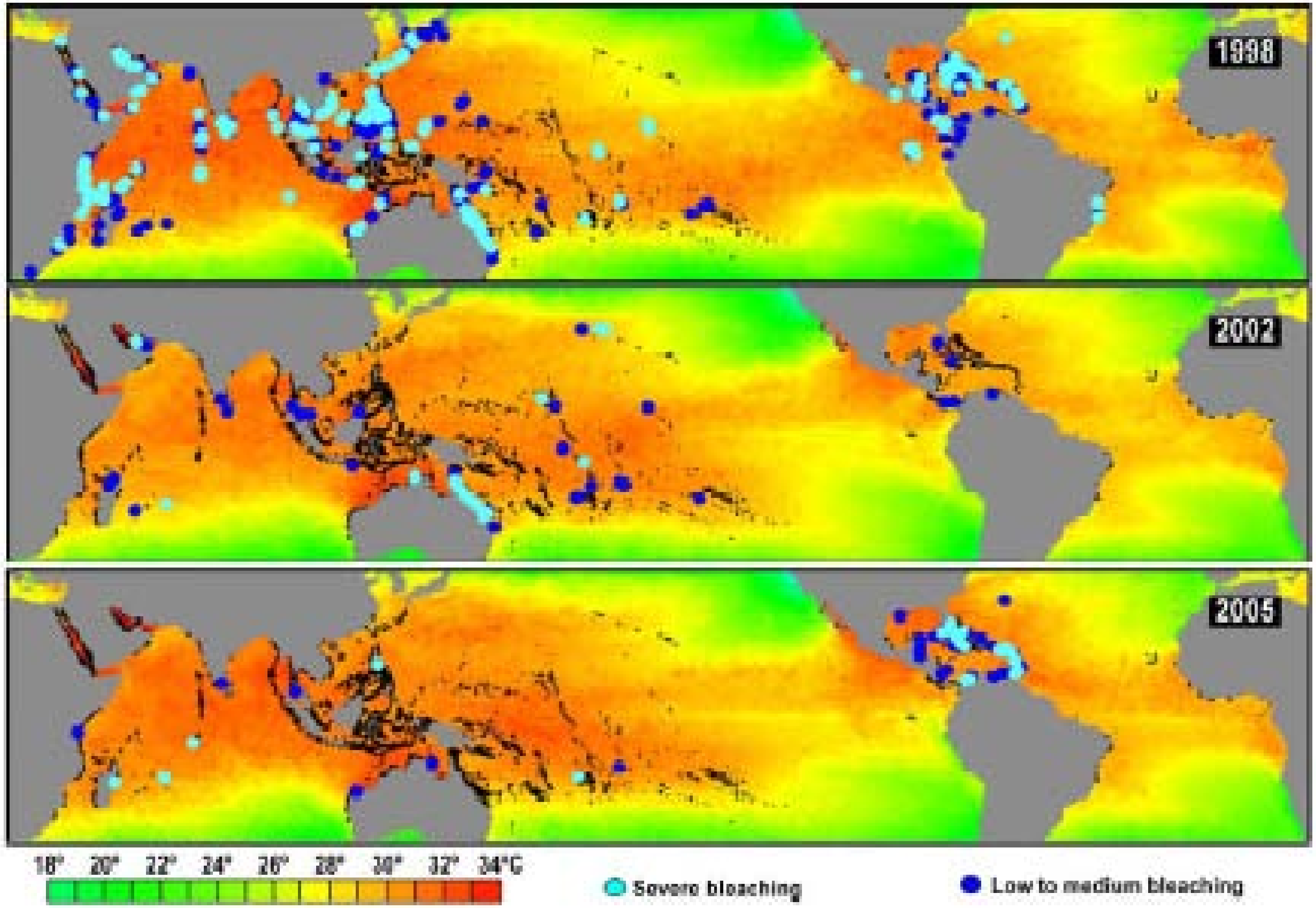
Ocean temperatures are rising

Ocean temperatures have increased to depths of at least 3000 m.

Estimates of total heat content from independent analyses show inter-annual variability but a positive trend since 1961.



Recent coral bleaching events



Powering the Planet

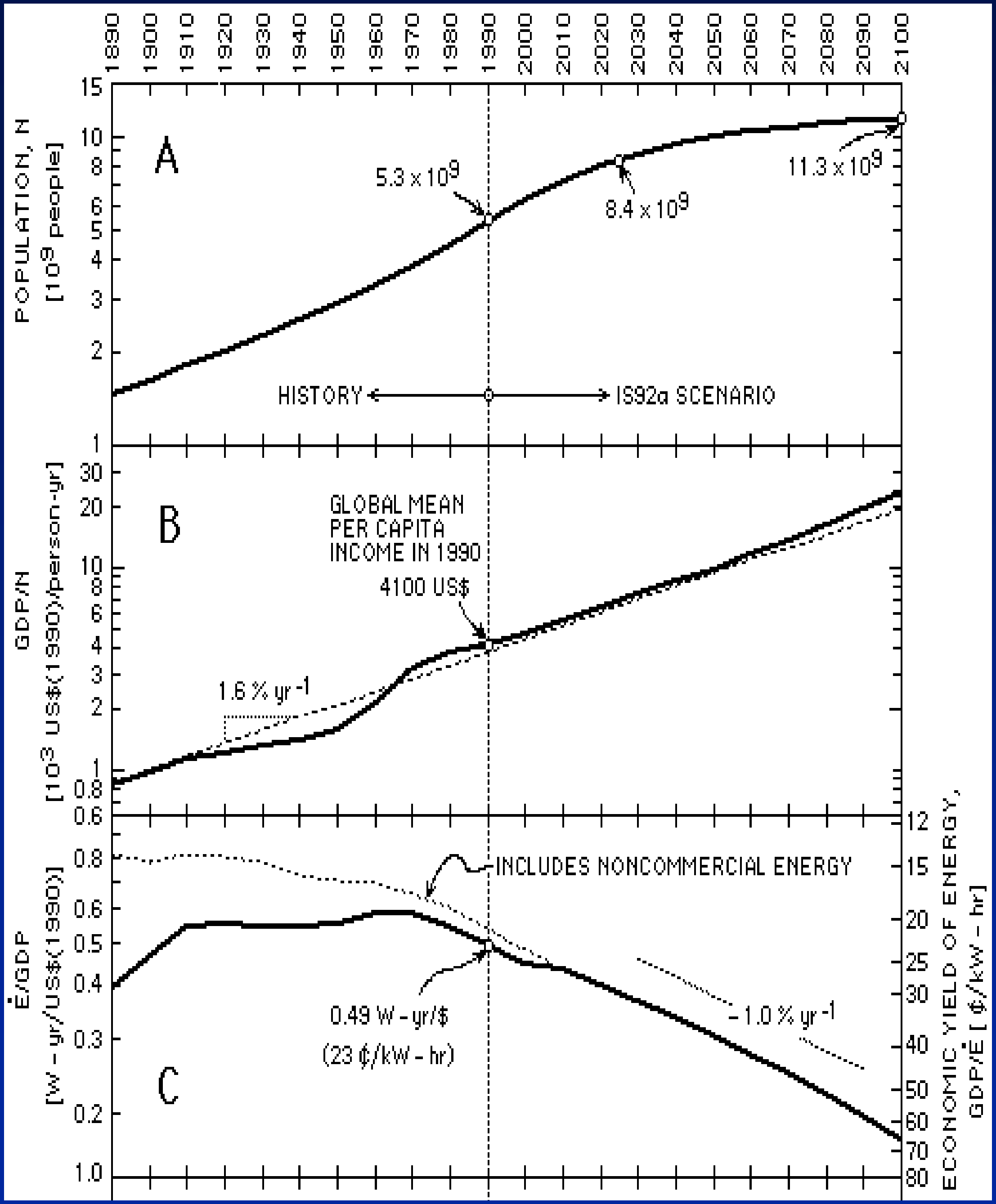
Nathan S. Lewis, California Institute of Technology

MRS Bulletin, **32** 808-820, October 2007

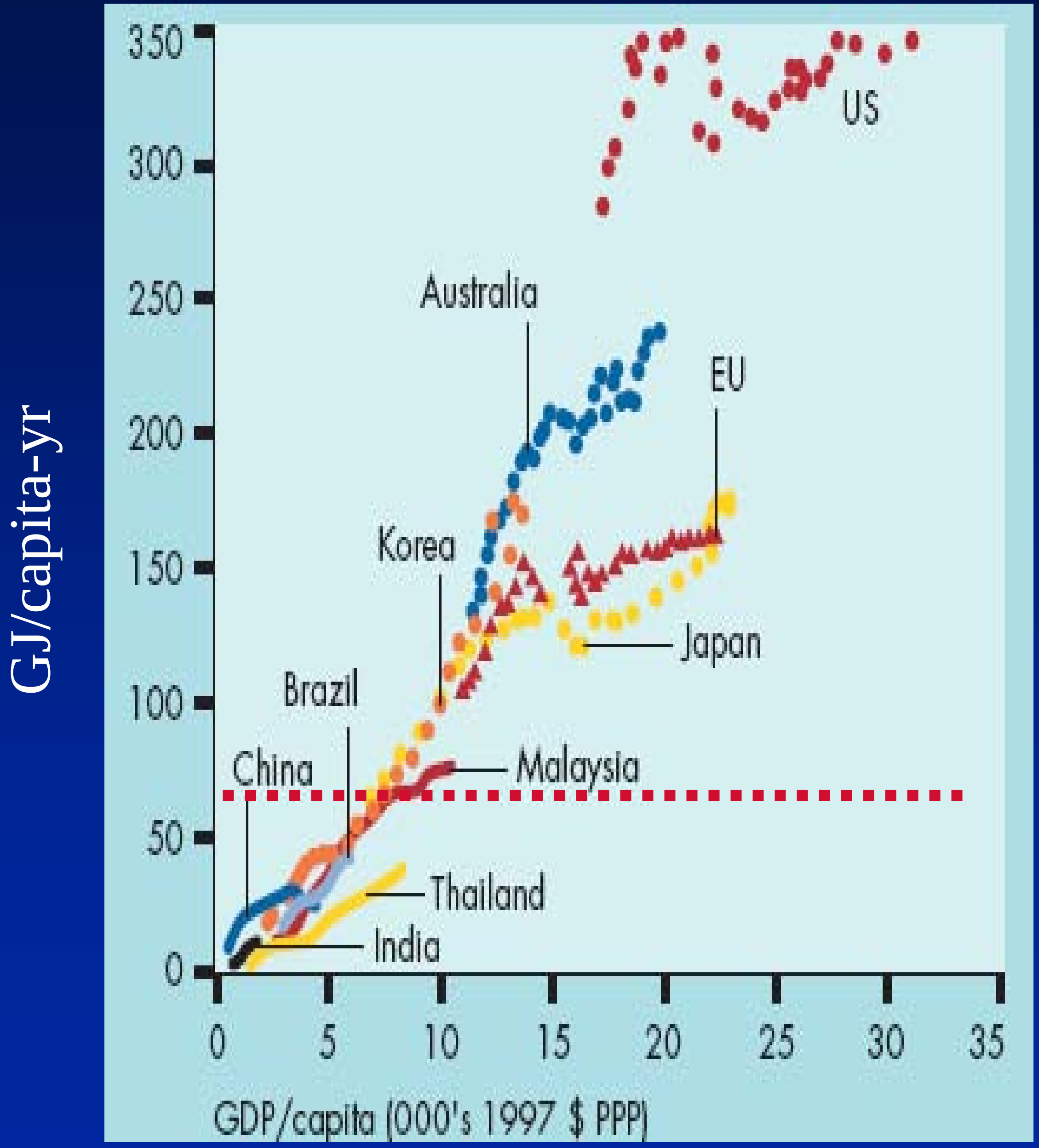
Population Growth to 10 - 11 Billion People in 2050

Per Capita GDP Growth at 1.6% yr^{-1}

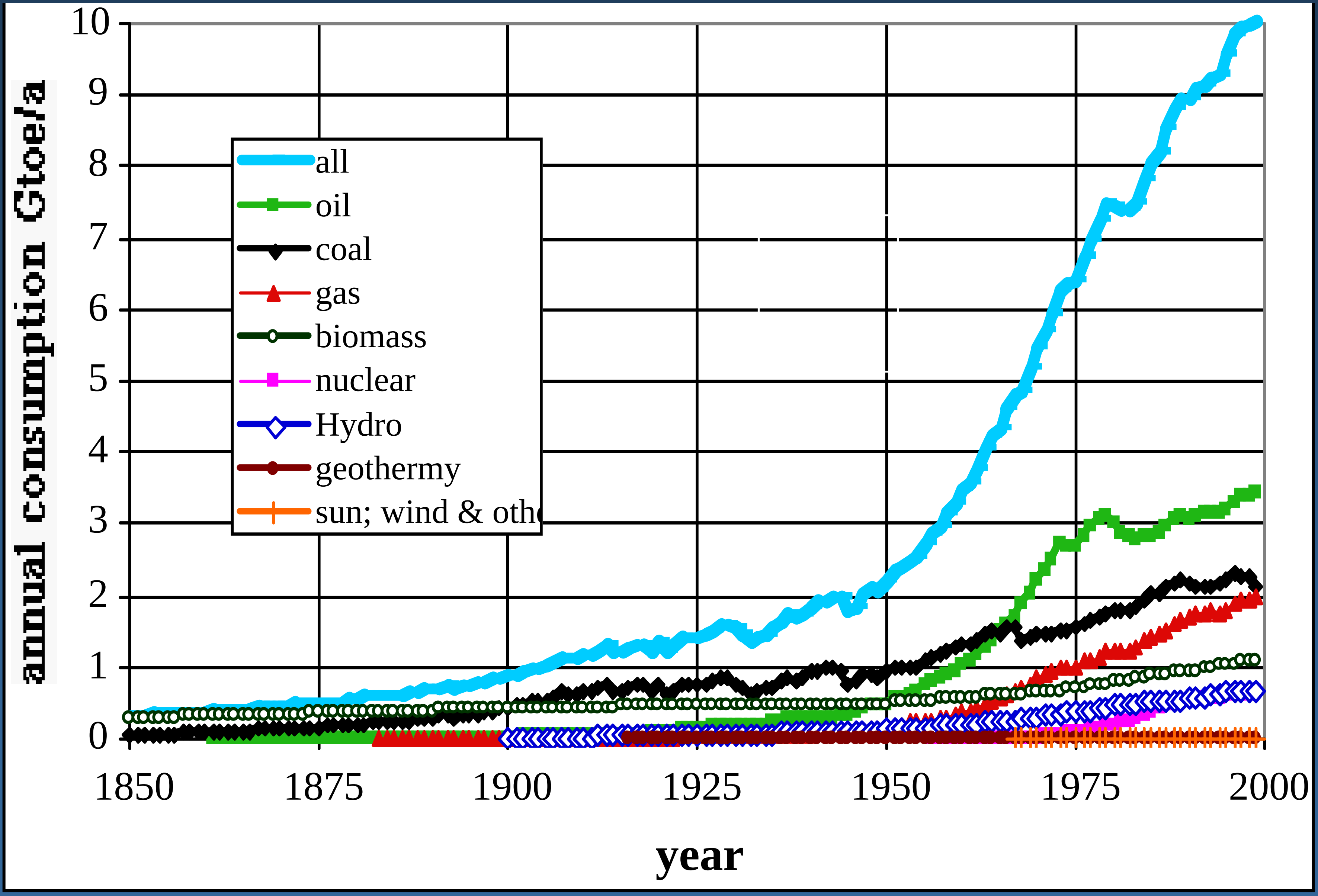
Energy consumption per Unit of GDP declines at 1.0% yr^{-1}



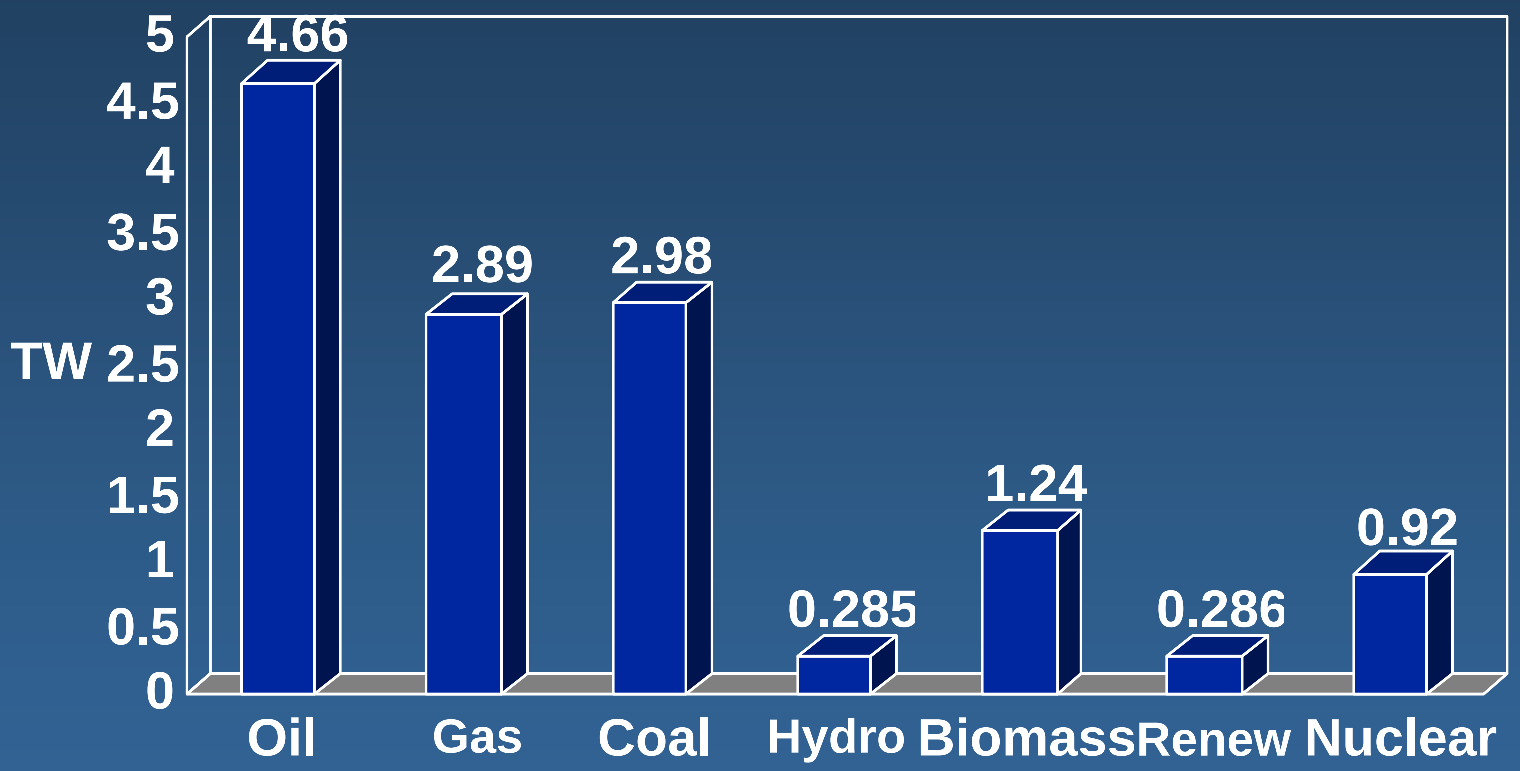
Energy Consumption vs GDP



Global Energy Consumption



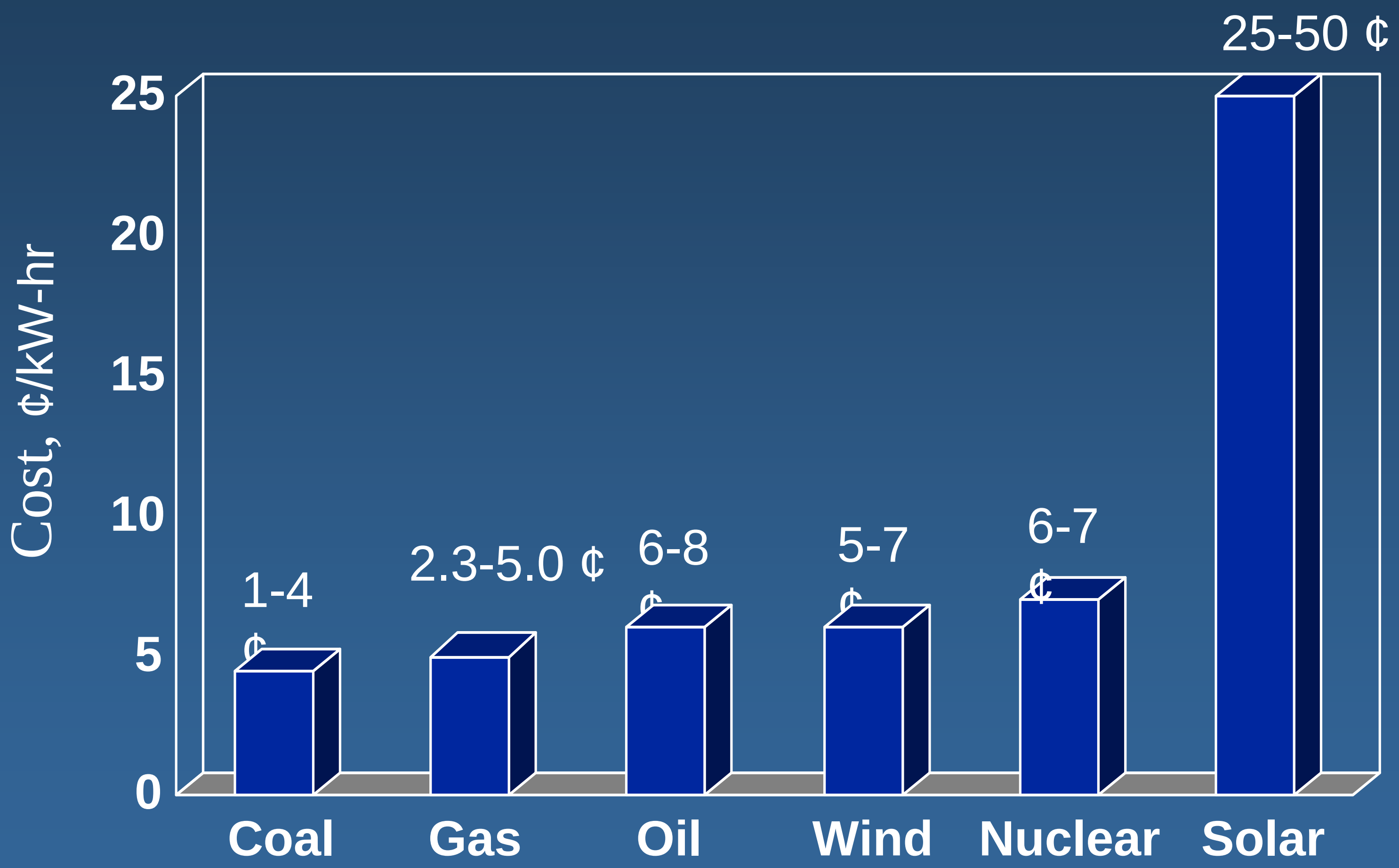
Global Energy Consumption, 2001



Total: 13.2 TW U.S.: 3.2 TW (96 Quads)

Today: Production Cost of Electricity

(in the U.S. in 2002)

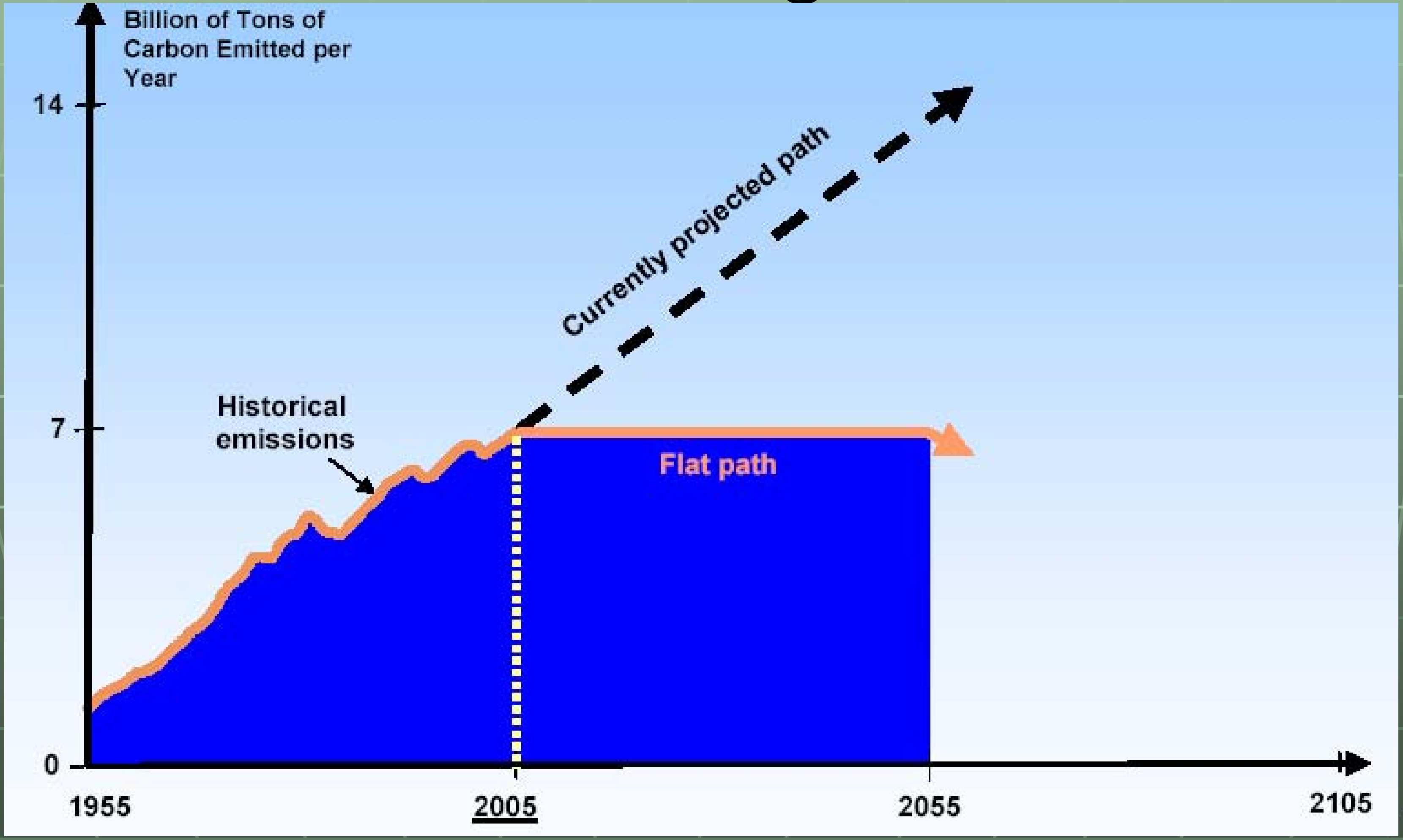


What we can do now: The Wedge Concept

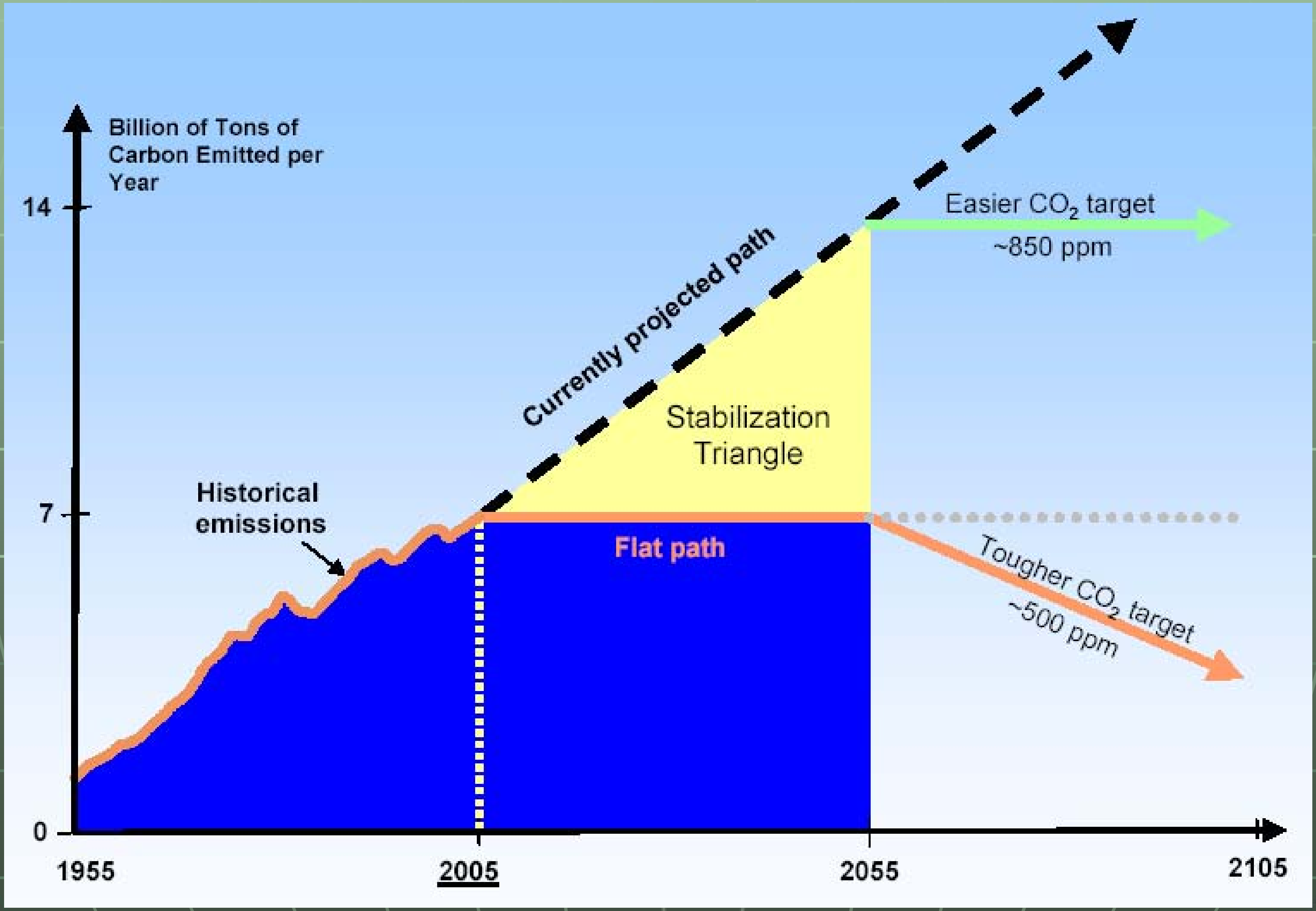
From Socolow & Pacala, Science (2004), 305 (5686), 968-972;

Data from Climate Mitigation Institute @ Princeton University

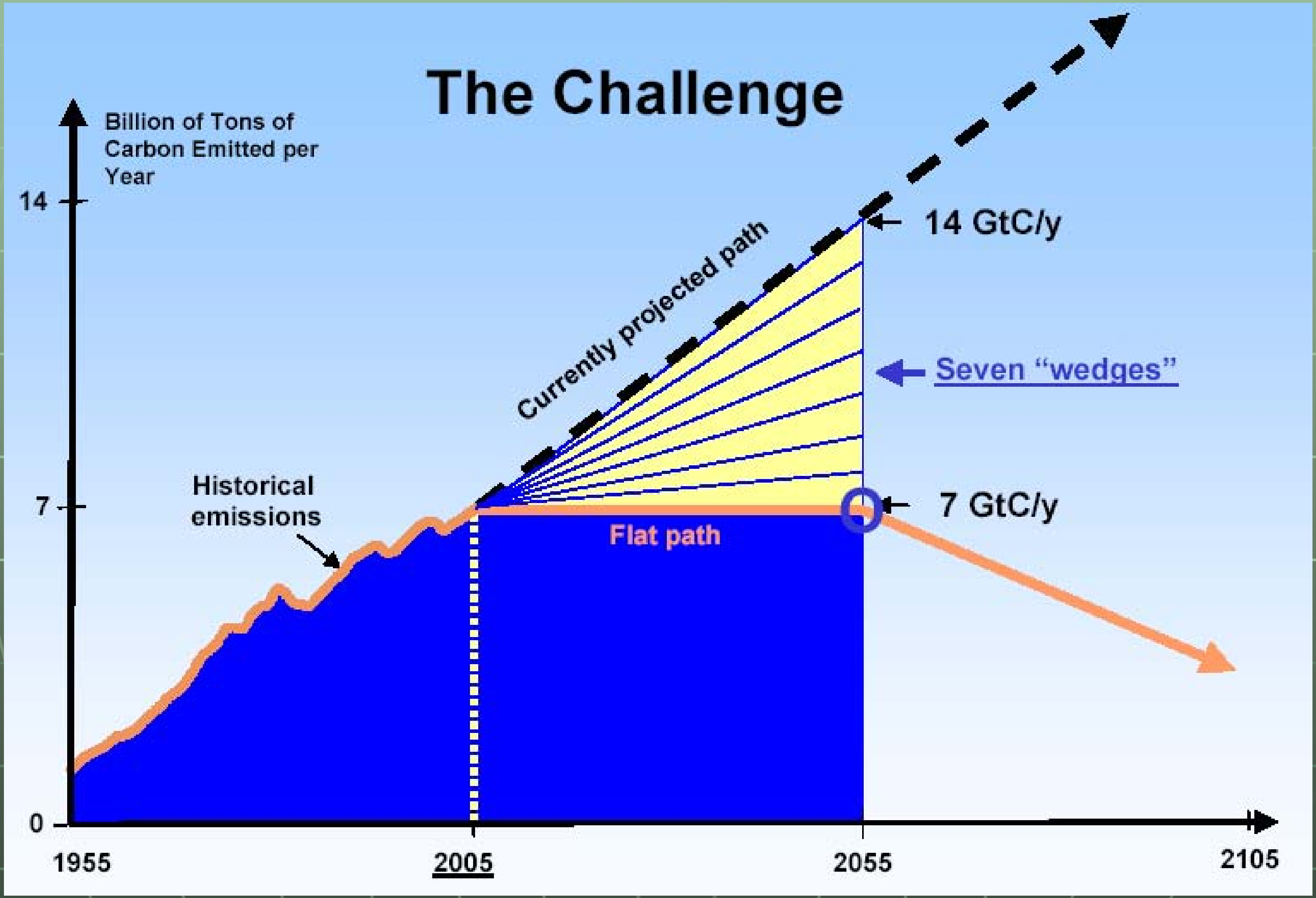
Green Engineering & Climate Change



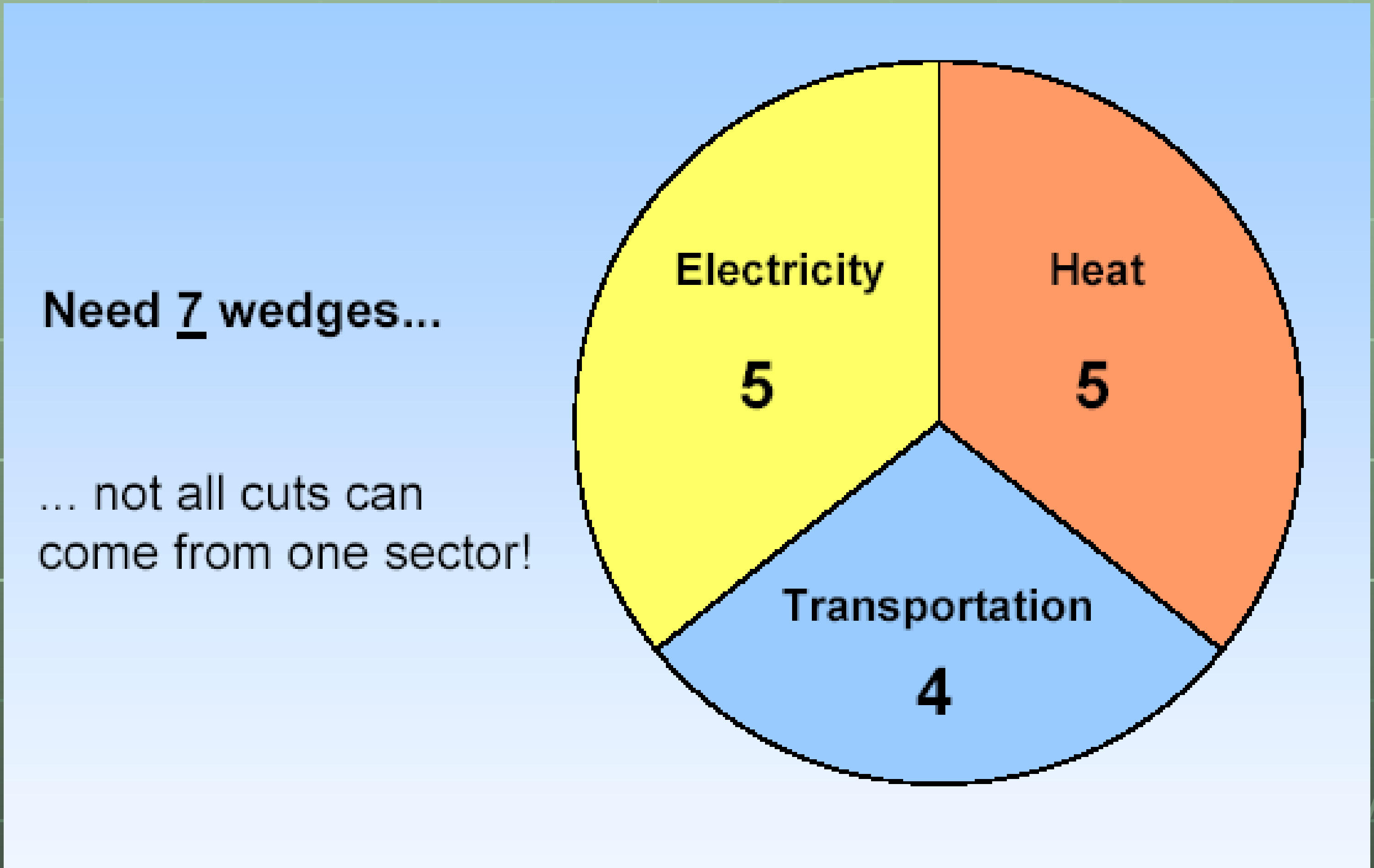
Where are we headed?



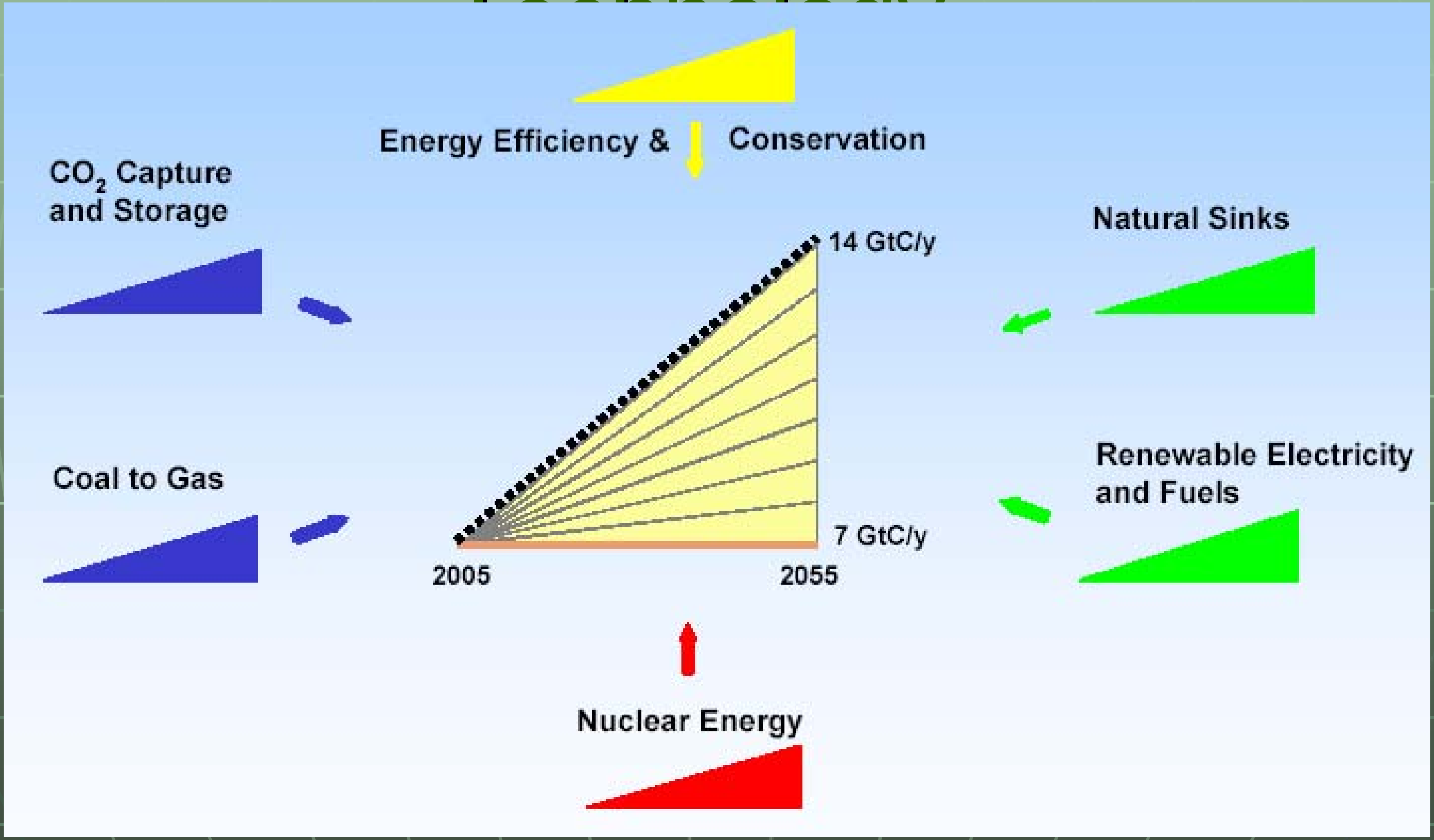
The wedge concept



Carbon Emissions by Sector



A Challenge: Cut Greenhouse Emissions using Current Technology



Efficiency

Double the fuel efficiency of the world's cars <u>or</u> halve miles traveled

There are about 600 million cars today, with 2 billion projected for 2055

Produce today's electric capacity with double today's efficiency

Average coal plant efficiency is 32% today

Use best efficiency practices in all residential and commercial buildings

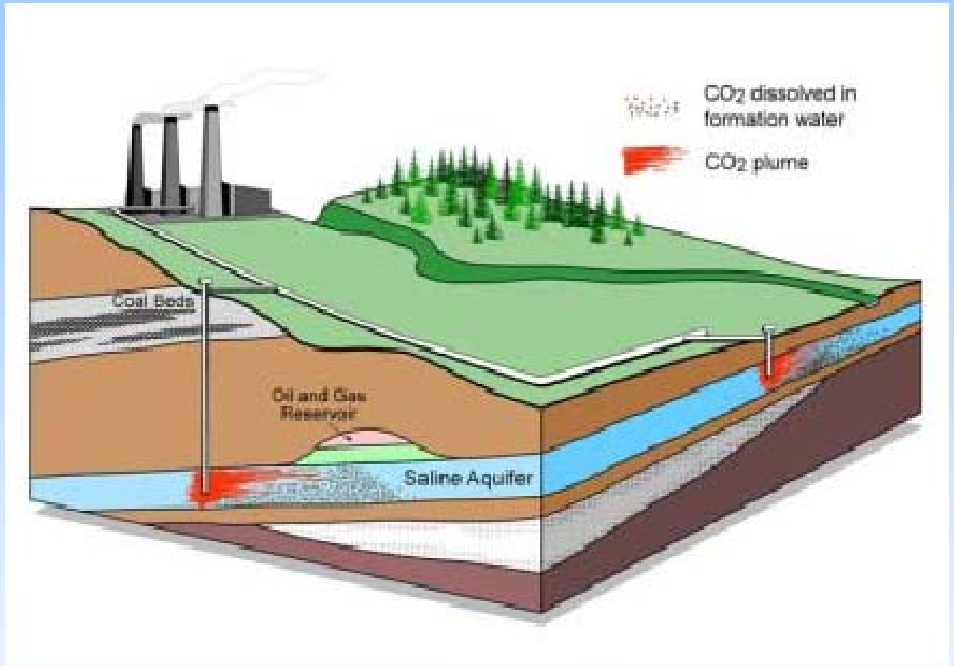
Replacing all the world's incandescent bulbs with CFL's would provide 1/4 of one wedge

E, T, H / $* / !*

Carbon Capture & Storage

Implement CCS at

- 800 GW coal electric plants or
- 1600 GW natural gas electric plants or
- 180 coal synfuels plants or
- 10 times today's capacity of hydrogen plants



Graphic courtesy of Alberta Geological Survey

E, T, H / $$ / !-!!

A wedge will require injecting an volume of CO_2 equal to the amount of oil extracted every year

CMI

Nuclear Electricity & Hydrogen

Triple the world's nuclear electricity capacity by 2055

OR

Build 600 high-temperature plants to produce hydrogen (none now)

Graphic courtesy of NRC

The rate of installation required for a wedge from electricity is equal to the global rate of nuclear expansion from 1975-1990.

E, T, H / $$-$$$ / !!!

Phasing out of nuclear electric power would create the need for another half wedge of emissions cuts

CMI

Wind Electricity

Photo courtesy of DOE

Install 2 million windmills to replace coal-based electricity,

OR

Use 4 million windmills to produce hydrogen fuel

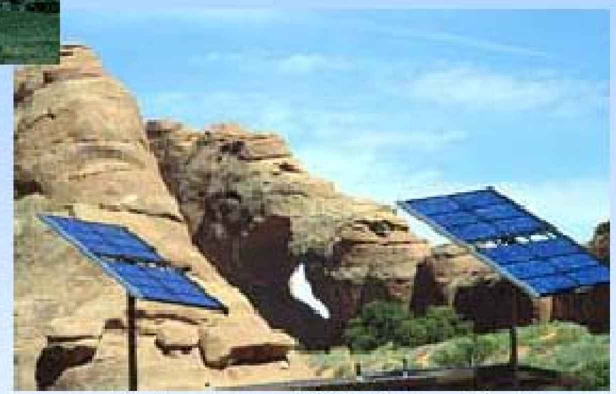
A wedge worth of wind electricity will require increasing current capacity by a factor of 50

E, T, H / $-$$ / !

An electricity wedge would require land area equal to about 3% of U.S. land area

CMI

Solar Electricity



Photos courtesy of DOE Photovoltaics Program

Install 20,000 square kilometers for dedicated use by 2054

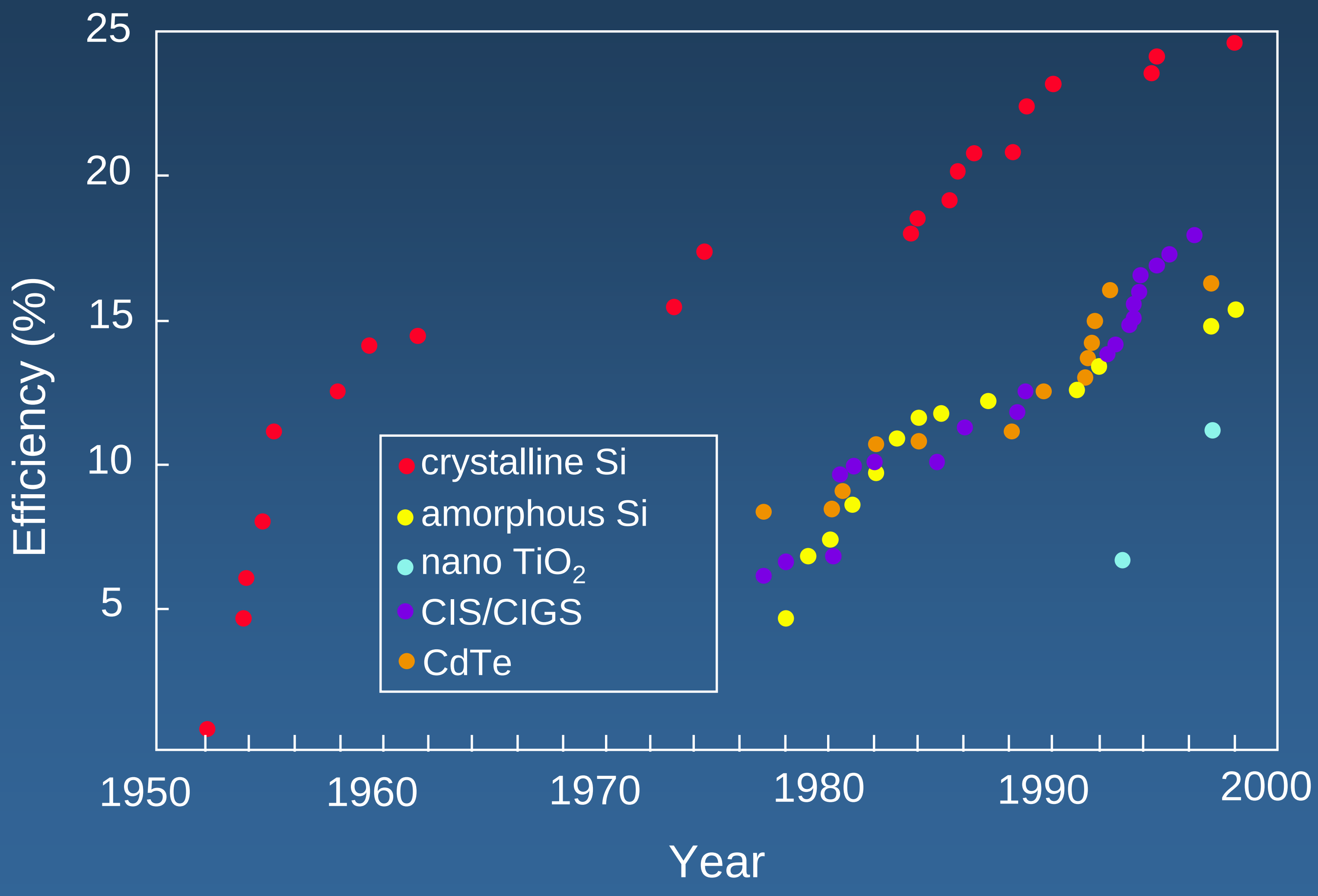
A wedge of solar electricity would mean increasing current capacity 700 times

A wedge would require an array of photovoltaic panels with an area approximately the size of New Jersey

E / $$$/ !

CMI

Efficiency of Photovoltaic Devices



Where can the materials community and industry make a difference?

- Innovation
- Manufacturing and production processes
- Product design
- Alternative materials
- Recycleable (see W Lee et al in Roadmap from ICC-1 (ACerS)) (Plastic bottles)
- Lifetime analysis (think how to reuse every component in an automobile, computers, after useful life)

Materials technology is key to sustainable production

- Sustainable growth
- Reduce emissions (catalysis, membranes, porous materials
- Advanced surface treatments (less material, more function, wear reduction)
- Smaller, more efficient products
- Quality of life (biomaterials, drug release substrates)

Materials design

- Less mass for improved energy efficiency (lightweighting – Al, foams, porous materials)
- Less energy using
- Mediate the influence of pollution
  - TiO_2 coated glass
  - Catalyze the detoxification of gaseous discharges - NOx, VOCs
- We must innovate – e.g. how do we replace reliance on precious metals like Pt?

Make ceramic processes more sustainable

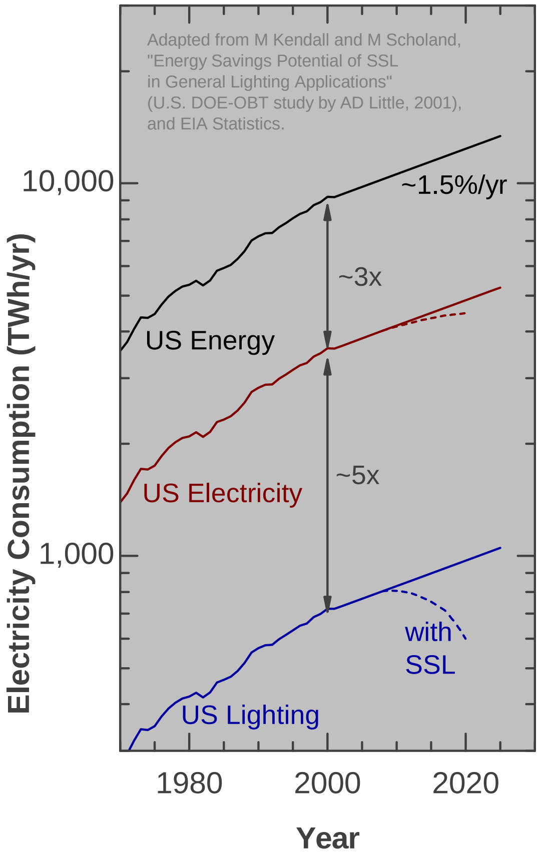
- Replace high temperature solid state synthesis processes with room temperature chemistries for synthesis of powders.
- Learn how to lower calcination processes
- Learn how to process with water-based instead of using organic solvents
- Develop processes for total recycle of non-aqueous media
- Invent organic free forming techniques that do not require organic binders
- Learn to sinter at <1000C
- Develop high efficiency sintering furnaces – why do we heat the entire furnace when only the part needs to be heated? Is microwave sintering really more energy efficient?

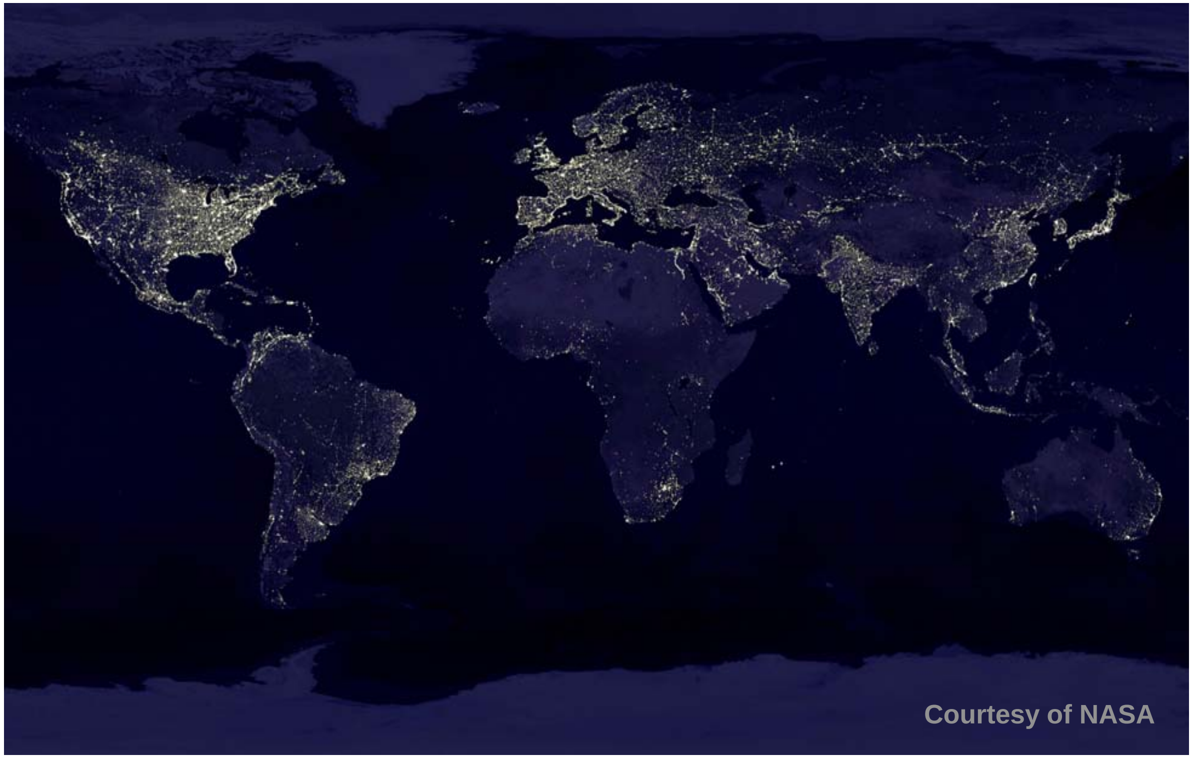
Materials in energy

- Better energy storage - e.g better battery materials ($LiFePO_4$?) to replace Li battery, peak load leveling (Beta alumina for Na-S battery (NGK)
- Thermoelectrics for heat recovery
- Fuel Cells
- Photovoltaics!
- Lighting

Batteries need to get smaller and more efficient

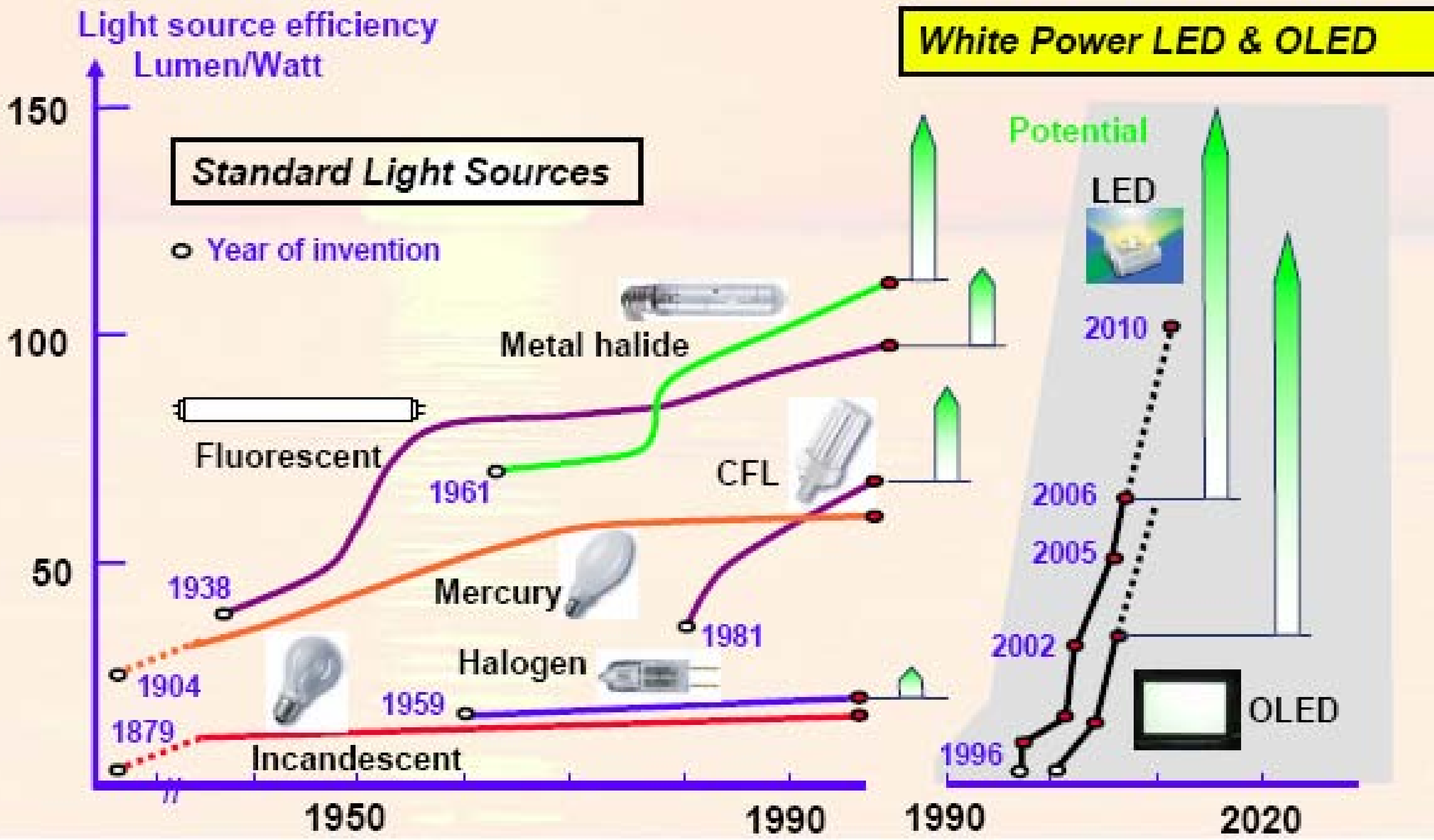
Lighting and Energy Consumption





Sandia National Laboratories

Solid-State Lighting = Semiconductor Light from Crystals and Organic Materials



Inorganic LEDs Boosting Efficiency and High Flux

There are less then 10 years between the first white LEDs in 1996 and todays LED powermodules

Progress of *White LEDs* since 1996 is impressive

	1996		today	*Improvement factor*
Internal Q.E.	10 %	→	60 %	6
Light extraction E.	25 %	→	75 %	3
Flux per device	0,5 lm	→	400 lm	400
Costs per Lumen	~ 3 €	→	~ 0,1 €	30

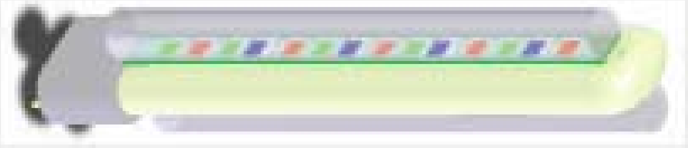
LEDs the enabler for LED based

Projection

LCD Backlight

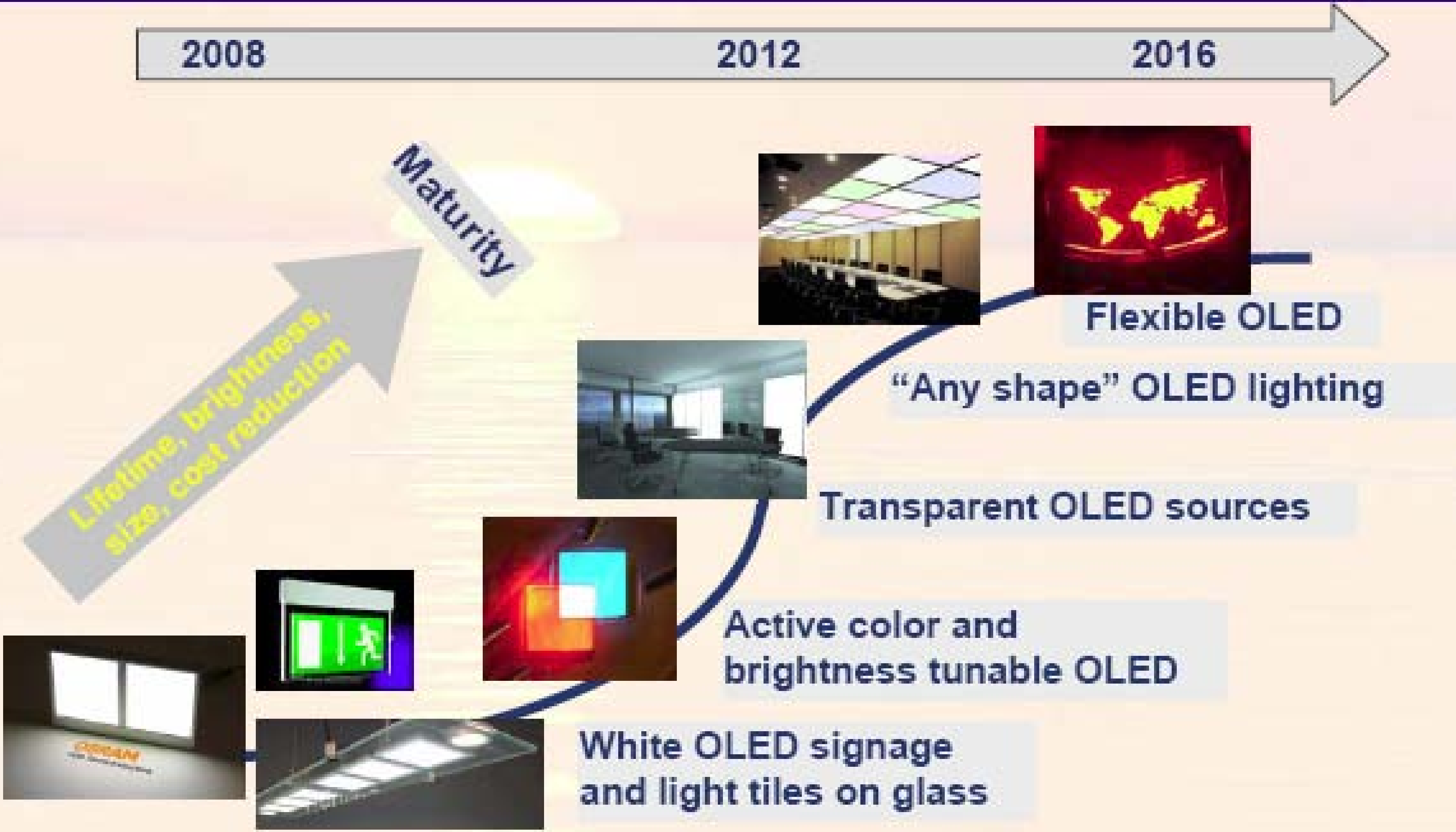
Headlamp

Hybrid Lamps the best of both flux and color tunability



CFL combined with LED

Organic LEDs the Next Wave in SSL



All I’m saying is now is the time to develop the technology to deflect an asteroid

“All I’m saying is now is the time to develop the technology to deflect an asteroid.”

The challenges and potential outcomes imposed by global warming on a sustainable world requires urgent coordination by the world powers of an international research program and set of energy policies like we have never seen before