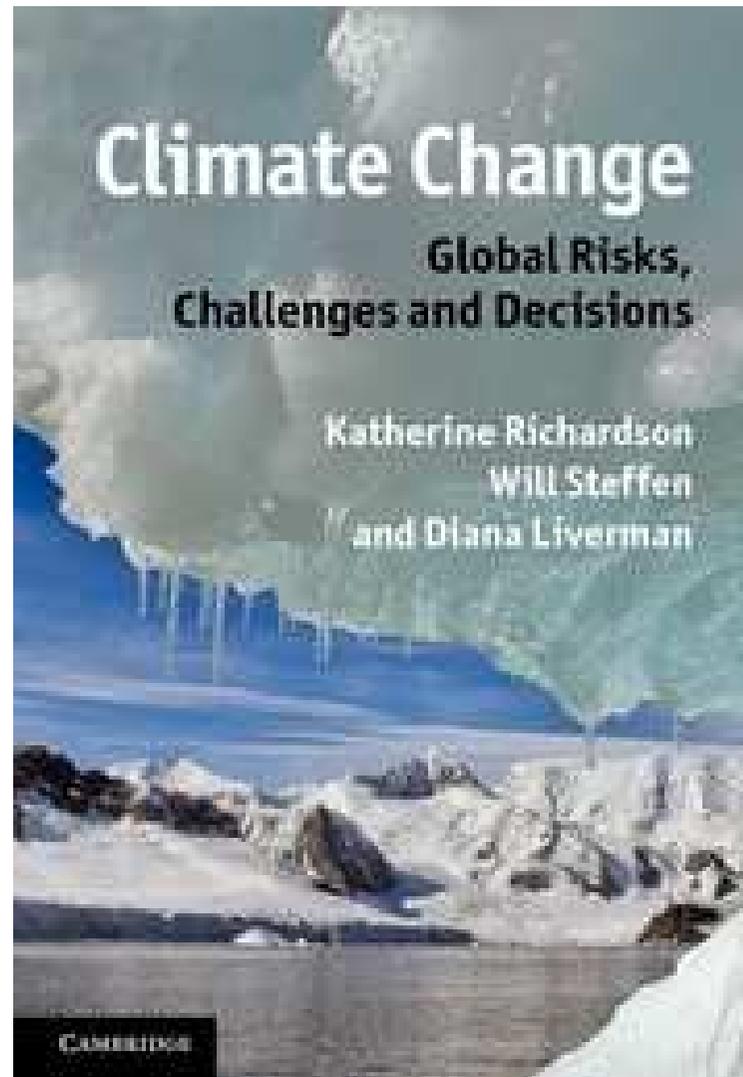


**Green Growth – key to economic success in the age of global resource shortage:**

**The new Danish energy strategy**

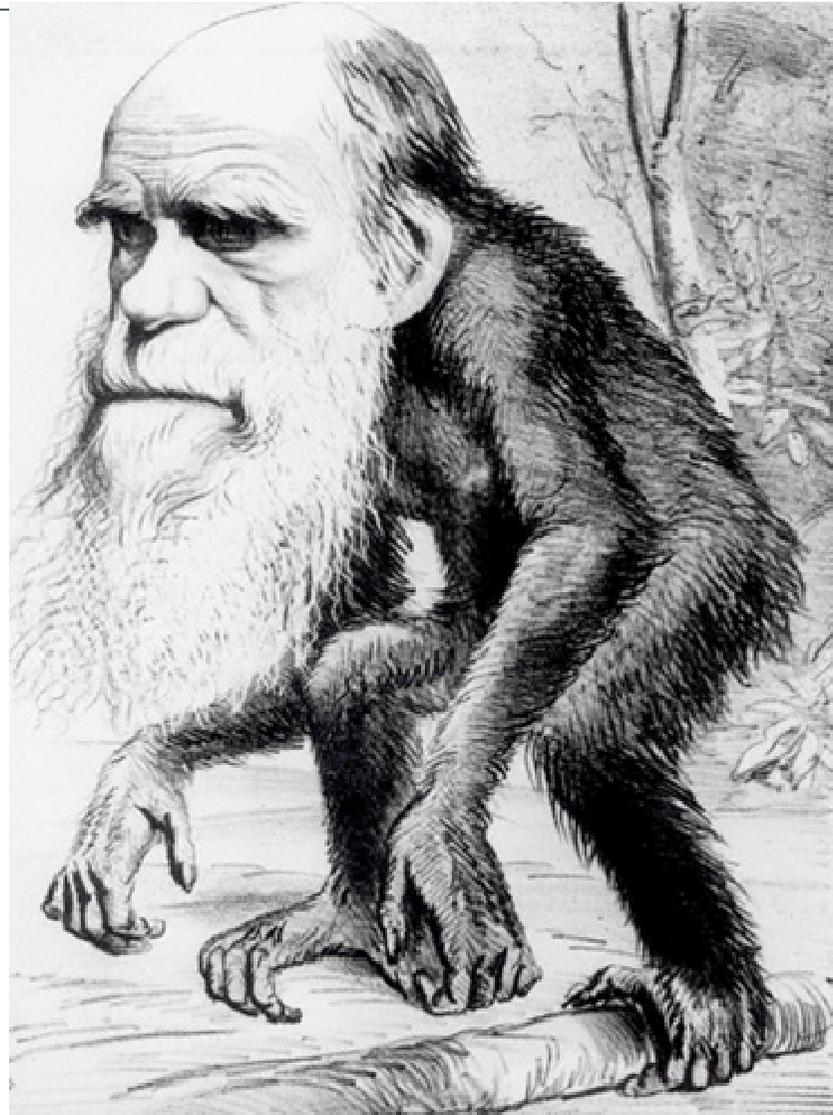
**Katherine Richardson,**



Cambridge University  
Press, Feb. 2011



## Faculty of Science

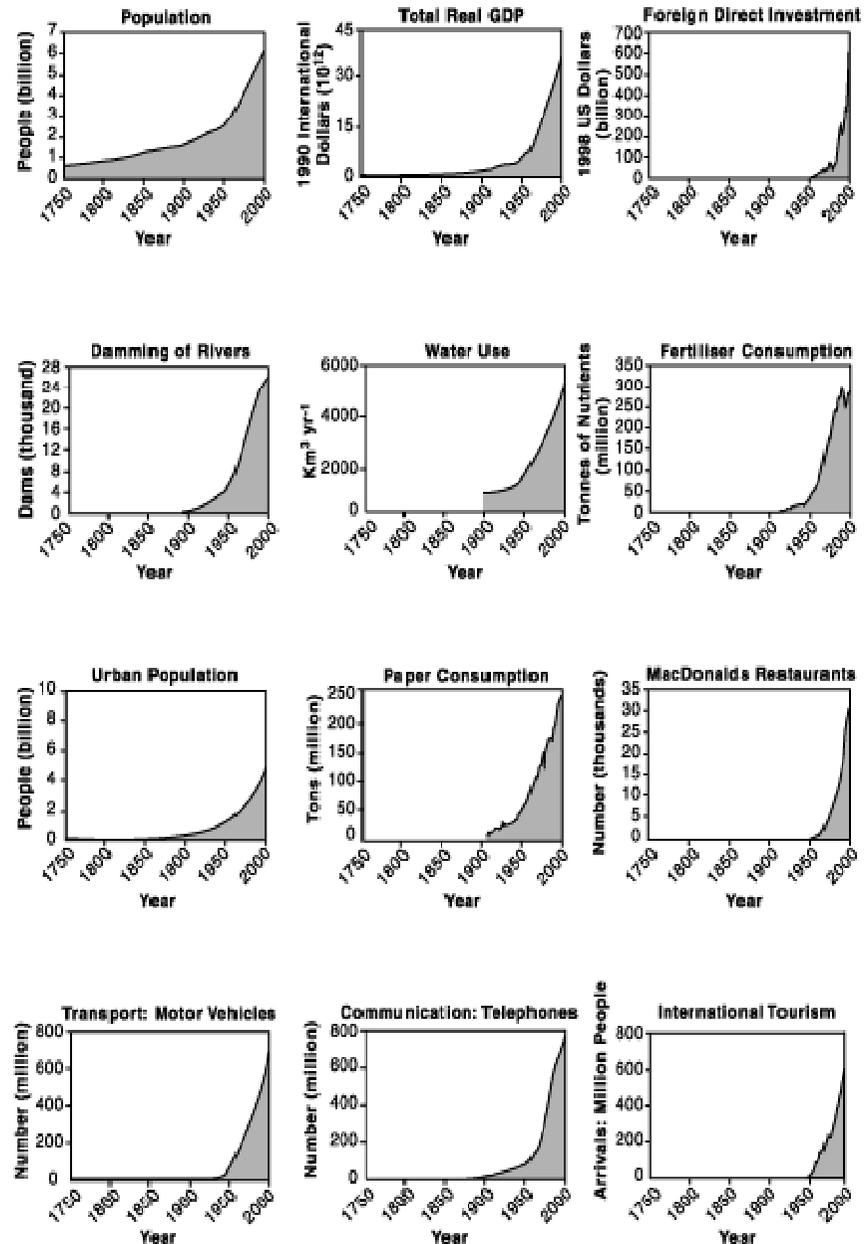


Sted og dato  
Dias 3



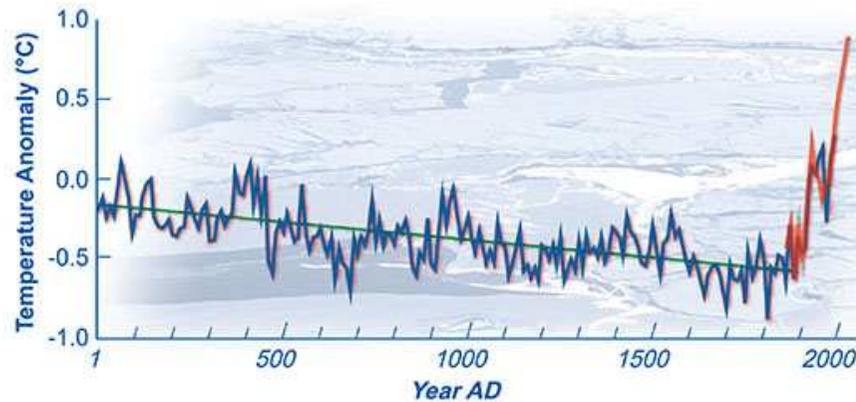
Human activities have dramatically increased over the last approx. 60 years

Sted og dato  
Dias 4

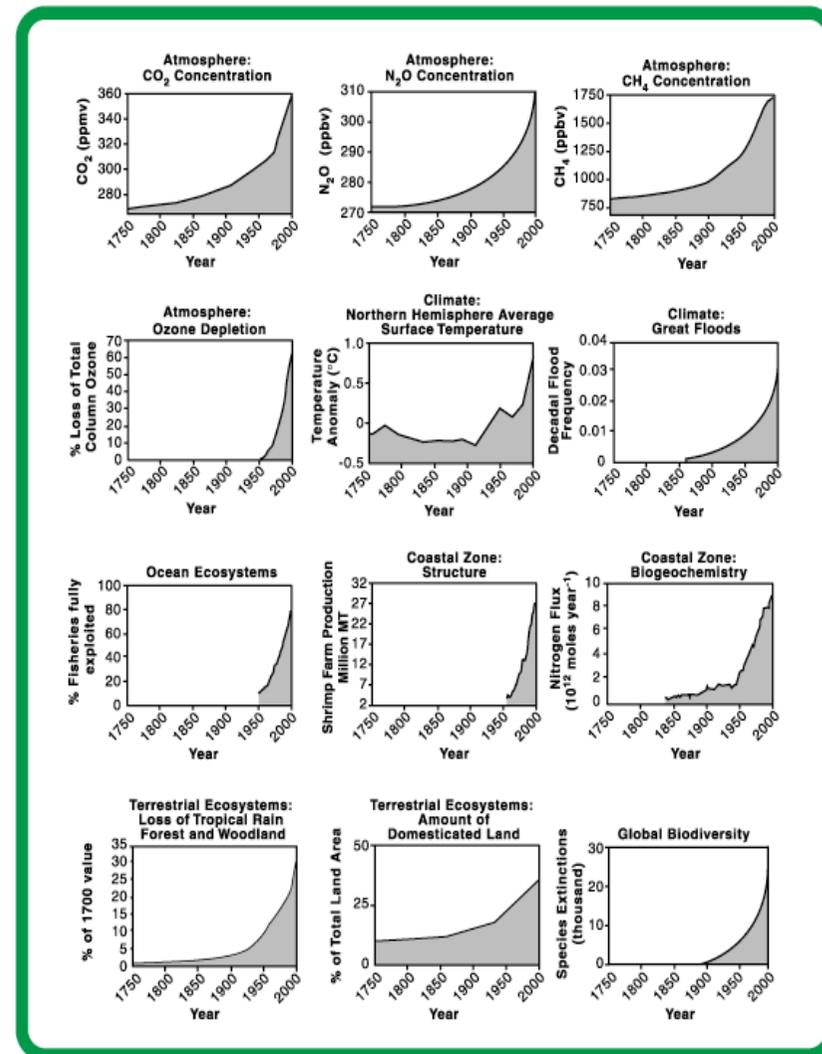


From: Steffen et al. 2004

# Concurrent changes in the Earth System:



Kaufman, Darrell S., et al. 2009. Recent Warming Reverses Long-Term Arctic Cooling. *Science*, September 4, 2009



Steffen, W., et al. 2004

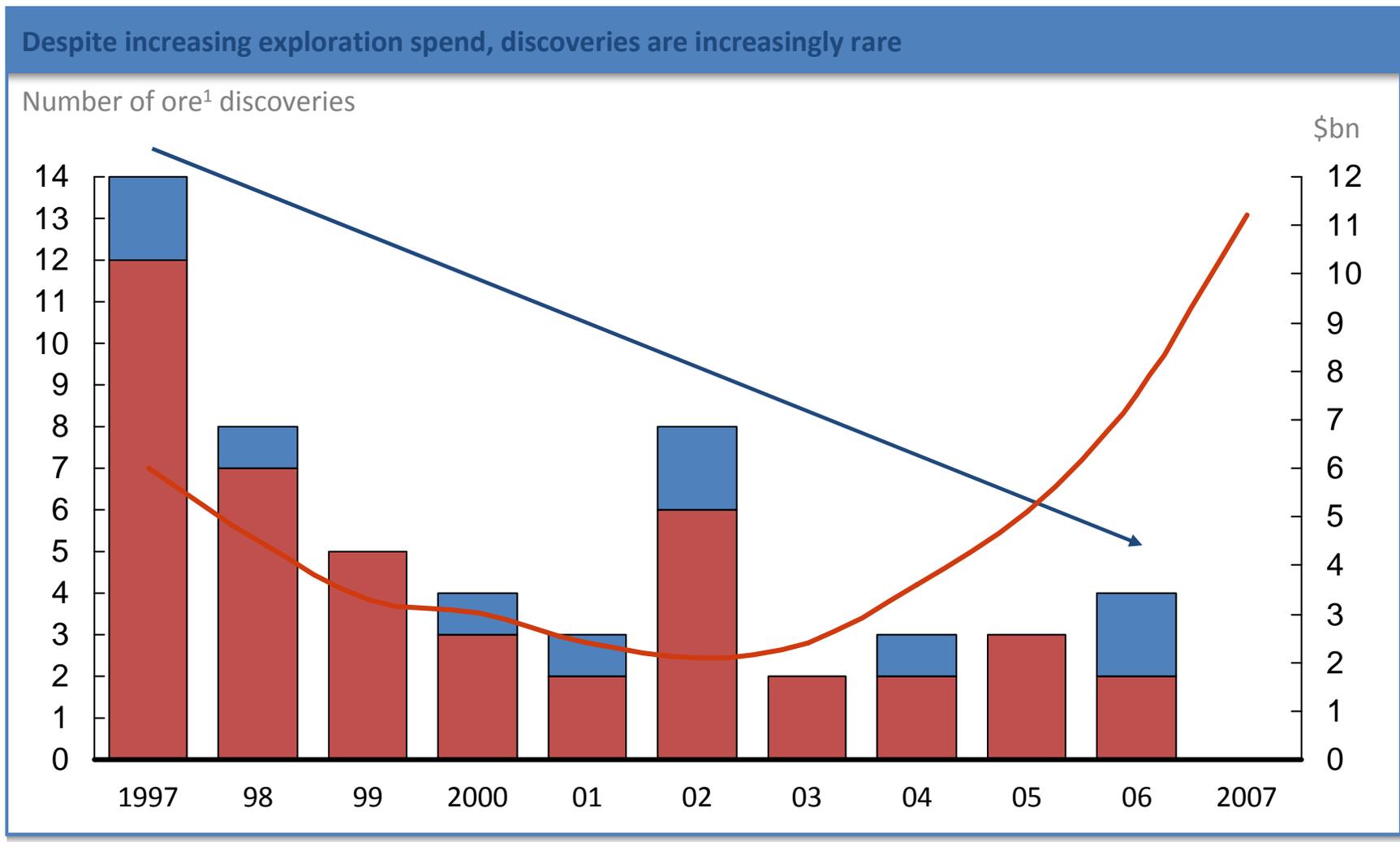


The challenge of the 21st Century is to develop mechanisms to share the Earth's resources among the (soon to be) 9 billion human inhabitants ...

And the successful business model one of resource efficiency....

# Reserve replenishment is increasingly difficult and more expensive

- Number of world-class discoveries
- Number of major discoveries
- Exploration expenditure \$b real



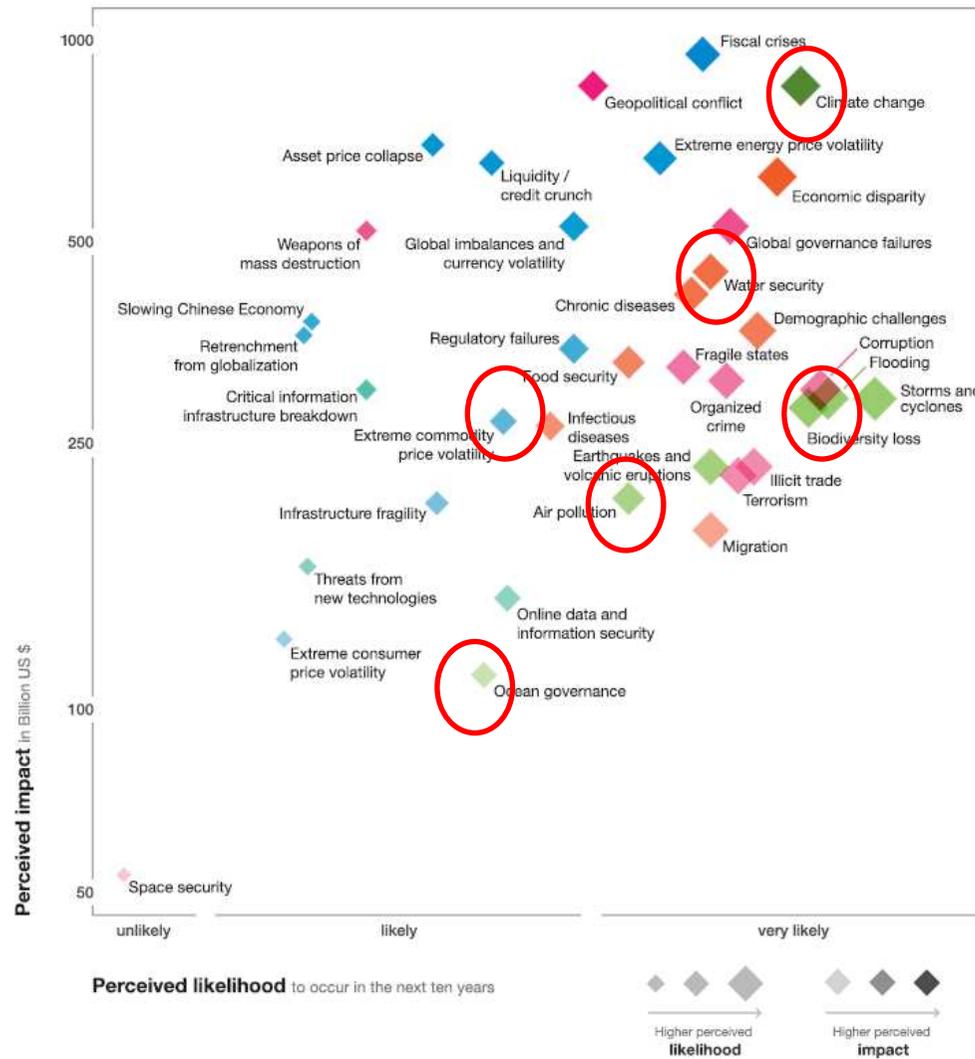
1 All metal and mining materials



Faculty of Science



Figure 1 | Global Risks Landscape 2011:  
Perception data from the World Economic Forum's Global Risks Survey



From World Economic Forum January 2011



## Planetary Boundaries: Exploring the safe operating space for humanity in the Anthropocene (*Nature*, 461 : 472 – 475, Sept 24 - 2009)

### FEATURE

## A safe operating space for humanity

Identifying and quantifying planetary boundaries that must not be transgressed could help prevent human activities from causing unacceptable environmental change, argue **Johan Rockström** and colleagues.

Although Earth has undergone many periods of significant environmental change, the planet's environment has been unusually stable for the past 10,000 years<sup>1-3</sup>. This period of stability — known to geologists as the Holocene — has seen human civilizations arise, develop and thrive. Such stability may now be under threat. Since the Industrial Revolution, a new era has arisen, the Anthropocene<sup>4</sup>, in which human actions have become the main driver of global environmental change<sup>5</sup>. This could see human activities push the Earth system outside the stable environmental state of the Holocene, with consequences that are detrimental or even catastrophic for large parts of the world.

During the Holocene, environmental change occurred naturally and Earth's regulatory capacity maintained the conditions that enabled human development. Regular temperatures, freshwater availability and biogeochemical flows all stayed within a relatively narrow range. Now, largely because of a rapidly growing reliance on fossil fuels and



#### SUMMARY

- New approach proposed for defining preconditions for human development
- Crossing certain biophysical thresholds could have disastrous consequences for humanity
- Three of nine interlinked planetary boundaries have already been overstepped

industrialized forms of agriculture, human activities have reached a level that could damage the systems that keep Earth in the desirable Holocene state. The result could be irreversible and, in some cases, abrupt environmental change, leading to a state less conducive to human development<sup>6</sup>. Without pressure from humans, the Holocene is expected to continue for at least several thousands of years<sup>7</sup>.

#### Planetary boundaries

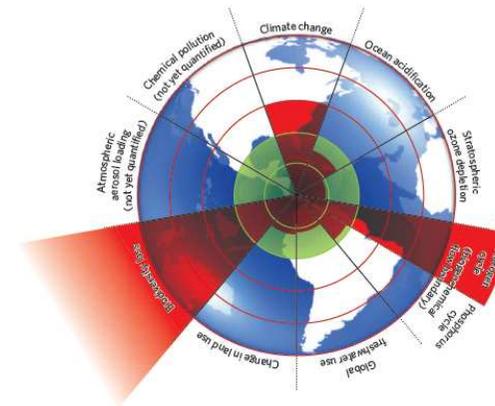
To meet the challenge of maintaining the Holocene state, we propose a framework based on 'planetary boundaries'. These

boundaries define the safe operating space for humanity with respect to the Earth system and are associated with the planet's biophysical subsystems or processes. Although Earth's complex systems sometimes respond smoothly to changing pressures, it seems that this will prove to be the exception rather than the rule. Many subsystems of Earth react in a nonlinear, often abrupt, way, and are particularly sensitive around threshold levels of certain key variables. If these thresholds are crossed, then important subsystems, such as a monsoon system, could shift into a new state, often with deleterious or potentially even disastrous consequences for humans<sup>8,9</sup>.

Most of these thresholds can be defined by a critical value for one or more control variables, such as carbon dioxide concentration. Not all processes or subsystems on Earth have well-defined thresholds, although human actions that undermine the resilience of such processes or subsystems — for example, land and water degradation — can increase the risk that thresholds will also be crossed in other processes, such as the climate system.

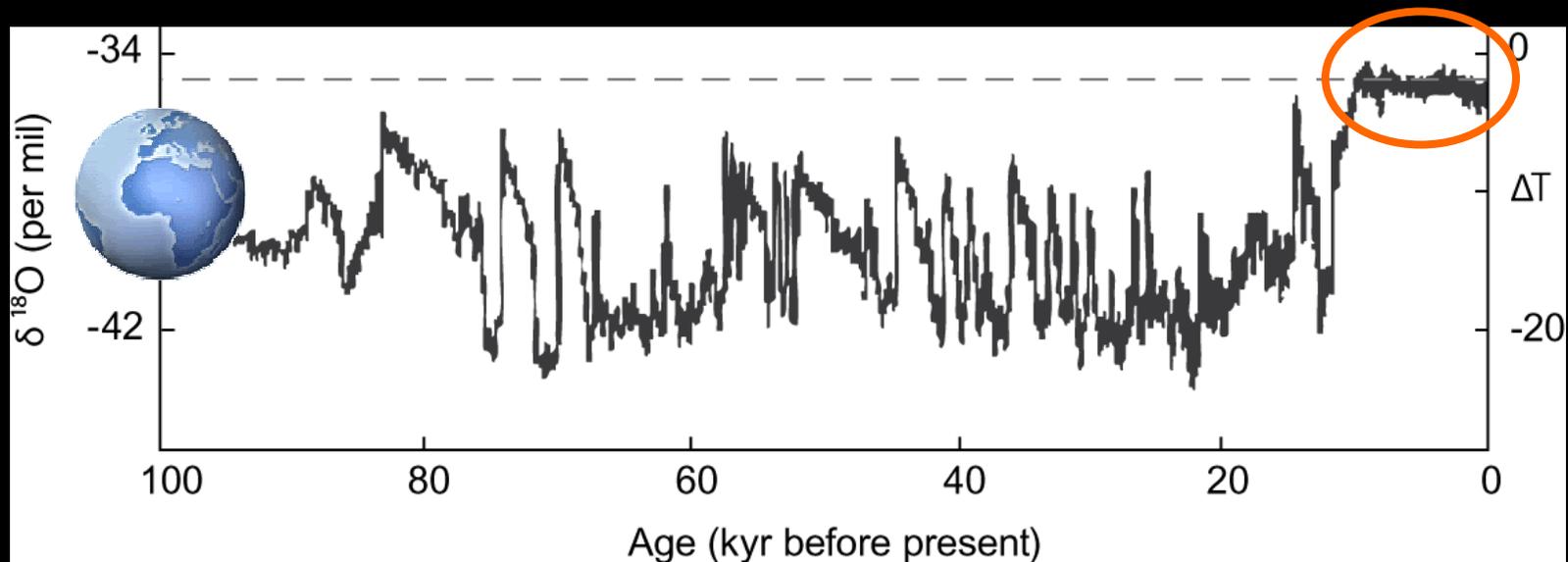
We have tried to identify the Earth-system processes and associated thresholds which, if crossed, could generate unacceptable environmental change. We have found nine such processes for which we believe it is necessary to define planetary boundaries: climate change; rate of biodiversity loss (terrestrial and marine); interference with the nitrogen and phosphorus cycles; stratospheric ozone depletion; ocean acidification; global freshwater use; change in land use; chemical pollution; and atmospheric aerosol loading (see Fig. 1 and Table).

In general, planetary boundaries are values for control variables that are either at a 'safe' distance from thresholds — for processes with evidence of threshold behaviour — or at dangerous levels — for processes without



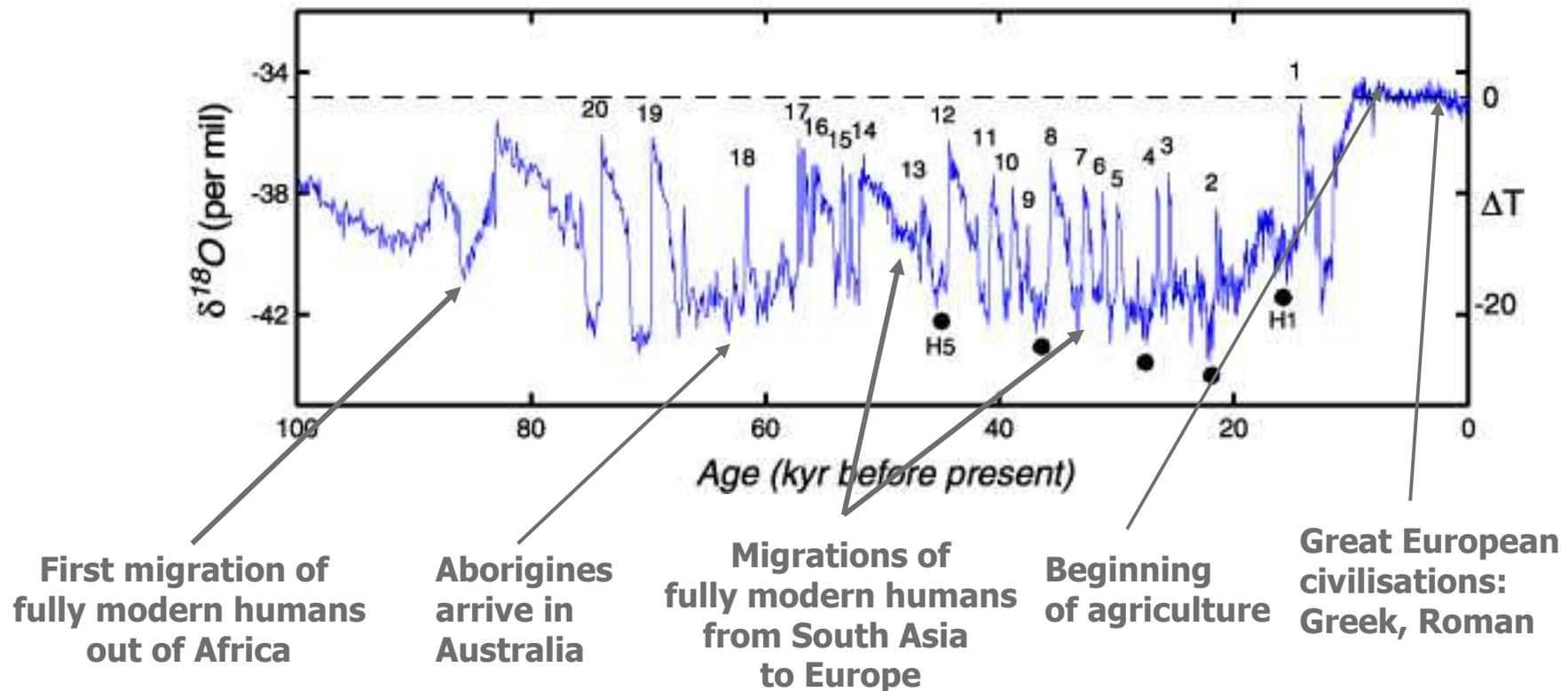
**Figure 1 | Beyond the boundary.** The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.

# Humanity's 12,000 years of grace





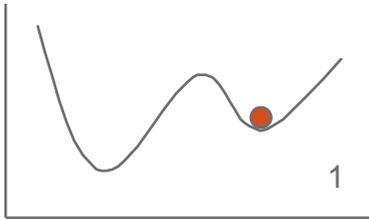
## Human development and climate change



Source: GRIP ice core data (Greenland)  
And S. Oppenheimer, "Out of Eden", 2004

# Valuable Ecosystem Services (Desirable)

# Loss of ecosystem services (Undesirable)



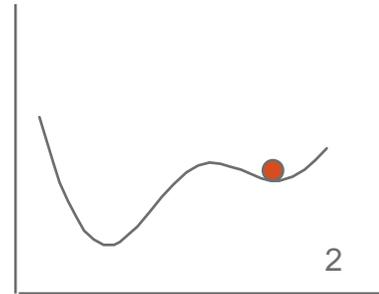
coral dominance



clear water



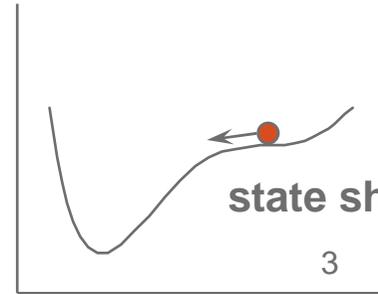
grassland



- overfishing, coastal eutrophication

- phosphorous accumulation in soil and mud

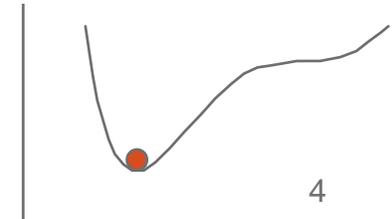
- fire prevention



- disease, hurricane

- flooding, warming, overexploitation of predators

- good rains, continuous heavy grazing



algal dominance



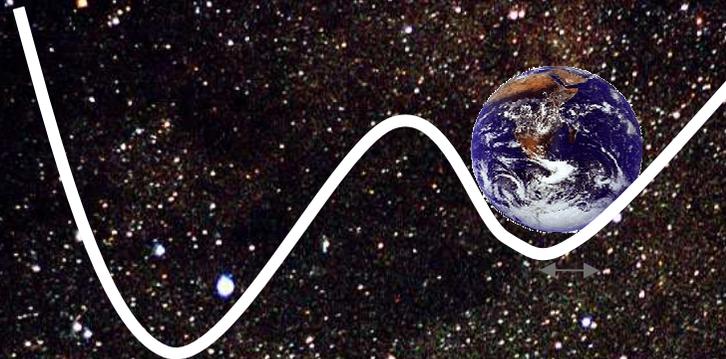
turbid water

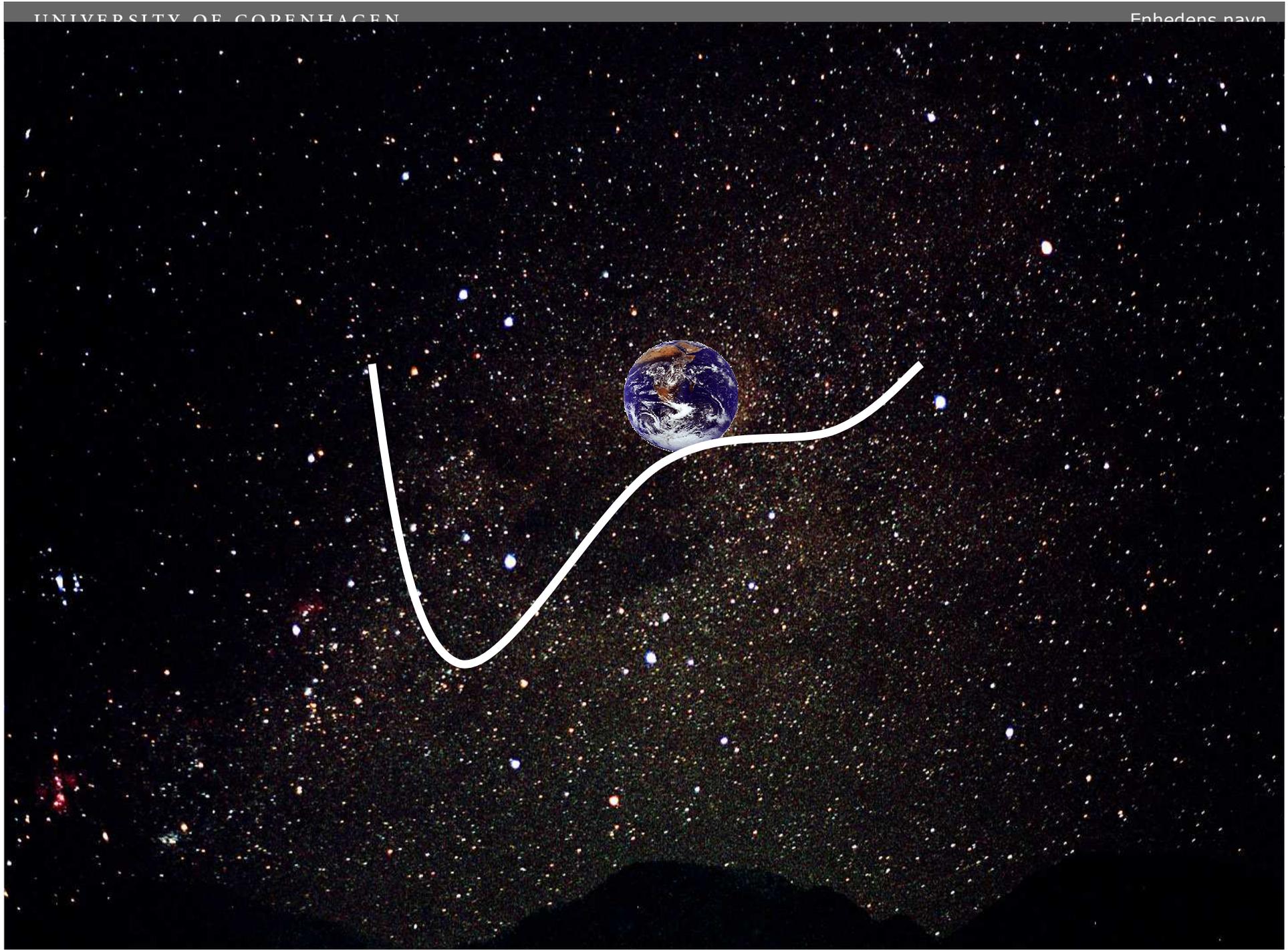


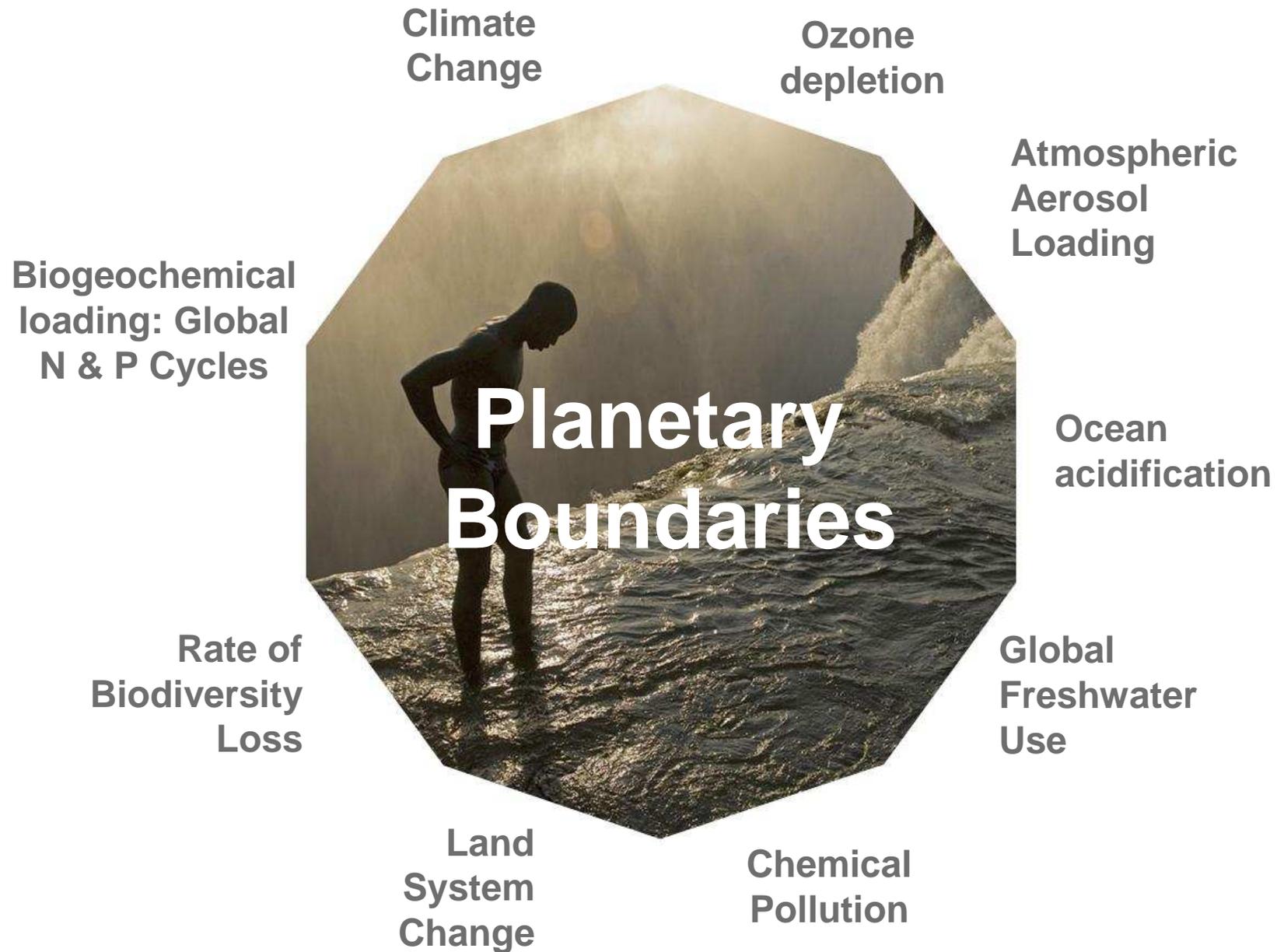
shrub-bushland



# The Resilience of the Earth System







**Climate Change**

$< 350 \text{ ppm CO}_2 < 1 \text{ W m}^2$   
( $350 - 500 \text{ ppm CO}_2$  ;  
 $1-1.5 \text{ W m}^2$ )

**Ozone depletion**

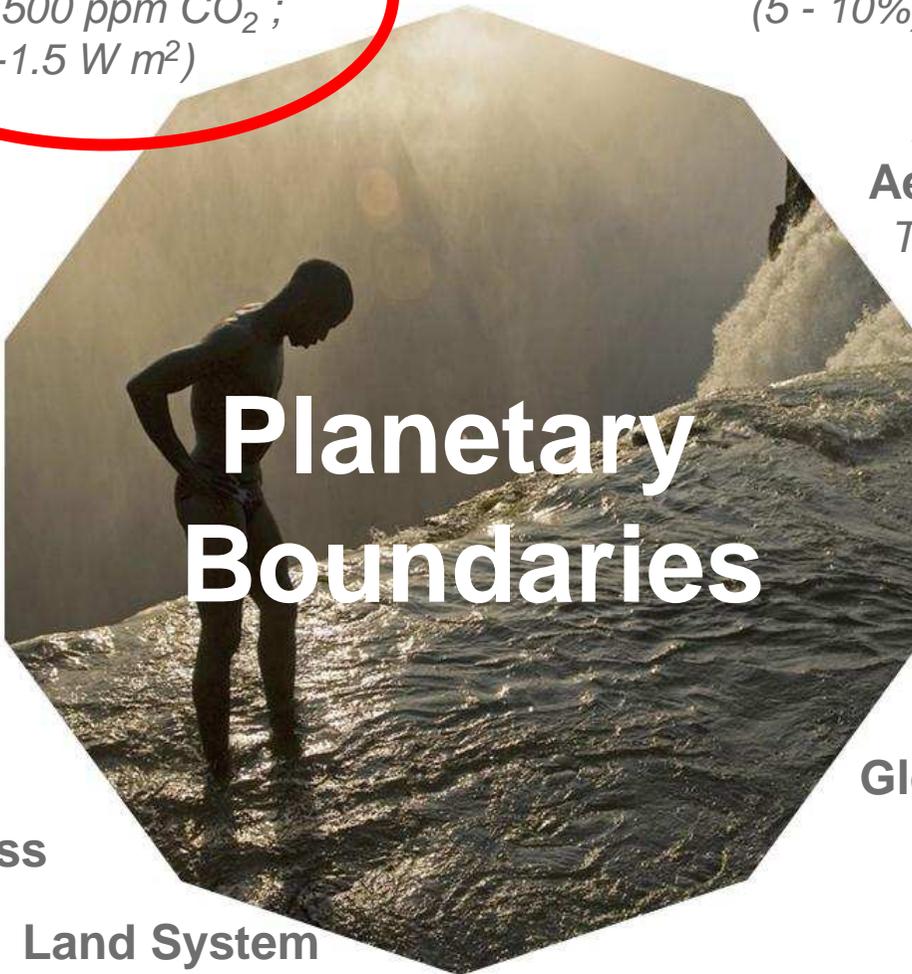
$< 5 \% \text{ of Pre-Industrial } 290 \text{ DU}$   
( $5 - 10\%$ )

**Biogeochemical loading: Global N & P Cycles**

*Limit industrial fixation of  $\text{N}_2$  to  $35 \text{ Tg N yr}^{-1}$  (25 % of natural fixation) (25%-35%)*  
 *$P < 10 \times$  natural weathering inflow to Oceans (10x – 100x)*

**Atmospheric Aerosol Loading**  
*To be determined*

**Ocean acidification**  
*Aragonite saturation ratio  $> 80 \%$  above pre-industrial levels ( $> 80\% - > 70\%$ )*



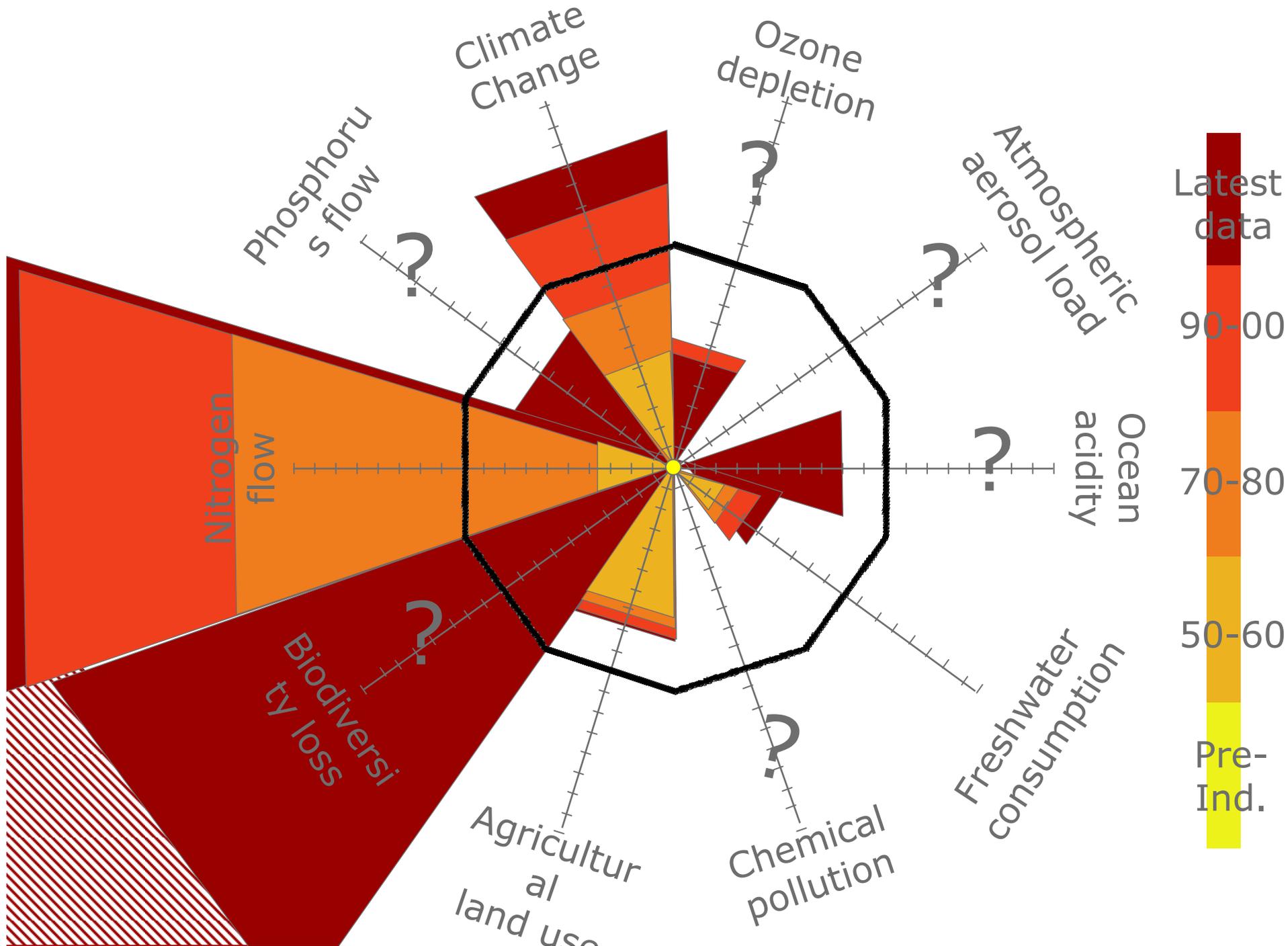
**Planetary Boundaries**

**Global Freshwater Use**  
 *$< 4000 \text{ km}^3/\text{yr}$   
( $4000 - 6000 \text{ km}^3/\text{yr}$ )*

**Rate of Biodiversity Loss**  
 *$< 10 \text{ E/MSY}$   
( $< 10 - < 1000 \text{ E/MSY}$ )*

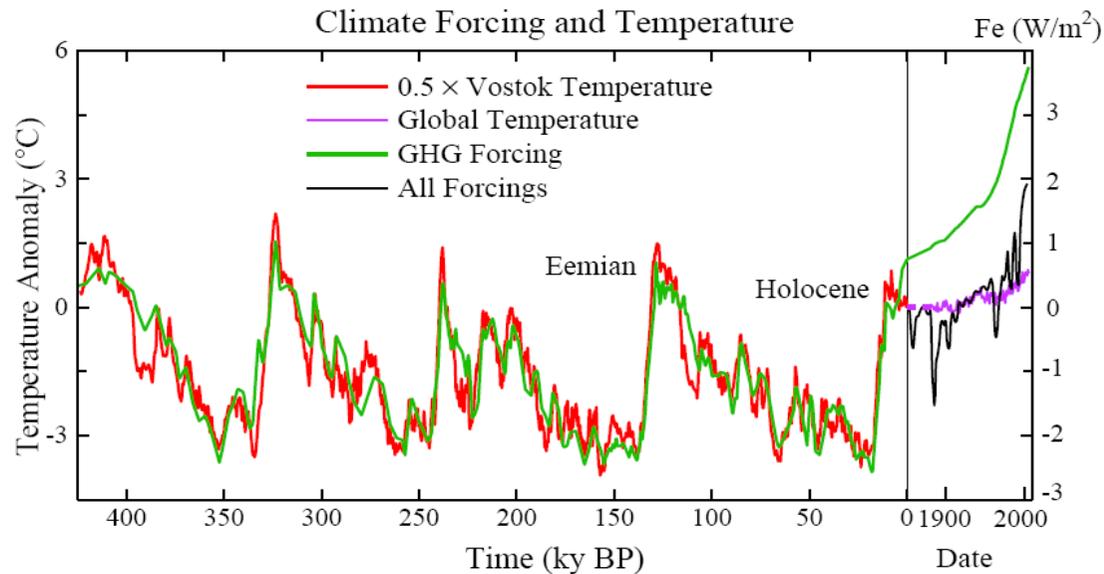
**Land System Change**  
 *$\leq 15 \% \text{ of land under crops}$   
(15-20%)*

**Chemical Pollution**  
*Plastics, Endocrine Disruptors, Nuclear Waste Emitted globally*  
*To be determined*



# Climate Change

what is required to avoid the crossing of critical thresholds that separate qualitatively different climate system states

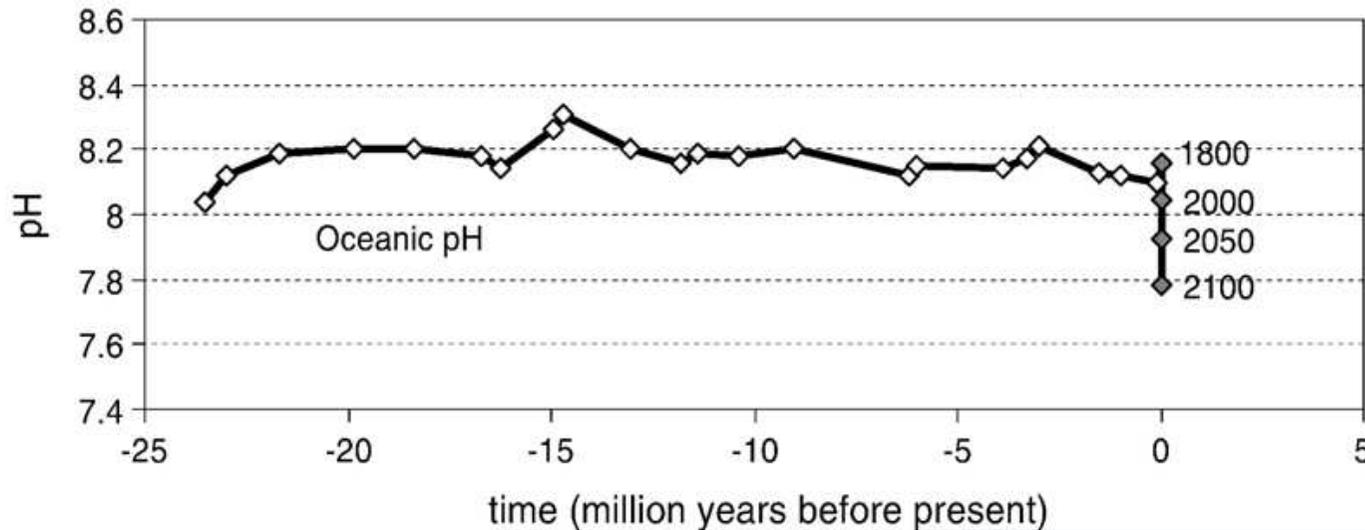


We suggest boundary values of 350 ppm CO<sub>2</sub> and 1 W m<sup>-2</sup> above pre-industrial level



## Ocean acidification

Challenge to marine biodiversity and ability of oceans to function as sink of CO<sub>2</sub>



Turley et al 2006

Southern Ocean and Arctic ocean projected to become corrosive to aragonite by 2030-2060





# Climate change is also a "resource" problem

## COP process.....



**KLIMAKOMMISSIONEN**  
DANISH COMMISSION ON CLIMATE CHANGE POLICY

# Green energy

– the road to a Danish  
energy system without  
fossil fuels

**Katherine Richardson,  
Chairman**



## The Commission's terms of reference

” The Danish Commission on Climate Change Policy is to examine how Denmark can reduce and ultimately eliminate dependency on fossil fuels in the long term. The Climate Commission shall describe how to implement this long-term vision.”

The Climate Commission's deliberations should take the following criteria into consideration:

1. Reducing the emission of greenhouse gases
2. Increasing energy efficiency
3. Maintaining the high security of energy supply
4. Ensuring macroeconomic cost-effectiveness by using market-based solutions
5. Continuing a high level of economic growth
6. Ensuring positive business development and promoting international competitiveness of business in Denmark
7. Ensuring environmentally sustainable development.



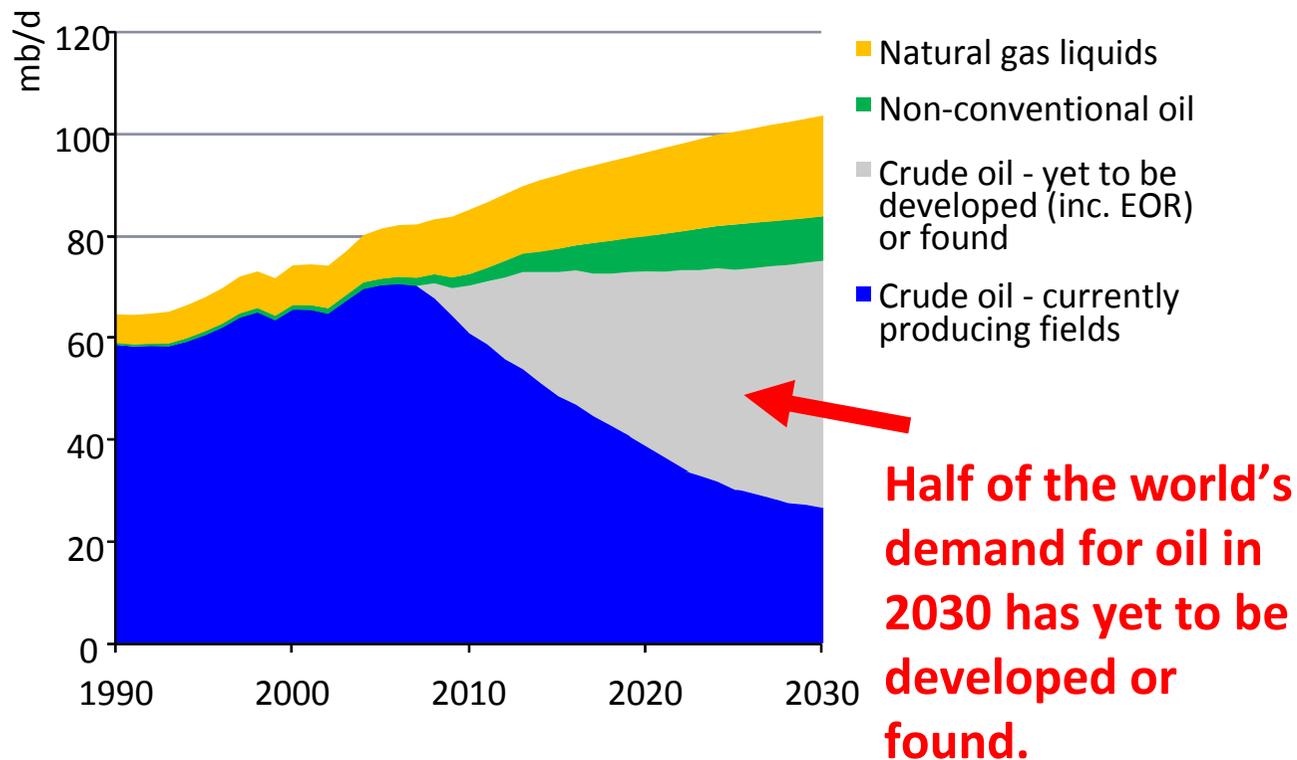
## Composition of the Commission

- Katherine Richardson (chairperson), Professor and Vice-Dean at the University of Copenhagen
- Dorthe Dahl-Jensen, Professor at the University of Copenhagen
- Jørgen Elmeskov, Director of the Policy Studies Branch of the OECD Economics Department
- Cathrine Hagem, Senior Researcher with Statistics Norway
- Jørgen Henningsen, Previously Director in the European Commission
- John A. Korstgård, Professor and Head of Department at Aarhus University
- Niels Buus Kristensen, Head of Department for DTU Transport at the Technical University of Denmark
- Poul Erik Morthorst, Research Specialist at Risø DTU, the National Laboratory for Sustainable Energy at the Technical University of Denmark
- Jørgen E. Olesen, Research Professor at University of Aarhus
- Mette Wier, Executive Director of AKF, Danish Institute of Governmental Research

21 meetings. Scientific analyses. Documentation can be found on:  
[www.klimakommissionen.dk](http://www.klimakommissionen.dk)



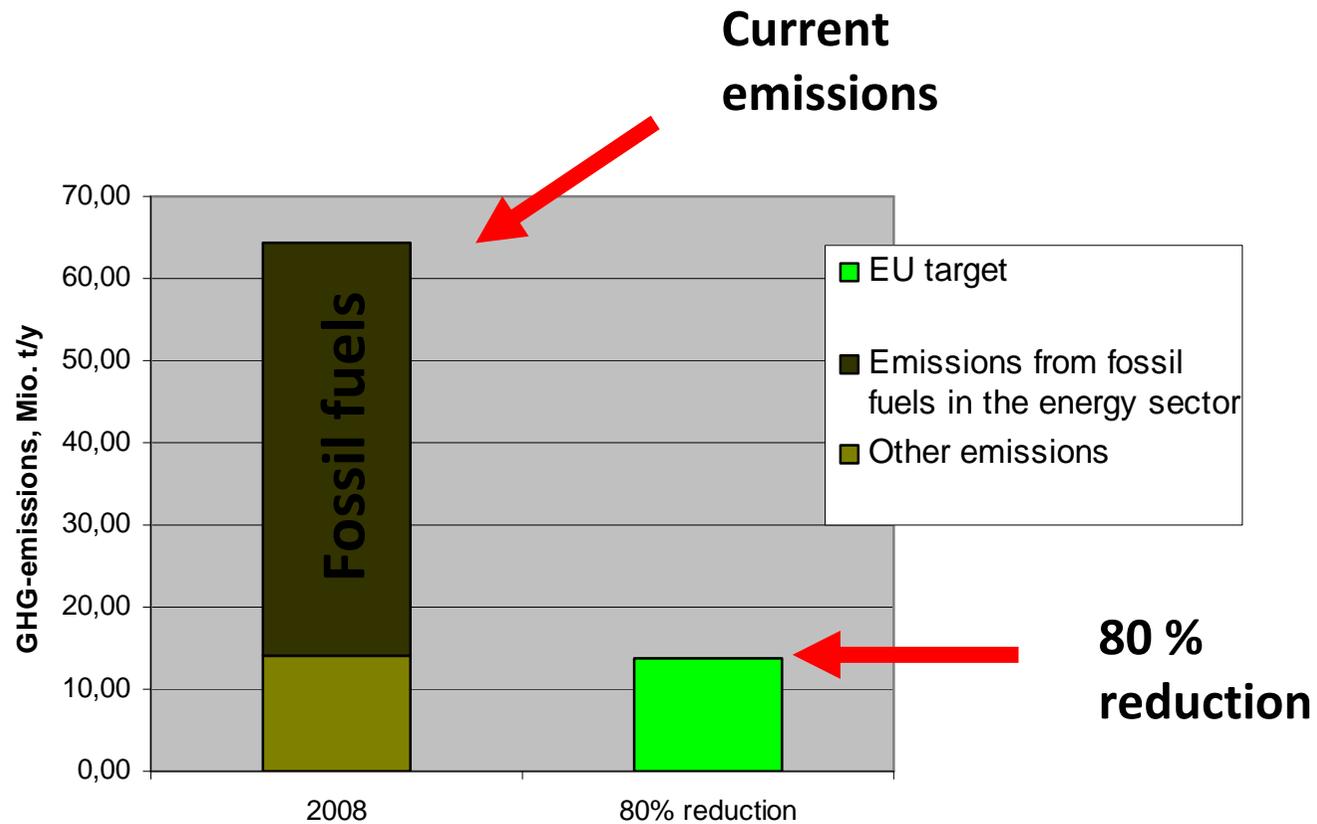
## Challenge: Increasing demand on the (limited) fossil fuel resources (especially oil and natural gas)



- Rising prices
- Fluctuating prices
- Known oil and natural gas are concentrated in a few countries



**Challenge: Fossil fuels generate the bulk of carbon emissions. An effort is necessary here in order to achieve the goal**





## TWO GOALS FOR THE COMMISSION

**Independence from oil,  
coal and natural gas**

**Renewable energy  
can cover  
Denmark's energy  
needs.**

**Ambitious climate goal**

**Derived from EU's  
target of 80-95 %  
reduction of  
emissions by 2050**



## THE COMMISSION'S PRINCIPLES

Economic growth will continue

"Denmark is not an island"

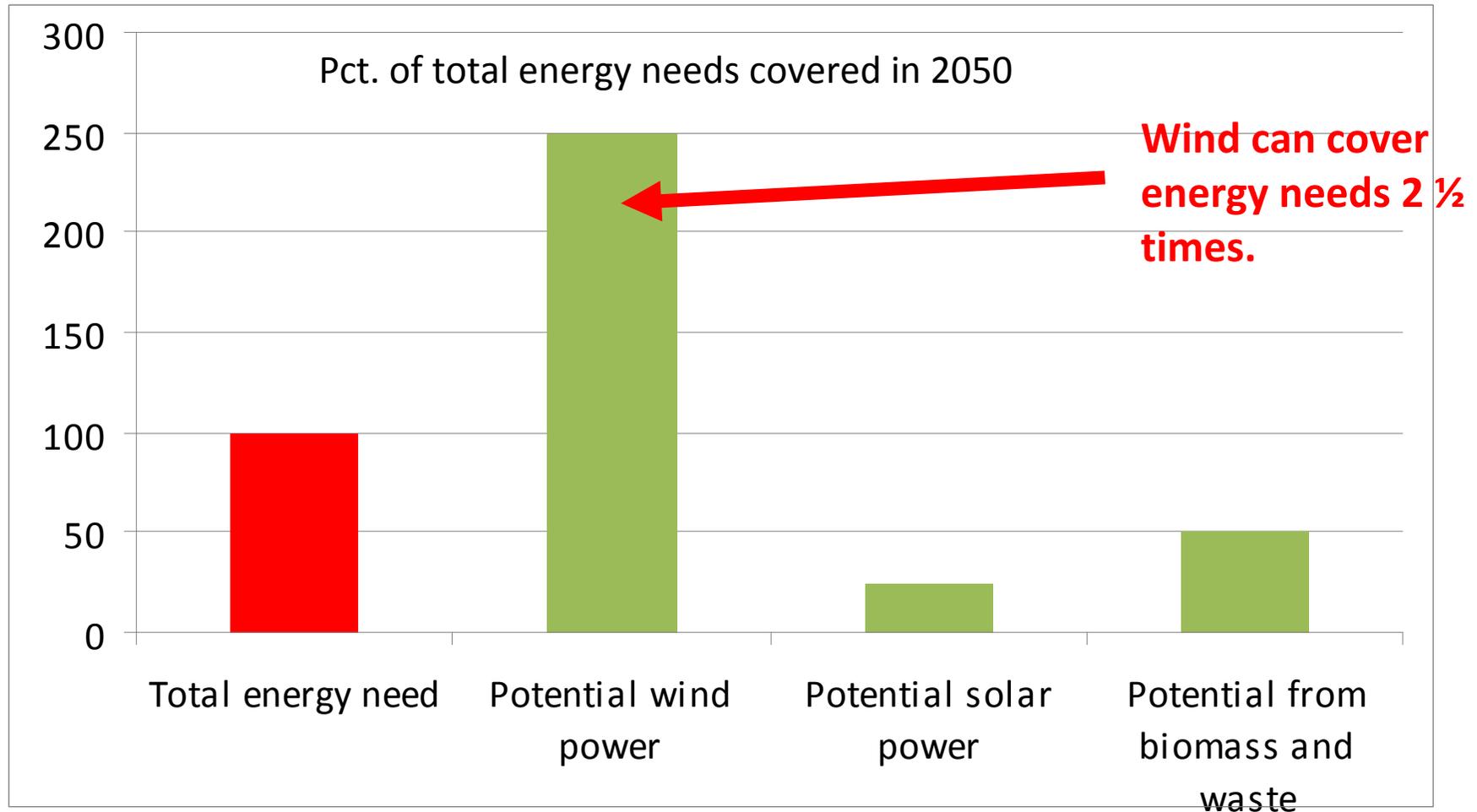
Independence should be obtained at the lowest possible societal cost

There are no chosen technologies.  
"Market choice rather than command and control"

Biomass gives both opportunities and challenges

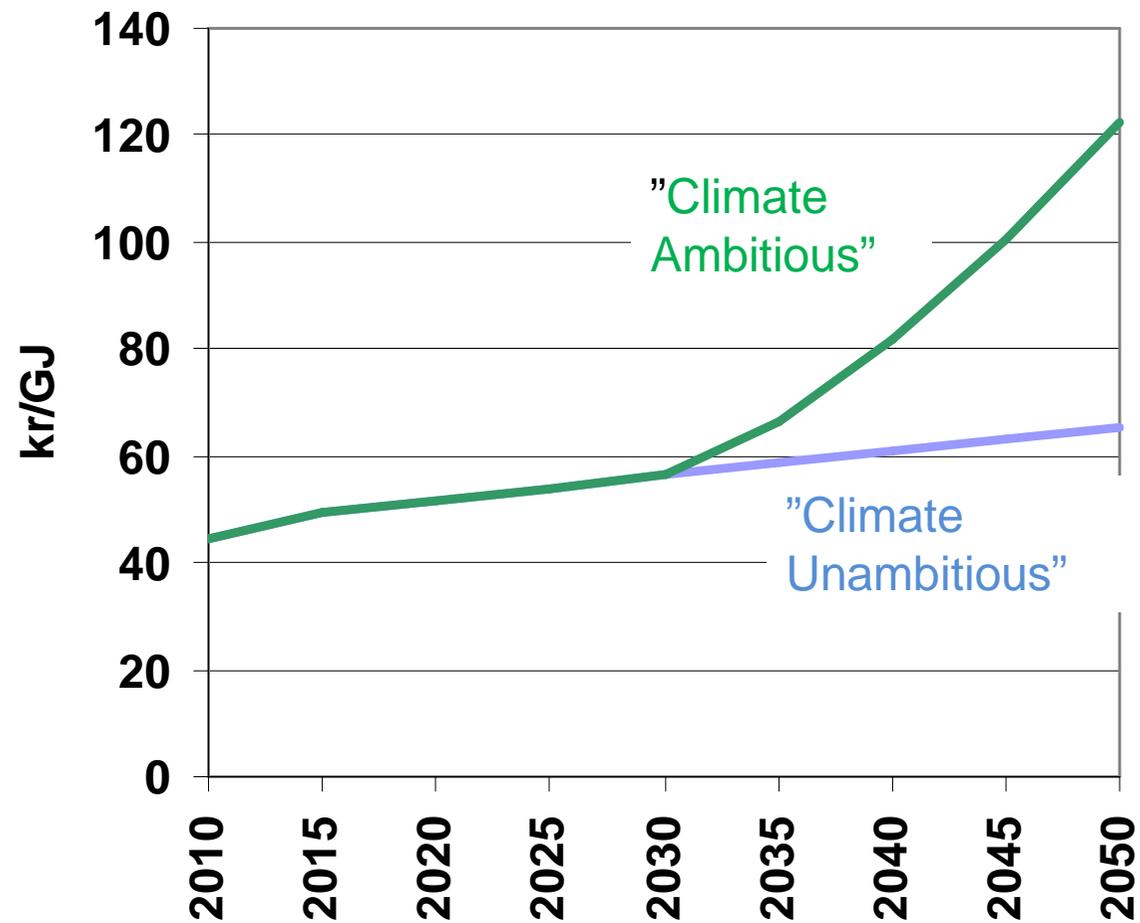


# Our energy needs will rise, but there are ample renewable resources





## PRICE OF BIOMASS WILL DEMAND ON INTERNATIONAL DEMAND





## The Commission's Results

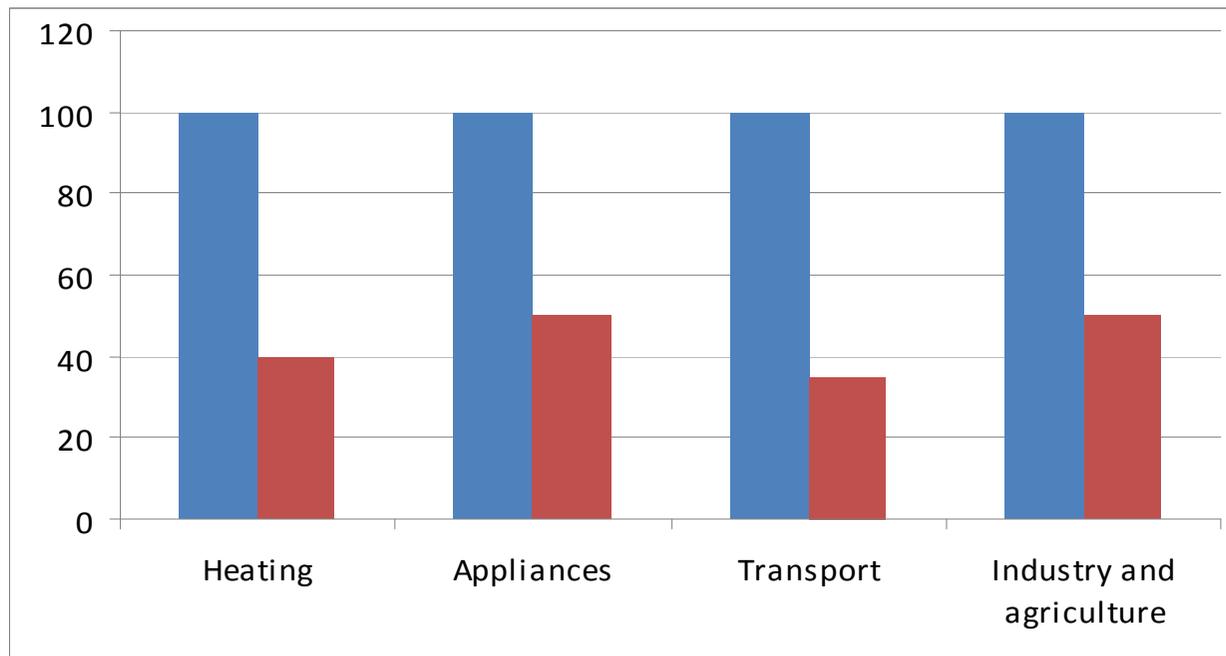
- Denmark can become independent of fossil fuels by 2050.
- Even as our energy demand doubles.
- The technology is available today, but more will become available.
- Only a small additional cost as continued dependence on fossil fuels will become an increasingly expensive habit.



## STRATEGY WITH TWO ELEMENTS

**1. We need to use energy more effectively. Technological solutions and investments have a large potential**

More effective energy use by **2050** relative to **today**

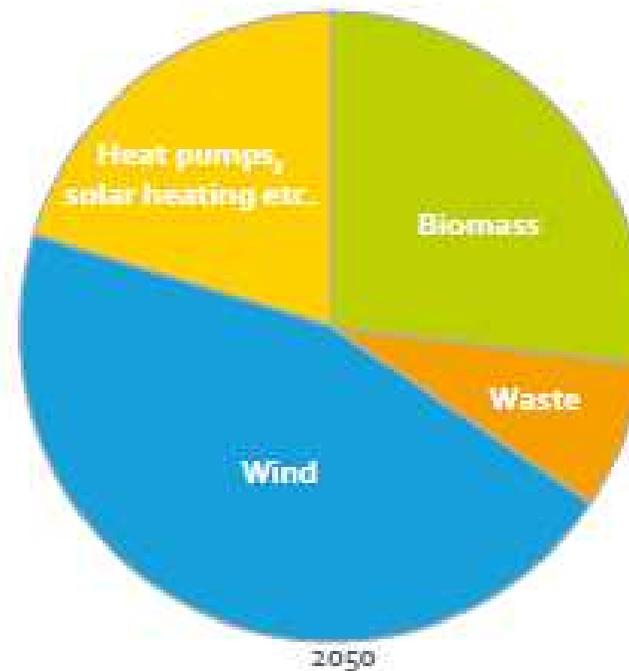
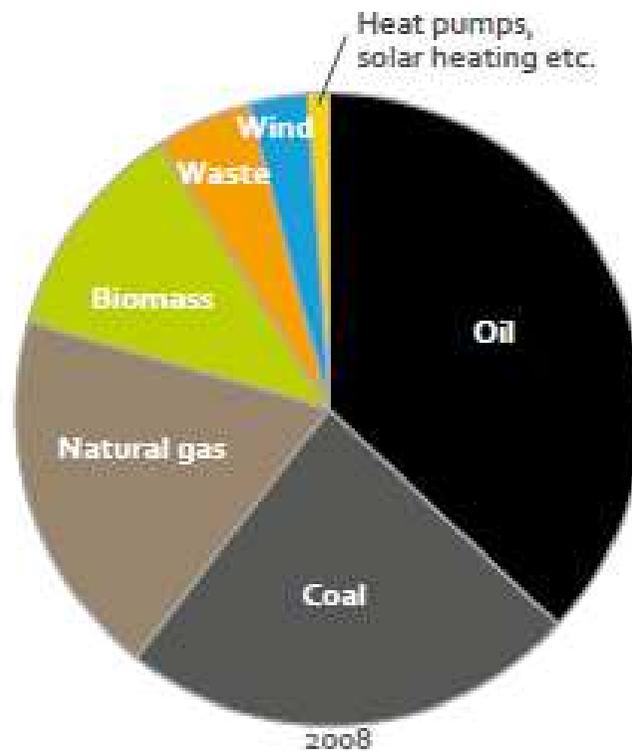


**We can halve the amount of energy that we use on household appliances relative to today**



## STRATEGY WITH TWO ELEMENTS

### *2. The energy of the future will come from renewable sources*

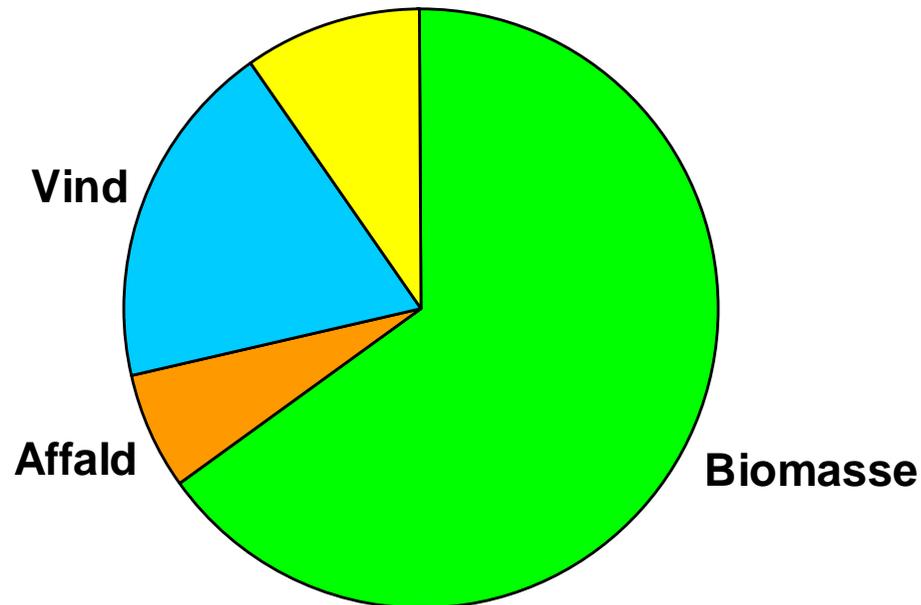


AMBITIOUS WORLD: DK  
ENERGY MIX 2050



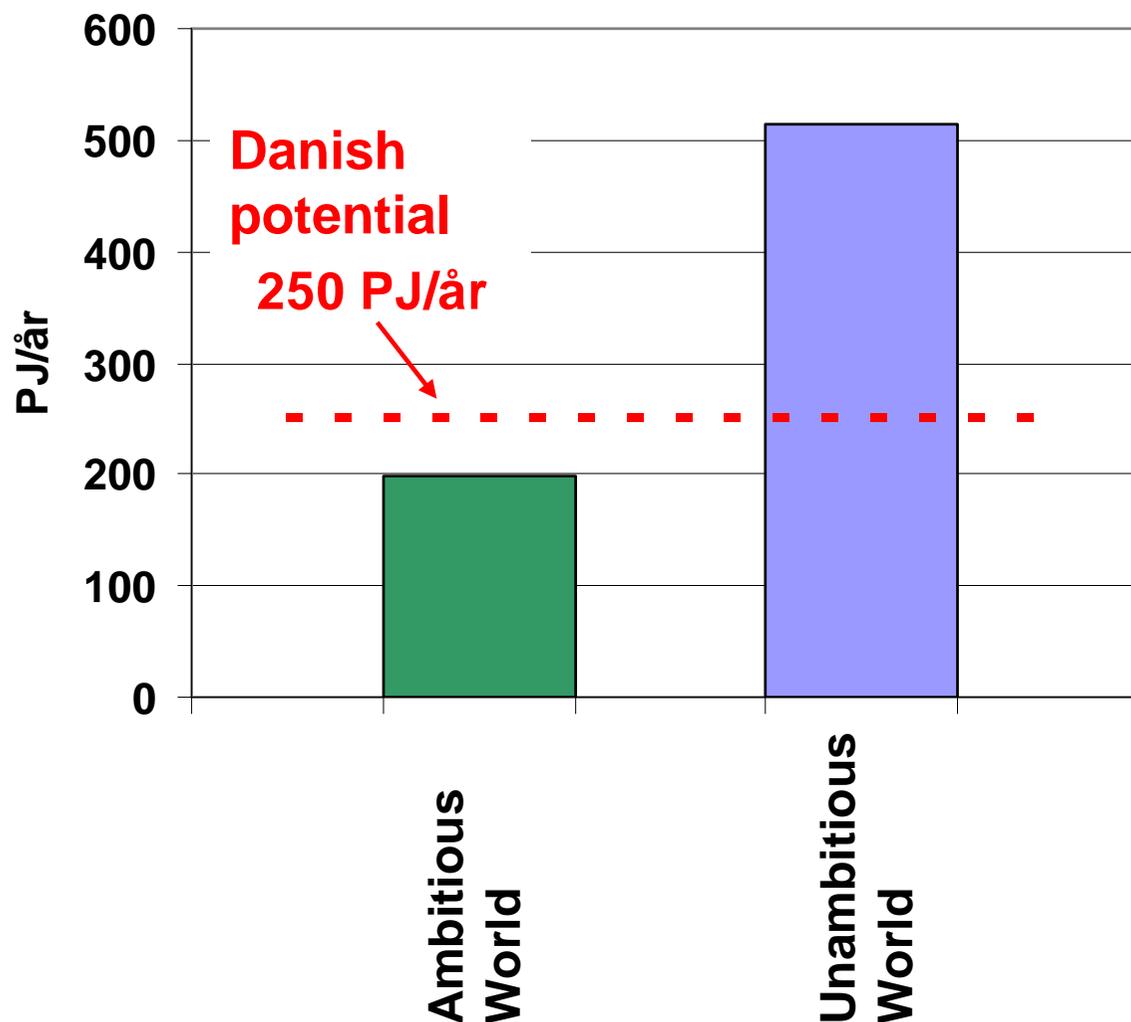
## UNAMBITIOUS WORLD: DK ENERGY MIX IN 2050

Varmepumper,  
solvarme m.m.





## USE OF BIOMASS WILL DEPEND ON PRIS (AND AVAILABILITY) OF THE RESOURCE



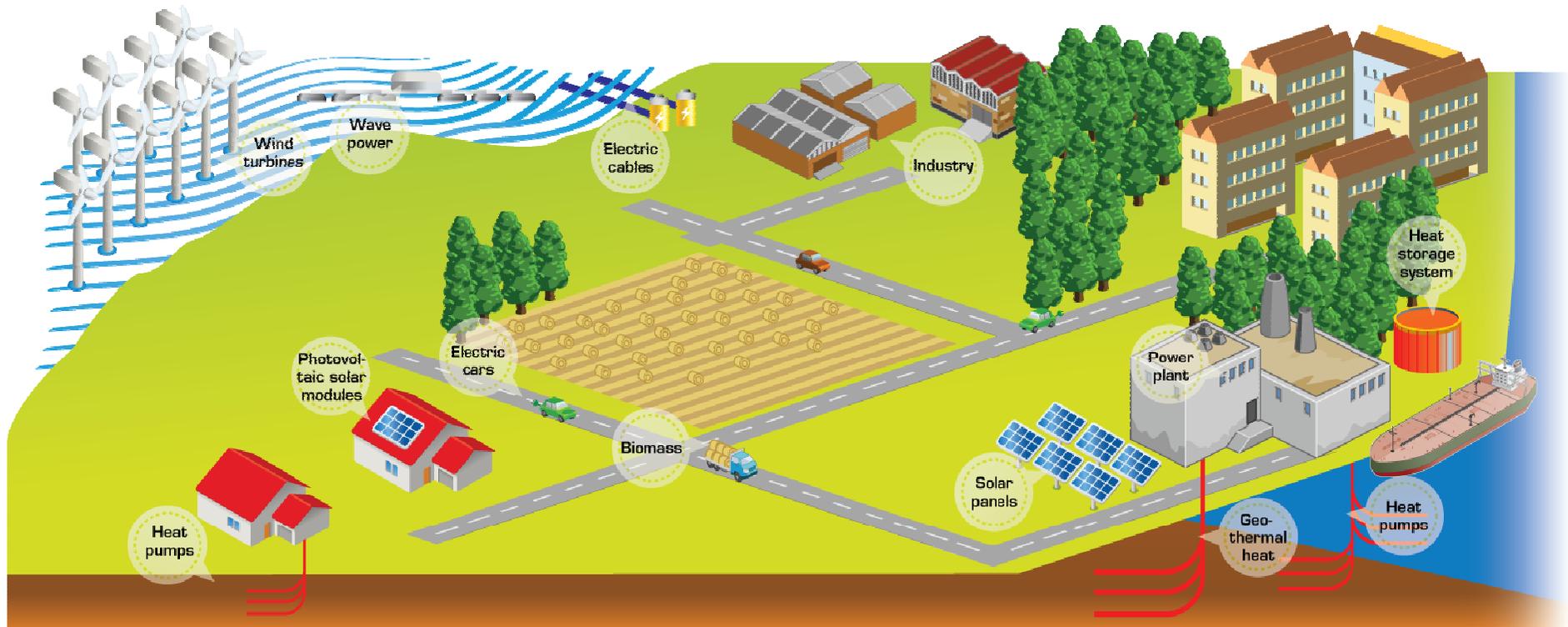


## IN AN AMBITIOUS WORLD, BIOMASS WILL BE USED WHERE THERE ARE NOT ALTERNATIVES (i.e. probably not for routine heat and el production)

- Transport sector, where electricity not a possibility
- In industry as a reserve when the price of electricity is high and for processes requiring high temperature
- Electricity production when markets price is high and the other renewable energy sources cannot deliver
- Central heating in combination with electricity production so that heat from electricity production can be utilised



# THE ENERGY SYSTEM OF THE FUTURE





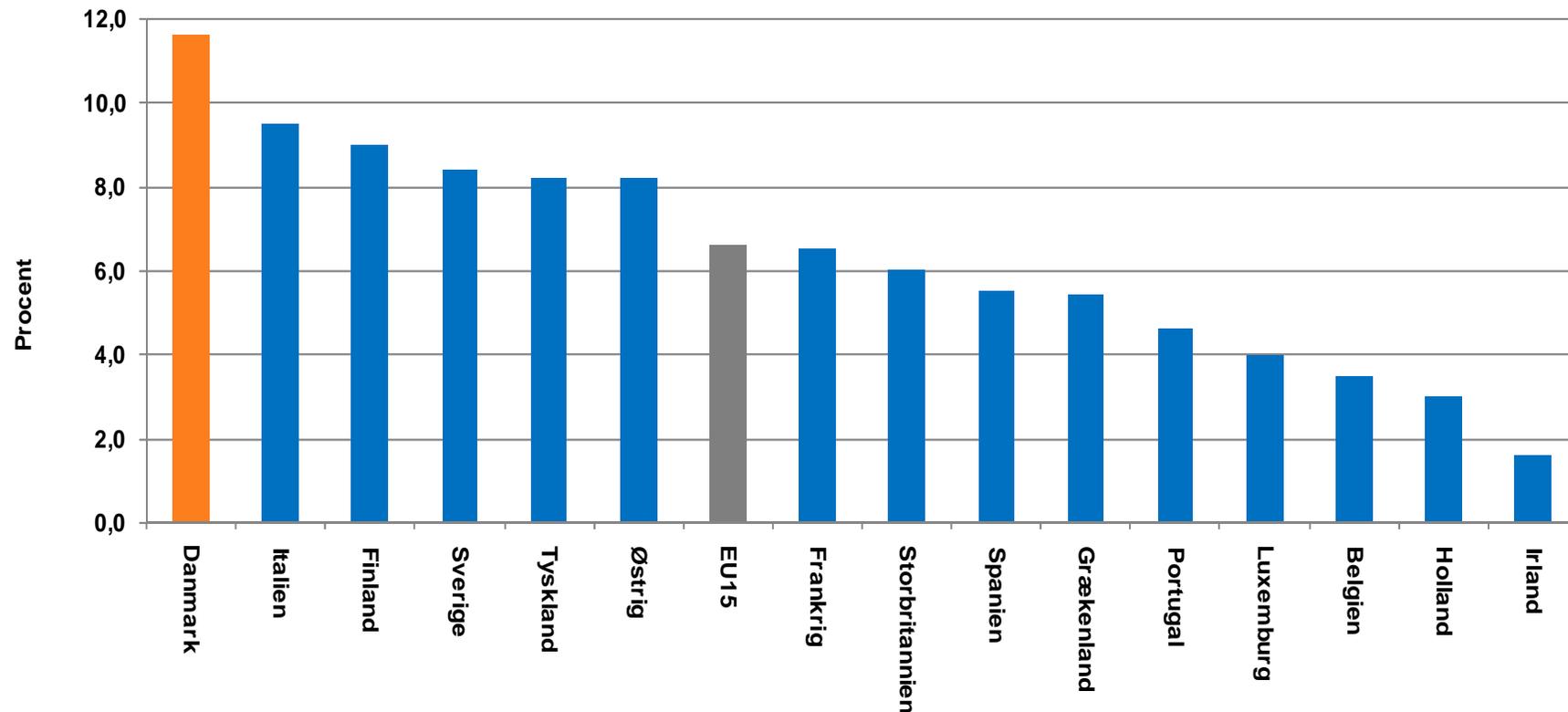
## EARLY TRANSITION TO A NEW ENERGY SYSTEM CAN STIMULATE GROWTH

- Denmark has a strong basis to build on and can, potentially, be among the first country's making the transition to a green energy system



## Denmark already has a strong profile in green energy and energy efficiency

Energy technology as % of total export for EU-15 countries, 2009.



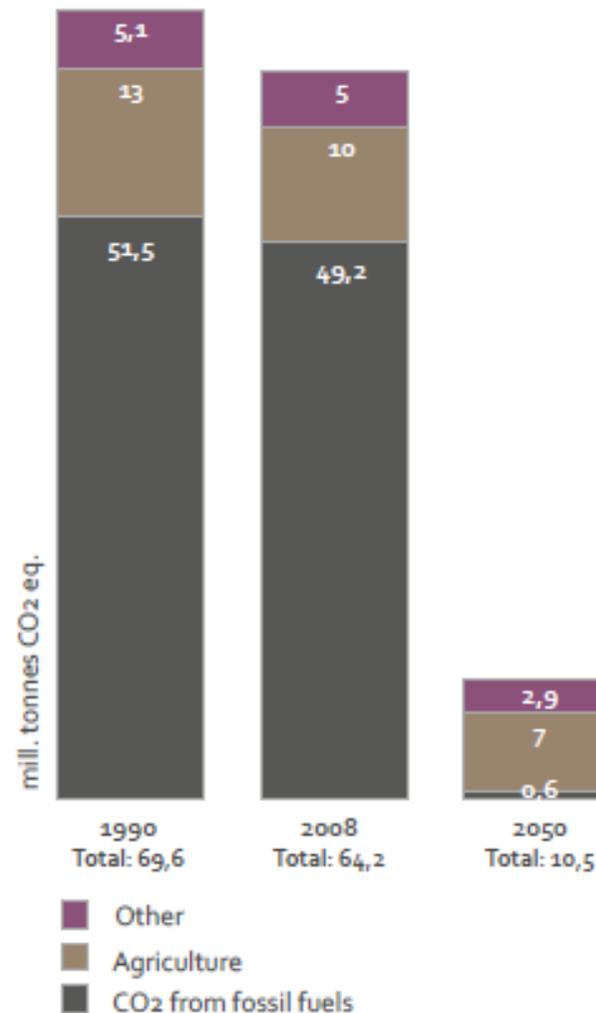


## TECHNOLOGICAL DEVELOPMENT WANTED:

- El and hybrid vehicles
- Incorporation of fluctuating el-production (smart grid), including:
  - Infrastructur for elbiler (charging stands, etc)
  - Intelligent el metering and intelligence built into appliances.
- Energy efficiency in products, appliances and buildings
- Remote Heating technology: incl. Large heat pumps, solar and seasonal storage of heat.
- Wind technology – including turbines in deeper water



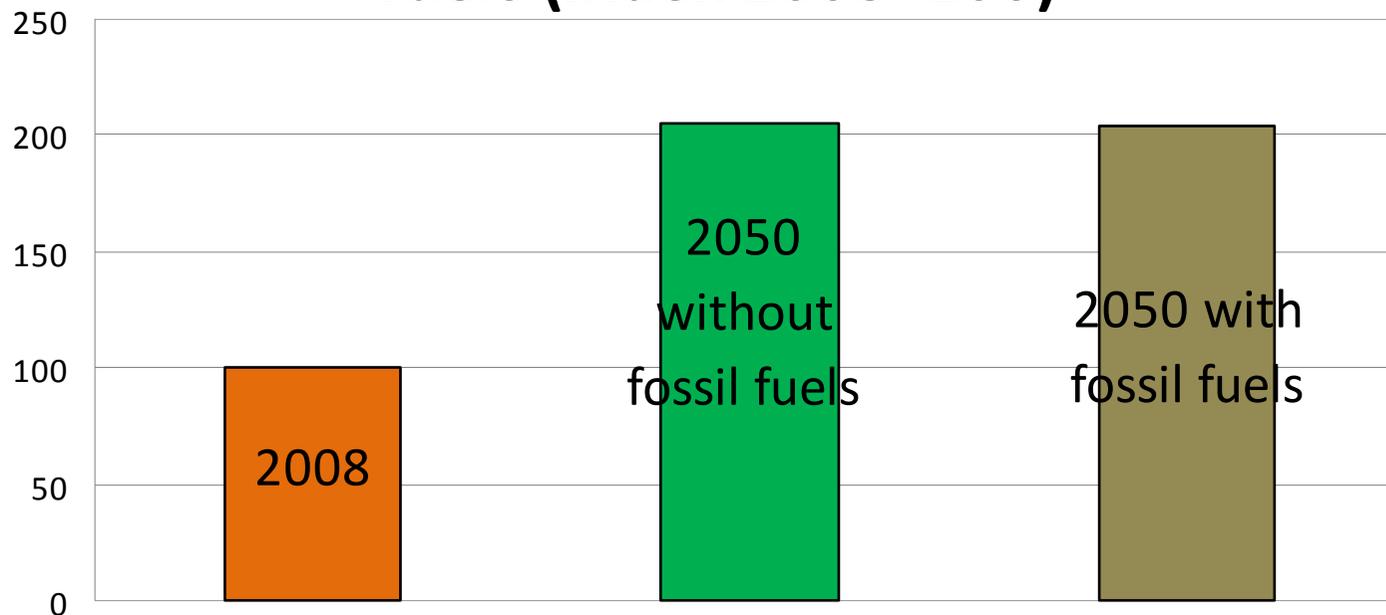
## The remaining emissions derive primarily from the agricultural sector





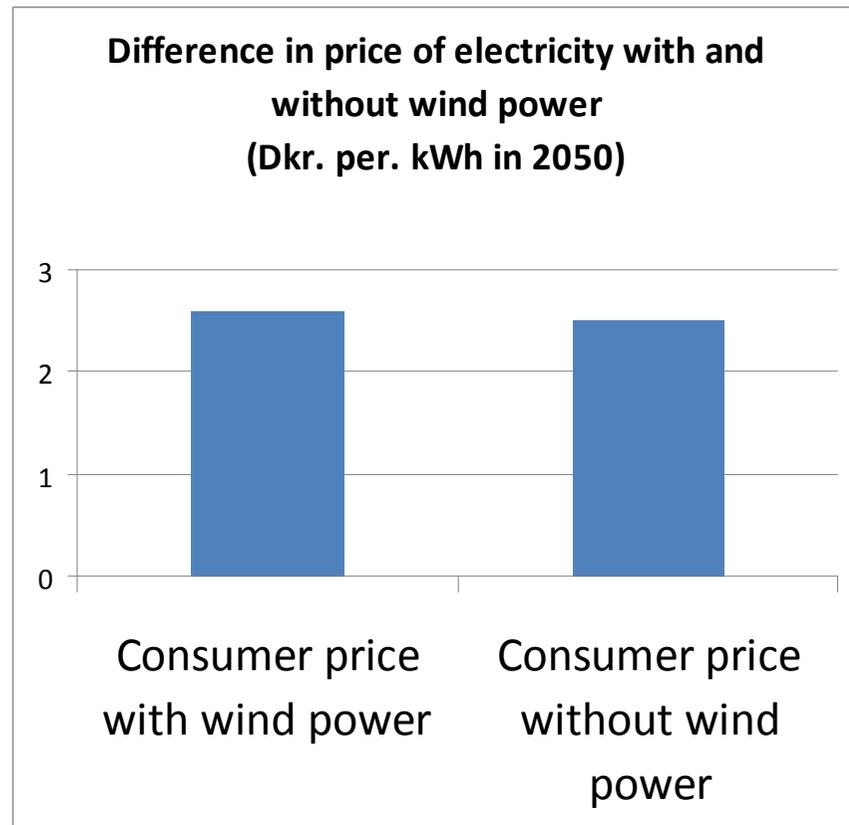
## The extra price tag for independence is small

### GNP in 2050 – with and without fossil fuels (index 2008=100)





## Consumers will pay about the same



Despite our energy needs doubling by 2050 the total cost for heating, transport and energy will remain the same as today.

Primarily due to gains from energy efficiency.



## THE COMMISSION'S 40 RECOMMENDATIONS

- All focus on things that should be done during the next 10-15 years in order to establish the framework that will best allow market mechanisms to promote the transition to green energy (i.e. tax on fossil fuel use)
- Are robust irrespective of whether the world is **AMBITIOUS** or **UNAMBITIOUS**
- Should be seen as a "package" – to change an energy system, several balls have to be in the air at the same time!



## **FOCUS MUST BE ON THE SYSTEM AS A WHOLE!**

### **A NUMBER OF THINGS HAVE TO HAPPEN AT THE SAME TIME:**

- Improved energy efficiency (also in industry!!)
- Establish infrastructure for green energy (WIND).
- Establish storage capacity in the system.
- Establish "smart grid" with built in "intelligence".
- Expansion of transmission facilities (domestic and international) (WE WILL USE MORE ELECTRICITY!)
- Long-term planning (also to increase investment interest)
- Revamping of the tax system
- Gain experience with new transport technologies

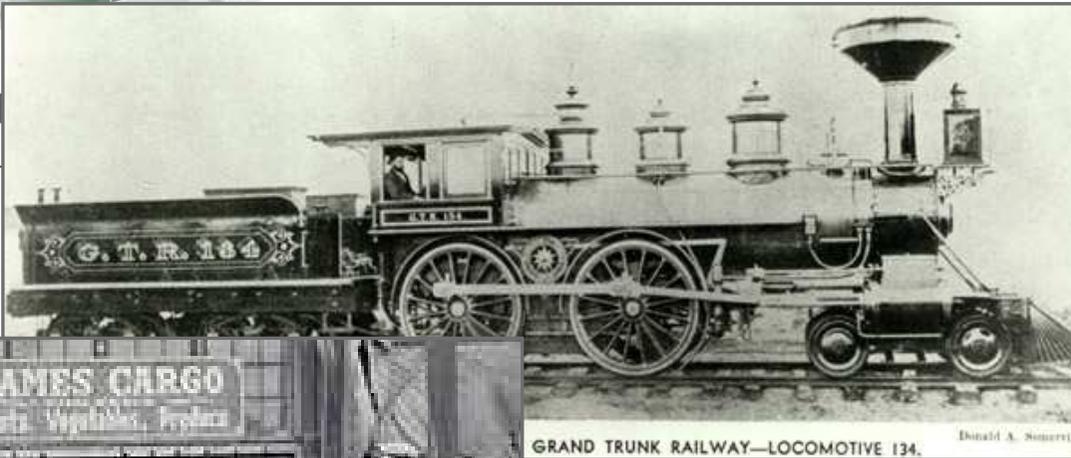


- FU – and not least – Demonstration!
- Strategic energy planning
- Action in international political fora (i.e., EU mm) – standards!
- Legal framework
- periodic evaluation of progress.



## Putting things in perspective...

- The Earth was formed about 4.7 billion years ago
- The present form of our species showed up about 250,000 years ago...
- We are ca. generation # 10,000...
- Most generations lived in caves...



- 6-8 generations ago, we replaced animal power with machines
- 4-5 generations we discovered the automobile...





- We are the first generation that **KNOWS** (thanks to research) that our combined activities impact the Earth at the system level...
- **The first generation with the POWER and RESPONSIBILITY to change and manage our species' relationship with the planet.**

