Global Environmental Policy

Makoto Akai

National Institute of Advanced Industrial Science and Technology (AIST)

Lecture Plan

June 05: Overview

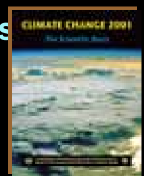
June 12: Challenges and strategies towards Deep GHG Reduction

July 03: Reporting and Discussion

Background

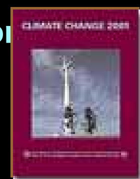
Recent Findings on Climate Change

IPCC 3rd Assessment Report (TAR) Suggest
WG1:Scientific Basis-SPM



- An increasing body of observations gives a collective picture of a **warming world** and other changes in the climate system,
- There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to **human activities**,
- Human influences **will continue** to change atmospheric composition throughout the 21st century.

IPCC 3rd Assessment Report (TAR) Suggestion
WG3:Mitigation-SPM



- **Earlier actions**, including a portfolio of emissions mitigation, technology development and reduction of scientific uncertainty, **increase flexibility** in moving towards stabilization of atmospheric concentrations of greenhouse gases,
- **Rapid near-term action** would decrease environmental and human risks associated with rapid climatic changes.

IPCC 4th Assessment Report (AR4)
Direct Observations of Recent Climate Change

- Warming of the climate system is **unequivocal**, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.

IPCC 4th Assessment Report (AR4)
Understanding and Attributing Climate Change

- Most of the observed increase in global average temperatures since the mid-20th century is ***very likely*** due to the observed increase in anthropogenic greenhouse gas concentrations.
  - This is an advance since the TAR's conclusion that "most of the observed warming over the last 50 years is ***likely*** to have been due to the increase in greenhouse gas concentrations".

NOTE: *Virtually certain* > 99% probability of occurrence, *Extremely likely* > 95%, *Very likely* > 90%, *Likely* > 66%, *More likely than not* > 50%, *Unlikely* < 33%, *Very unlikely* < 10%, *Extremely unlikely* < 5%

IPCC 4th Assessment Report (AR4)
Projections of Future Changes in Climate

- For the next two decades, a warming of about 0.2 °C per decade is projected for a range of SRES emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1 °C per decade would be expected.
- Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century.

IPCC 4th Assessment Report (AR4)
Projections of Future Changes in Climate

- Increasing atmospheric carbon dioxide concentrations lead to increasing **acidification of the ocean**. Projections based on SRES scenarios give reductions in average global surface ocean pH of between 0.14 and 0.35 units over the 21st century, adding to the present decrease of 0.1 units since pre-industrial times.

IPCC 4th Assessment Report (AR4)

How can Emissions be Reduced?

Sector	Key mitigation technologies and practices currently commercially available. (Selected)	Key mitigation technologies and practices projected to be commercialized before 2030. (Selected)
Energy Supply	efficiency; fuel switching; nuclear power; renewable (hydropower, solar, wind, geothermal and bioenergy); combined heat and power; early applications of CO2 Capture and Storage (CCS)	CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewables (tidal and waves energy, concentrating solar, solar PV)
Transport	・・・	・・・

IPCC 4th Assessment Report (AR4)

Long Term Mitigation (after 2030)

- Mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilization levels

Stab level (ppm CO_2-eq)	Global Mean temp. increase at equilibrium (°C)	Year global CO_2 needs to peak	Year global CO_2 emissions back at 2000 level	Reduction in 2050 global CO_2 emissions compared to 2000
445 - 490	2.0 - 2.4	2000 - 2015	2000- 2030	-85 to -50
490 - 535	2.4 - 2.8	2000 - 2020	2000- 2040	-60 to -30
535 - 590	2.8 - 3.2	2010 - 2030	2020- 2060	-30 to +5
590 - 710	3.2 - 4.0	2020 - 2060	2050- 2100	+10 to +60
710 - 855	4.0 - 4.9	2050 - 2080		+25 to +85
855 - 1130	4.9 - 6.1	2060 - 2090		+90 to +140

The Kaya equation

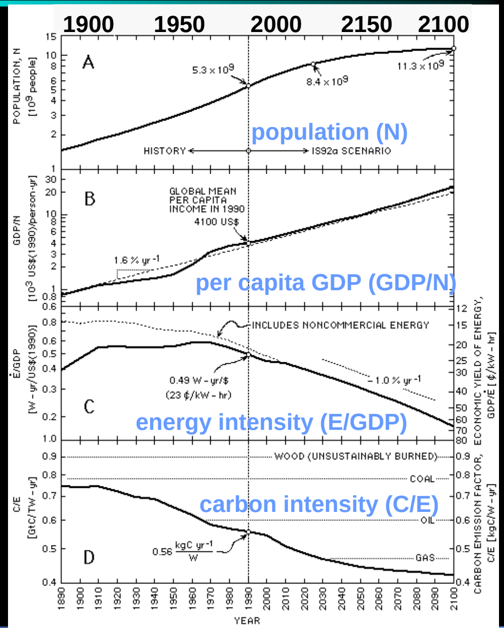
- C = N × (GDP/N) × (E/GDP) × (C/E)

  - C carbon emissions
  - N population
  - GDP/N per capita GDP
  - E/GDP energy intensity of economic productivity
  - C/E carbon intensity of primary energy

CO_2 emissions

= N x (GDP/N) x (E/GDP) x (C/E)

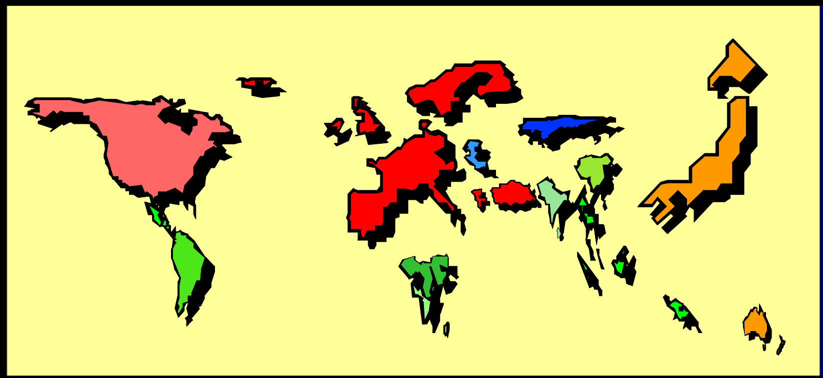
IPCC IS92a "Business as usual" scenario assumptions



Hoffert et al., 1998

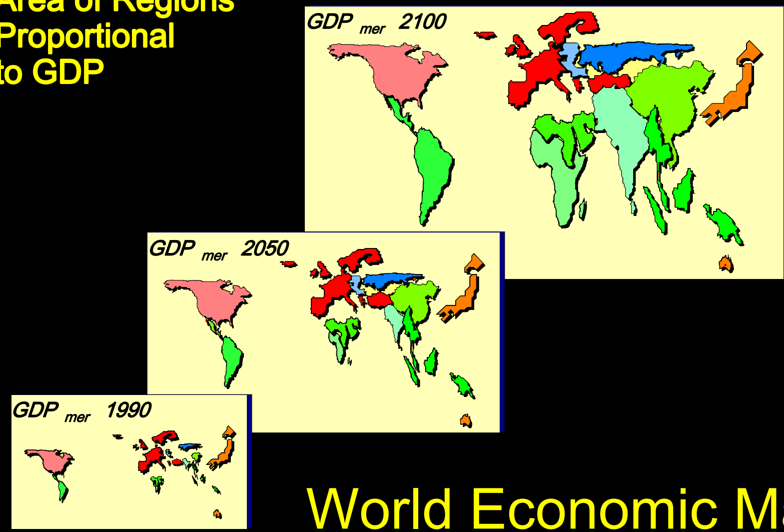
World Economic Map

Areas of Regions Proportional to 1990 GDP



Naki Nakicenovic

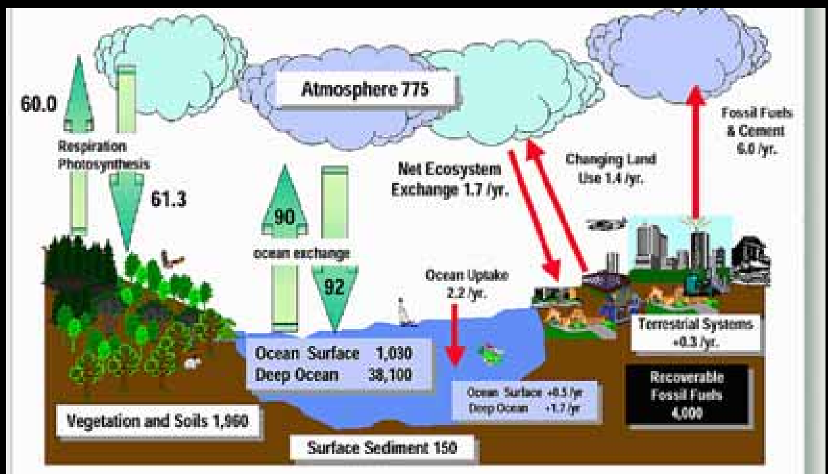
Area of Regions Proportional to GDP



World Economic Map

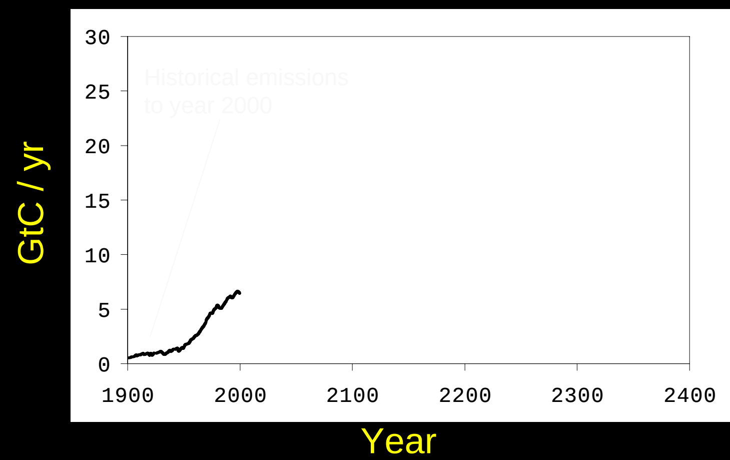
Naki Nakicenovic

Global Carbon Cycle

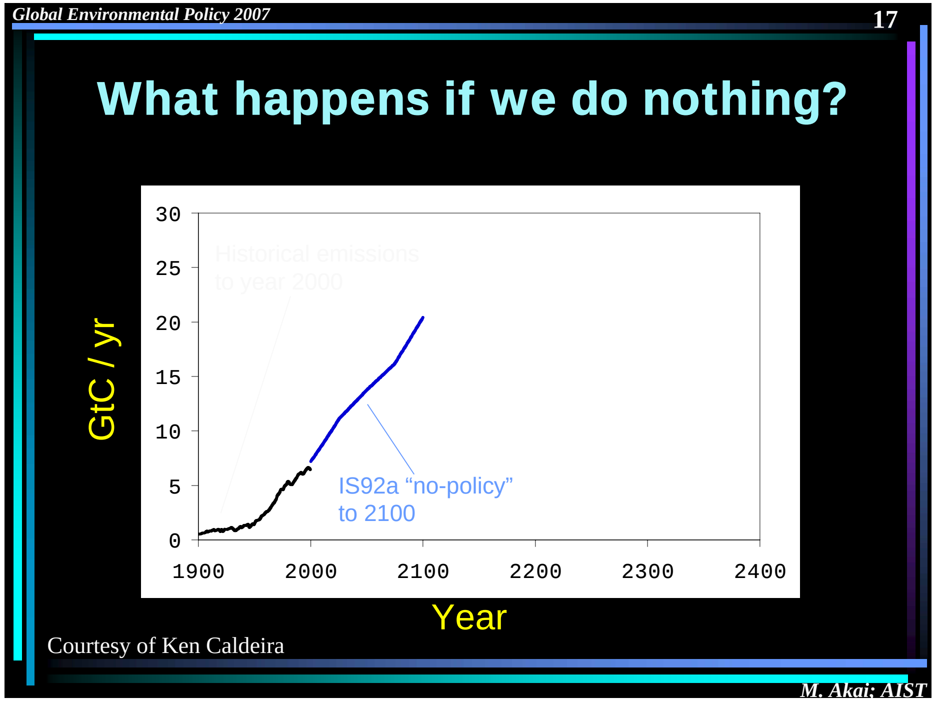


Carbon Fluxes in Gt

What happens if we do nothing?



Courtesy of Ken Caldeira


Global Environmental Policy 2007
17
What happens if we do nothing?
GtC / yr
30
25
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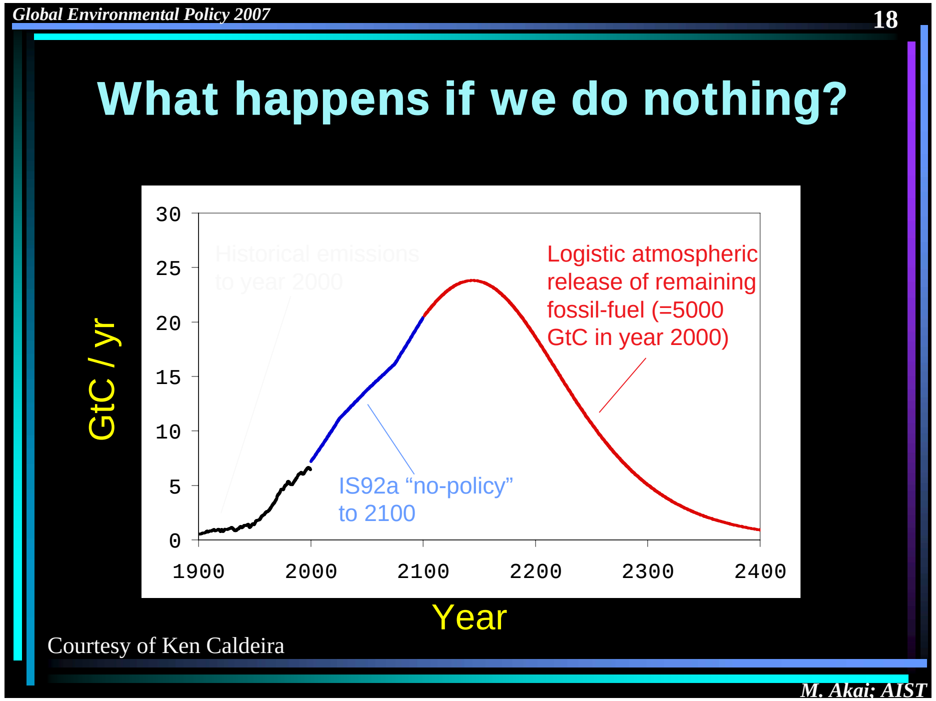
Year
Historical emissions to year 2000
IS92a "no-policy" to 2100
Courtesy of Ken Caldeira
M. Akai; AIST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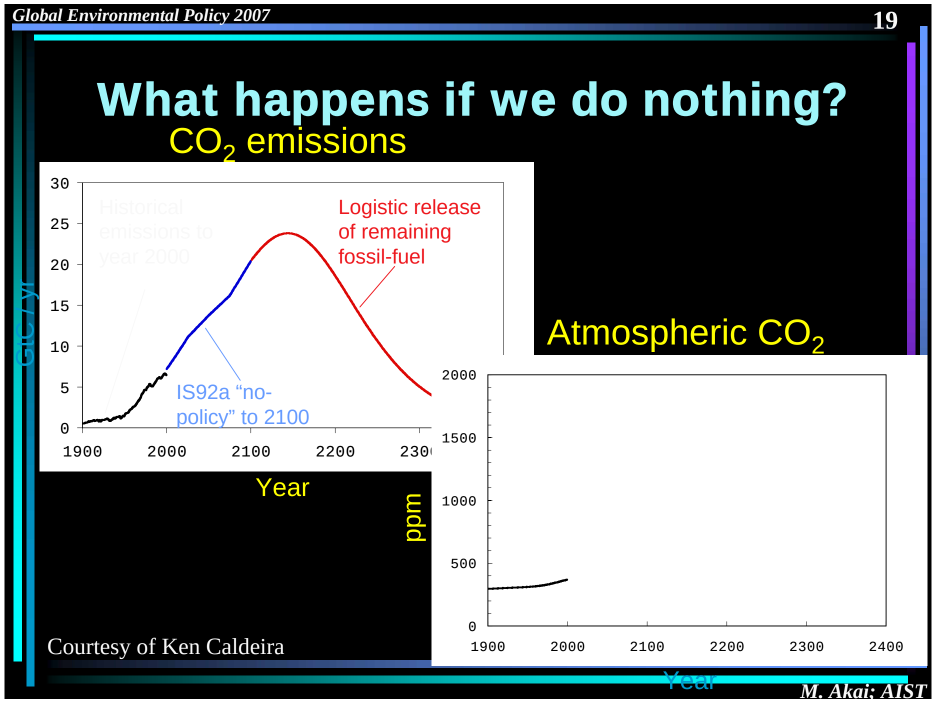
Year
Historical emissions to year 2000
IS92a "no-policy" to 2100
Logistic atmospheric release of remaining fossil-fuel (=5000 GtC in year 2000)
Courtesy of Ken Caldeira
M. Akai; AIST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Historical emissions to year 2000
Logistic release of remaining fossil-fuel
IS92a "no-policy" to 2100
Atmospheric CO2
ppm
2000
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Year
Courtesy of Ken Caldeira
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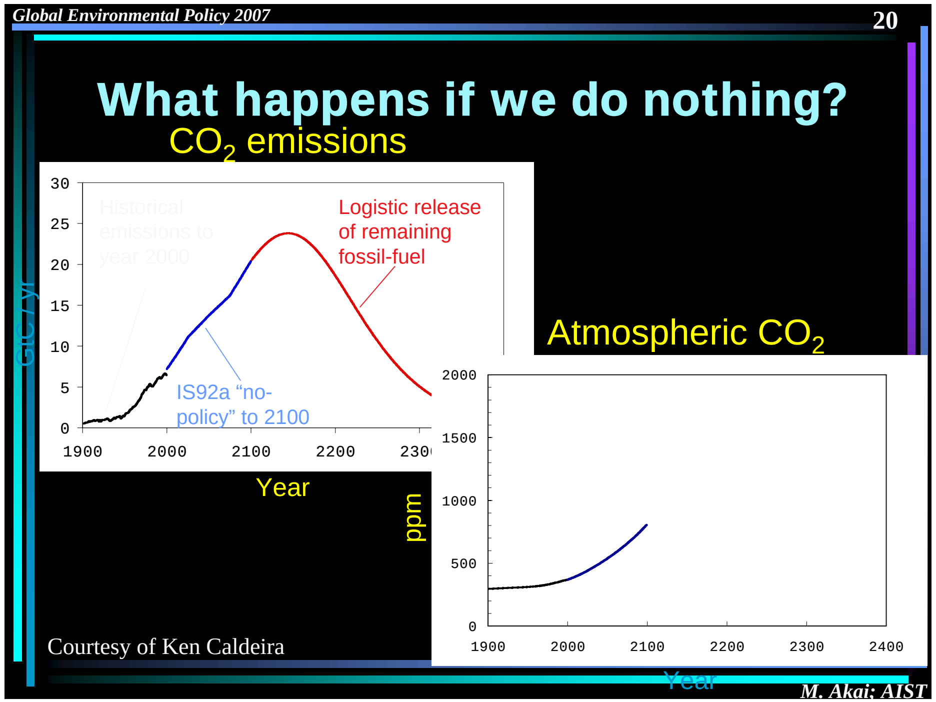
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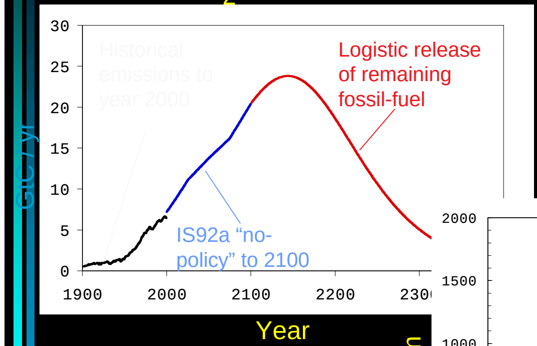
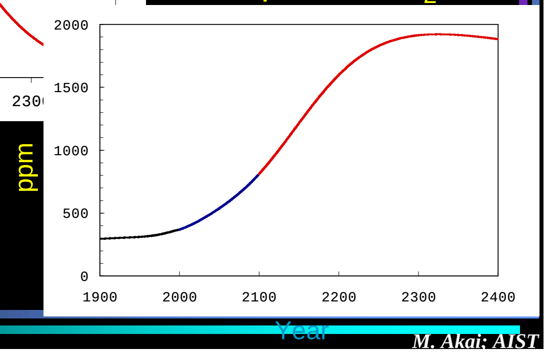
What happens if we do nothing?

CO_2 emissions

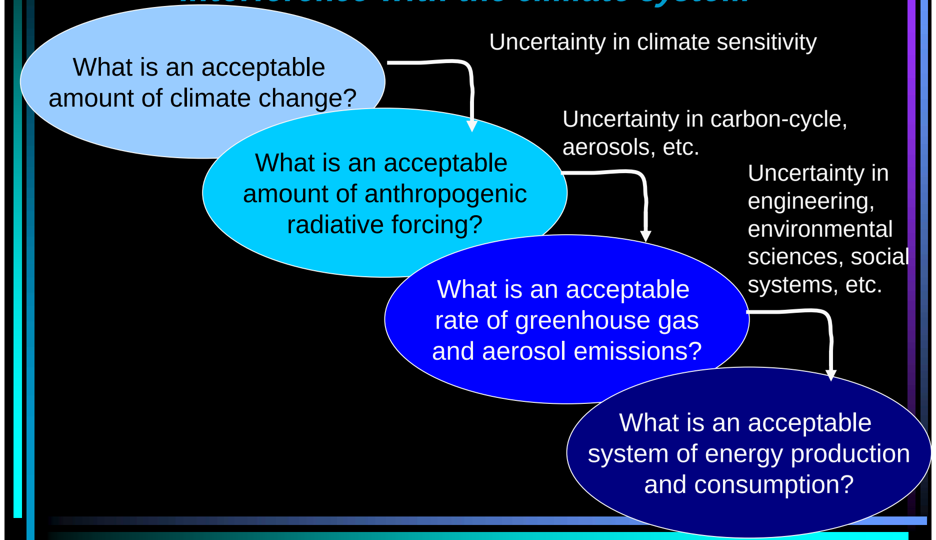


Atmospheric CO_2



Courtesy of Ken Caldeira

"stabilization of greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system"



The Road to Kyoto

History of Global Warming (1/2)

1827	French mathematician Jean-Baptiste Fourier suggests the existence of an atmospheric mechanism keeping the Earth warmer than it would otherwise be. He likens it to a greenhouse.
1863	Irish scientist John Tyndall publishes a paper describing how atmospheric water vapor could contribute to this mechanism.
1890s	Swedish scientist Svante Arrhenius and American P.C. Chamberlain independently investigate the potential problems that could be caused by carbon dioxide (CO_2) building up in the atmosphere. They both suggest that burning fossil fuels could lead to global warming, but neither suspect the process might already have started.
1890s - 1940	Average surface air temperatures increase by about 0.25 C. Some scientists see the American Dust Bowl (a devastating, persistent drought in the 1930s) as a sign of the greenhouse effect at work.
1940 - 1970	Global temperatures cool by 0.2 C. Scientific interest in global warming declines. Some climatologists predict a new ice age.

History of Global Warming (2/2)

1957	U.S. oceanographer Roger Revelle warns that people are conducting a "large-scale geophysical experiment" on the planet by releasing greenhouse gases. Colleague David Keeling establishes the first continuous monitoring of atmospheric CO_2. He rapidly confirms a regular year-on-year rise.
1970s	A series of studies by the U.S. Department of Energy increases concerns about possible long-term effects of global warming.
1979	First World Climate Conference adopts climate change as major issue and calls on governments "to foresee and prevent potential man-made changes in climate".
1985	First major international conference on global warming in Villach (Austria) warns that average global temperatures in the first half of the 21st century could rise significantly more than at any other time in human history. Warmest year on record. The 1980s is the warmest decade on record, with seven of the eight warmest years of the century.
1987	Global temperatures cool by 0.2 C. Scientific interest in global warming declines. Some climatologists predict a new ice age.

Road to Kyoto

1988	•Heat wave in U.S. granary •Testimony by Dr. Hansen •Toronto Conference •Establishment of IPCC
1990	•IPCC First Assessment Report
1992	•Earth Summit ⇒UNFCCC
1995	•COP-1 (Berlin) ⇒Berlin Mandate •IPCC Second Assessment Report
1996	•COP-2 (Geneva)
1997	•COP-3 (Kyoto) ⇒Kyoto Protocol

1988 - Year of Breaking Out

- Dr. Hansen testified before the U.S. Senate
  - 99 percent sure ... the greenhouse effect has been detected and it is changing our climate now.
- *World Conference on the Changing Atmosphere: Implications for Global Security (Toronto)* called for 20 % cuts in global CO_2 emissions by the year 2005
- WMO and UNEP established the Intergovernmental Panel on Climate Change (IPCC).

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Earth Summit

UN Conf. on Environment and Development

- The centerpiece was the ratification of the UNFCCC and was signed by 154 nations.
- UNFCCC does not contain binding targets for GHG emission reductions, but recognizes the importance of reducing GHG emissions in order to prevent "dangerous interference" with the climate system.

UNFCCC

- Sets an initial target for industrialized countries to reduce their GHG emission to 1990 levels by the year 2000.
- Demanded each industrialized nation to submit national communication on GHG emission inventory, and to provide financial and technical assistance to developing countries for the reporting.
- Came into force on 21 March 1994.

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COP-1

Conference of the Parties on its First Session

- Berlin Mandate
  - To initiate a process to enable Governments to take appropriate action for the period beyond 2000, including a strengthening of developed country commitments.
  - The work should be completed as early as possible so that the results can be adopted at COP-3 in 1997.
  - Developing countries are explicitly exempted from these new commitments.

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Kyoto Protocol to the UNFCCC

- 38 developed countries agreed to reduce their emissions of six GHGs by a total of 5.2% between 2008 and 2012 from 1990 levels
  - CO_2, CH_4, N_2O, HFCs, PFCs, SF_6
- Party quantified emission limitation or reduction commitment include (% reduction):
  Austria (8); Canada (6); Japan (6); Romania (8); Russian Federation (0); Switzerland (8); USA (7); UK (8);

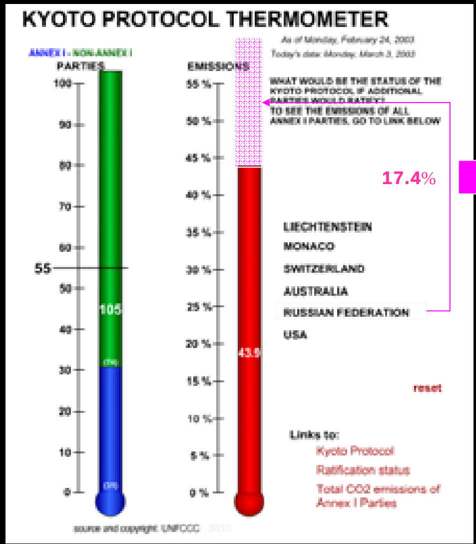
Kyoto Mechanisms

- Kyoto Protocol provided the basis for mechanisms to assist Annex I Parties in meeting their targets cost effectively, i.e.
  - Emissions trading system,
  - Joint implementation (JI) of emissions reduction projects between Annex I Parties,
  - Clean Development Mechanism (CDM) to encourage joint projects between Annex I and non-Annex I Parties. However,
  - It was left for subsequent meetings to decide on most of the rules and operational details that will determine how these cuts in emissions are achieved, measured and assessed.

Towards Effectuation of Kyoto Protocol

- In order for the Kyoto Protocol to enter into force, it must be ratified by 55 Parties to the UNFCCC, including Annex I Parties representing at least 55% of the total carbon dioxide emissions for 1990.

Kyoto Protocol Ratification Status

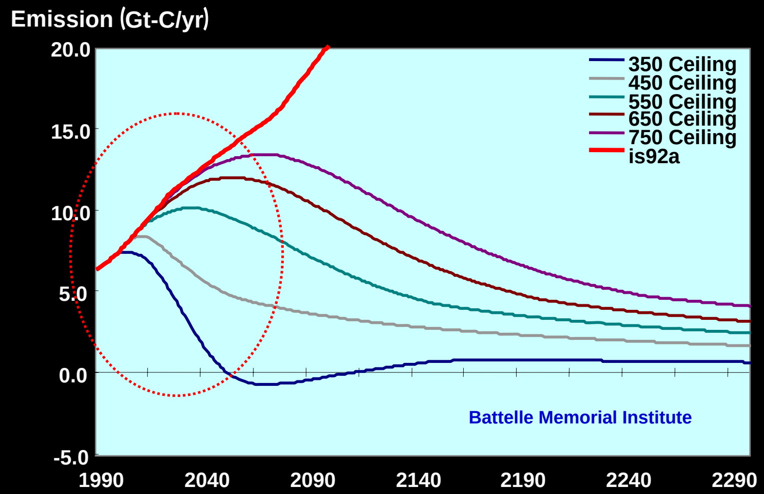


Enter into forth on
16 February 2005

Towards a Deep Reduction of Greenhouse Gas

CO_2 Stabilization Profiles

- Atmospheric Emissions -



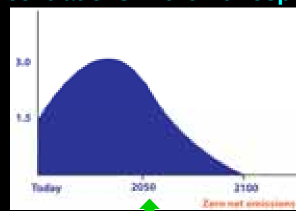
The Technology Challenge

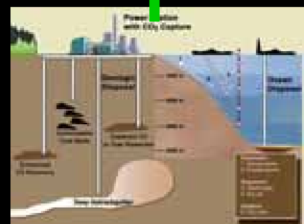
Stabilizing Greenhouse Gas Concentrations in the Atmosphere

Hydrogen Fuel Cell Vehicles

Zero Net Emission Buildings

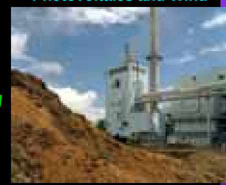
Nuclear Power Generation IV



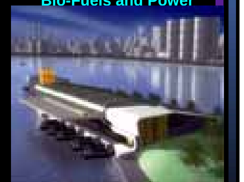


Carbon (CO_2) Sequestration

Renewables: Photovoltaics and Wind



Bio-Fuels and Power



Vision 21: Zero-Emission Power Plant

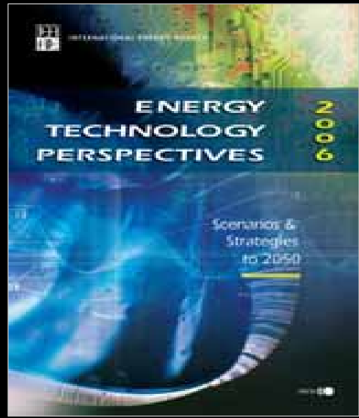
Technological Options for Deep Reduction of GHG Emissions

- Improvement of energy efficiency
- Switching to lower carbon fuels, e.g. coal to natural gas
- Use of non carbon fuels, e.g. renewables, nuclear
- Enhancement of natural sinks for CO_2, e.g. forestry
- Capture and sequestration of CO_2.

Energy Technology Perspectives

Scenarios and Strategies to 2050

In support of the G8 Plan of Action



IEA: International Energy Agency

Energy Technology Perspectives Presents

- Status and perspectives for key energy technologies in:
  - Power Generation
  - Transport
  - Buildings and Appliances
  - Industry
- Global scenarios to illustrate potentials for different technologies under accelerated policies
- Strategies for helping key technologies make a difference

Key Findings

- Current policies will not bring us on a path towards a sustainable energy future
- A more sustainable energy future is possible with a portfolio of clean and efficient technologies
- Using technologies that have an additional cost of less than 25 $/tonne CO_2 avoided:
  - Global CO_2 emissions can be returned to today's level by 2050
  - Expected growth in both oil and electricity demand can be halved
- Requires urgent action to promote, develop and deploy a full mix of energy technologies
- Collaboration between developing and developed nations will be essential

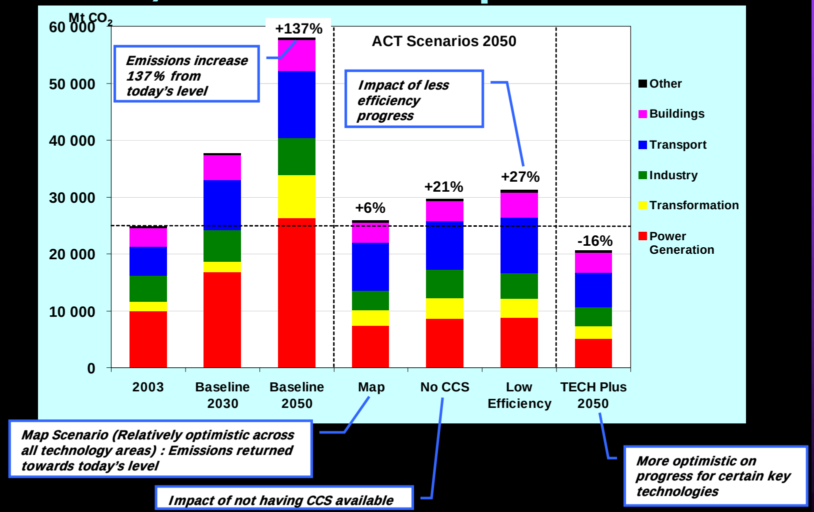
Scenario Analysis

- Scenarios analysed:
  - Baseline Scenario
  - Accelerated Technology Scenarios (ACT)
  - TECH Plus scenario
- ACT and TECH Plus scenarios:
  - Analyse the impact from R&D, Demonstration and Deployment measures
  - Incentives equivalent to 25 $/tonne CO_2 for low-carbon technologies implemented world-wide from 2030 and on
  - Individual scenarios differ in terms of assumptions for key technology areas

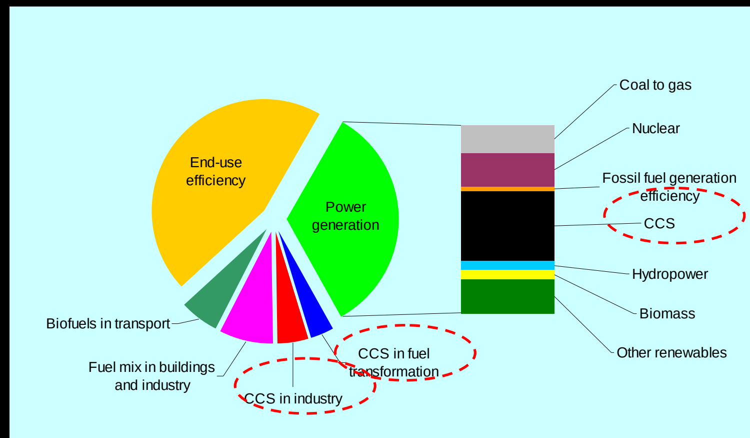
Technology Assumptions

Scenario	Renewables	Nuclear	CCS	H_2 fuel cells	Advanced biofuels	End-use efficiency
ACT Map	Relatively optimistic across all technology areas					2.0 % p.a. global improvement
ACT Low Renewables	Slower cost reductions					
ACT Low Nuclear		Lower public acceptance				
ACT No CCS			No CCS			
ACT Low Efficiency						1.7 % p.a. global improvement
TECH Plus	Stronger cost reductions	Stronger cost reductions & technology improvements		Break-through for FC	Stronger cost reductions & improved feedstock availability	

Global CO_2 Emissions 2003-2050 Baseline, ACT and TECH plus Scenarios



Emission Reduction by Technology Area ACT Map Scenario



Improved energy efficiency most important contributor to reduced emissions

Electricity Generation

CO_2 Capture and Storage a Key Option

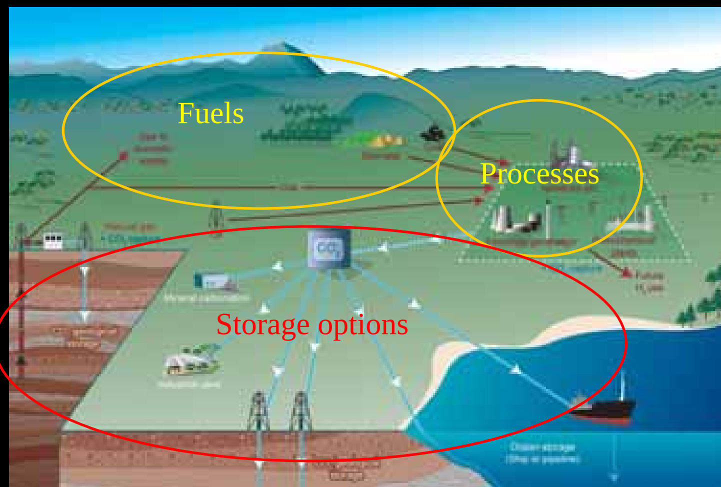
- CCS is crucial for the role coal can play in a CO_2 constrained world – without CCS coal-fired generation in 2050 drops below today's level
- By 2050 more than 5 000 TWh electricity globally can be produced by coal-plants equipped with CCS
- There is an urgent need for more R&D and for full-scale CCS demonstration plants
- Generation from renewables can quadruple by 2050
- Nuclear can gain a much more important role in countries where it is acceptable

Key Technologies

- A technology portfolio will be needed
- Improving energy efficiency is top priority
- CCS is key for a sustainable energy future
- Other important technologies:
  - Renewables, including biofuels
  - Nuclear
  - Efficient use of natural gas
  - In time and with effort, hydrogen and fuel cells

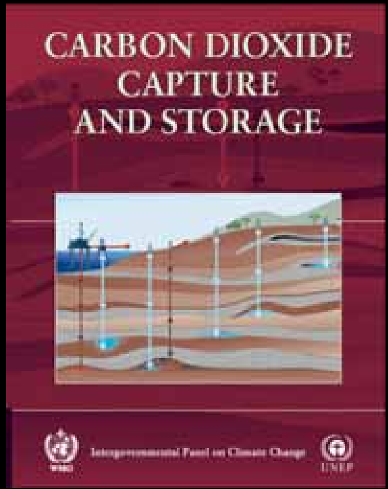
CO_2 Capture and Storage
or
CO_2 Capture and Sequestration
(CCS)

CO_2 Capture and Storage System



Source: IPCC SRCCS

The IPCC Special Report on Carbon Dioxide Capture and Storage



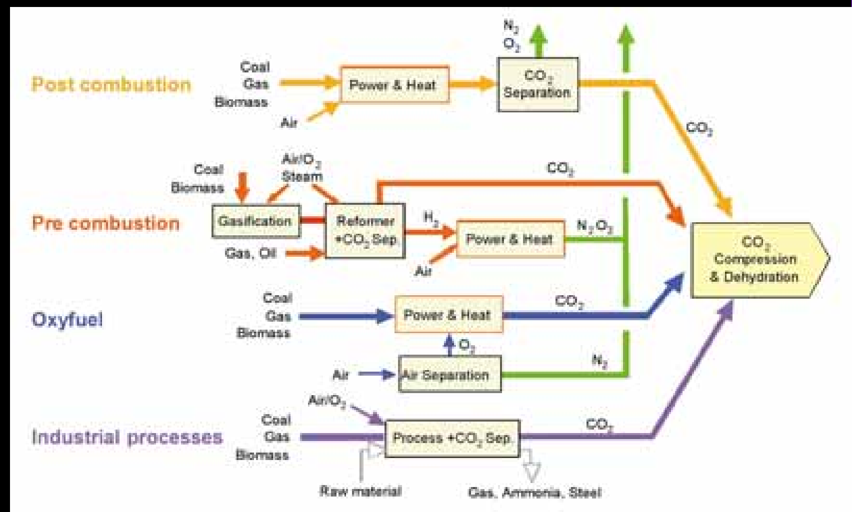
Structure of the Report

1. Introduction
2. Sources of CO2
3. Capture of CO2
4. Transport of CO2
5. Geological storage
6. Ocean storage
7. Mineral carbonation and industrial uses
8. Costs and economic potential
9. Emission inventories and accounting

How Could CCS Play a Role in Mitigating Climate Change?

- Part of a portfolio of mitigation options
- Reduce overall mitigation costs
- Increase flexibility in achieving greenhouse gas emission reductions
- Application in developing countries important
- Energy requirements point of attention

Capture of CO_2

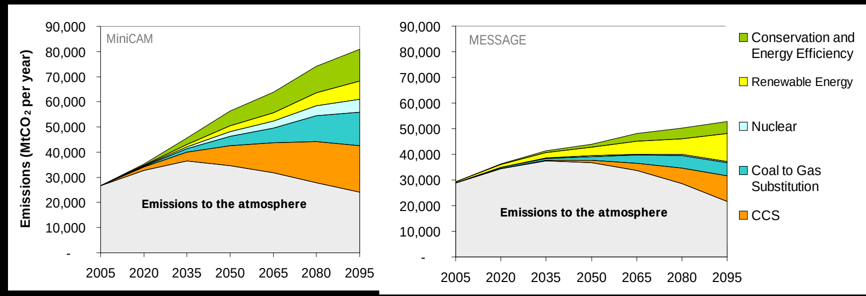


Source: IPCC SRCCS

CO_2 sources

- Large stationary point sources
- High CO_2 concentration in the waste, flue gas or by-product stream (purity)
- Pressure of CO_2 stream
- Distance from suitable storage sites

Economic Potential



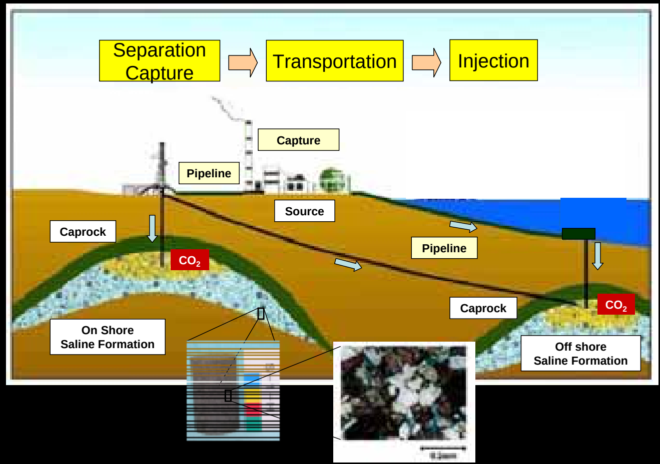
Economic Potential

- Cost reduction of climate change stabilisation: **30% or more**
- Most scenario studies: role of CCS **increases** over the course of the century
- Substantial application above CO2 price of **25-30 US$/$tCO_2$**
- **15 to 55%** of the cumulative mitigation effort worldwide until 2100, depending on the baseline scenario, stabilisation level (450 - 750 ppmv), cost assumptions
- **220 - 2,200 $GtCO_2$** cumulatively up to 2100

Storage Potential

- Geological storage: likely at least about **2,000 $GtCO_2$** in geological formations
    - *"Likely" is a probability between 66 and 90%.*
  - Oil/gas fields: 675 - 900 $GtCO_2$
  - Saline formations: 1000 - ~ 104 $GtCO_2$
  - Coal beds: 3 - 200 $GtCO_2$
- Ocean storage: on the order of thousands of $GtCO_2$, depending on environmental constraints

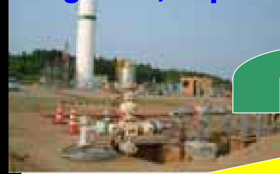
Schematic of Geological Storage
- Saline Formation -



- CO_2 will not be injected into a cavern!

Experimental Site and Core Sample

Nagaoka, Japan



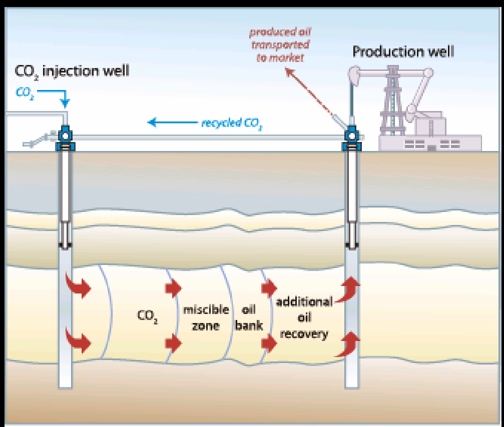
CO_2 was injected into this structure

Core Sample

Porosity (ϕ) = 24 ~ 25%

- Porosity describes how densely the material is packed, and defined by the proportion of the non-solid volume to the total volume
- Examples:
  - ϕ < 1% for solid granite;
  - ϕ > 50% for peat and clay

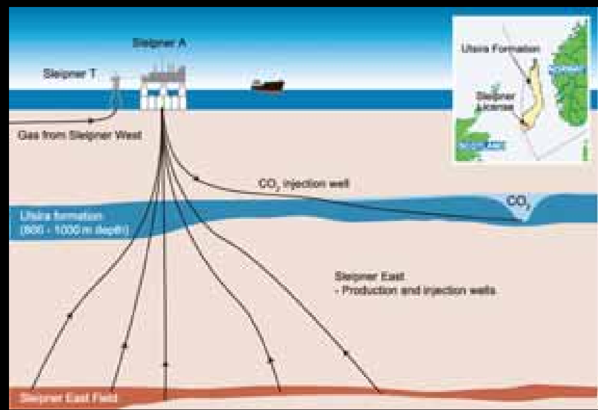
Injection of CO_2 for Enhanced Oil Recovery (EOR)



From IPCC SRCCS

- CO_2 produced with the fossil fuel combustion is captured and re-injected back into the formation.
- Recycling of produced CO_2 decreases the amount of CO_2 that must be purchased and avoids emissions to the atmosphere.

Sleipner CO_2 Storage Project.



CO_2 (about 9%) from Sleipner West Gas Field is separated, then injected into a large, deep, saline formation 800 m below the seabed.

Approximately 1 MtCO_2 is injected annually started in October 1996 and, by early 2005, more than 7 MtCO_2 had been injected at a rate of approximately 2700 t/day.

Weyburn CO_2-EOR Project.

Dakota Gasification.

The source of the CO_2 for the Weyburn CO_2-EOR Project is the Dakota Gasification Company facility, located approximately 325 km south of Weyburn, in Beulah, North Dakota, USA. At the plant, coal is gasified to make synthetic gas (methane), with a relatively pure stream of CO_2 as a by-product. This CO_2 stream is compressed and piped to Weyburn in Saskatchewan, Canada, for use in the field.

The Weyburn CO_2-EOR Project is designed to take CO_2 from the pipeline for about 15 years, with delivered volumes dropping from 5000 to about 3000 t/day over the life of the project.

In Salah Gas Project, Algeria.

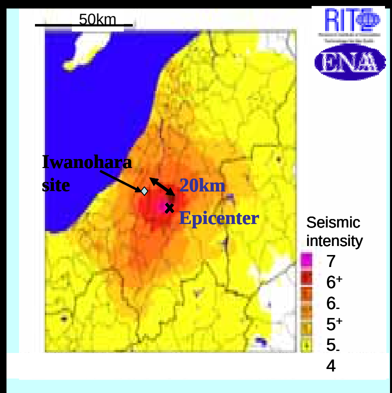
The Krechba Field at In Salah produces natural gas containing up to 10% CO_2 from several geological reservoirs and delivers it to markets in Europe, after processing and stripping the CO_2 to meet commercial specifications.

The project involves re-injecting the CO_2 up to 1.2 $MtCO_2$/yr into a sandstone reservoir at a depth of 1800 m. Injection started in April 2004 and it is estimated that 17 $MtCO_2$ will be stored over the life of the project.

Big Earthquake and Nagaoka Project

Niigata Chuetsu Earthquake

- Main shock: 23 Oct 2004
- M6.8 at 10km depth
- Max. Seismic intensity (J): 7
  - Injection site: ~6
- Distance between the epicenter and the injection site is about 20km.



(GSJ, 2004 http://www.gsj.jp/jishin/chuetsu_1023/)

Injection was automatically stopped at the main shock.

Response to Big Earthquake in Nagaoka Injection Project

- Injection was automatically stopped at the main shock.
- Safety inspection made:
  - Surface Inspection
  - Press & Temp
  - Geophysical Logging
  - Acoustic Borehole Televiewer
  - Cross Well Seismic Tomography
- Injection was carefully resumed after confirming safety (6 Dec 2004)
  - Injection rate: 40t-CO_2/day

No damage to the project

Relevance of CO_2 Capture and Sequestration

- CO_2 capture and sequestration might have a important role in deep reduction of GHG emissions allowing **continuous use of fossil fuels** for the time being.
  - Technological "surprise" needed to not to rely on sequestration technologies
- However, there still remains the issues apart from their associated risk and environmental impact…

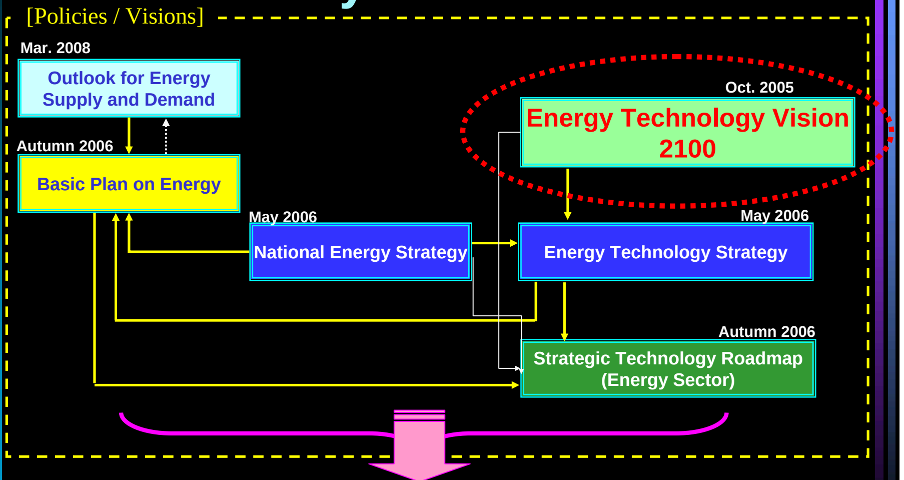
Energy Technology Vision 2100

Agency for Natural Resources and Energy
Ministry of Economy, Trade and Industry

- An approach to LCS from Energy Policy
- Purpose
  - To establish strategic energy R&D plan by
    - identifying technologies and developing technology portfolio to prepare for **resource and environmental constraints**
    - considering optimum R&D resource allocation in METI
- Timeframe:
  - Vision and Technology roadmap: - 2100

⇒http://www.iae.or.jp/2100.html

Overview of Energy Related Policy & Measures



[Policy Planning, Resource Allocation / Policy Implementation / Policy Evaluation]

Why to consider Ultra Long-term?

- Timeframe for future risk or constraint
  - Resource (10s ~ 100yrs?)
  - Environment (100 ~ 1000 yrs)
- Long lead time for energy sector in general
  - Research and development to commercialization
  - Market diffusion
  - Stock turnover time (10s yrs)
  - Infrastructure development

Scope of Work

- Timeframe
  - Vision: - 2100
  - Technology roadmap: -2100
    - Benchmarking years: 2030 and 2050
- Approach
  - To introduce backcasting methodology
  - To compile experts' view
  - To confirm long-term goal using both top-down and bottom-up scenario analysis

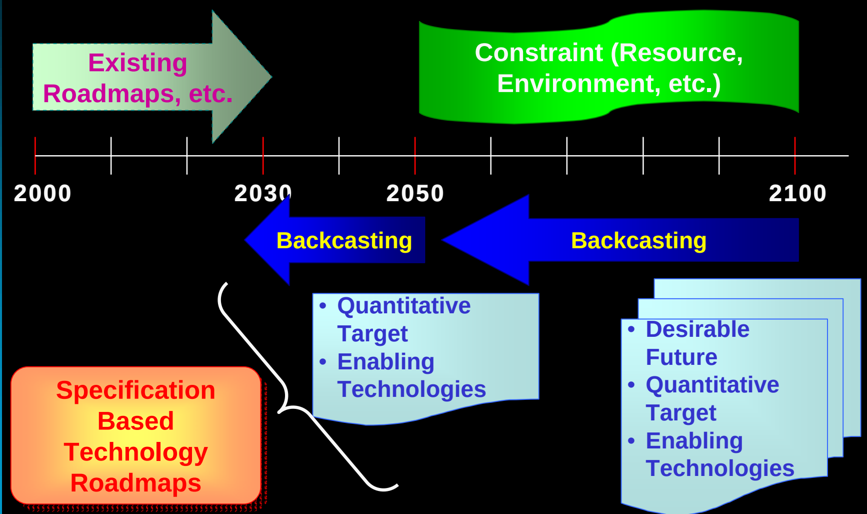
Methodology - Backcasting

Exploratory (opportunity-oriented):
- *what futures are likely to happen? ⇒ Forecasting*
  - starts from today's assured basis of knowledge and is oriented towards the future

Normative (goal-oriented):
- *how desirable futures might be attained? ⇒ Backcasting*
  - first assesses future goals, needs, desires, missions, etc. and works backward to the present

Clement K. Wang &Paul D. Guild

Framework of Backcasting



Premises

- Resource and environmental constraints do not degrade utility but enrich the human race (improve utility)
- To develop the technology portfolio for the future in order to realize it through development and use of the technologies.
- Not to set preference to specific technology such as hydrogen, distributed system, biomass, etc.

Assumptions

Developing a Challenging Technology Portfolio

- The effect of modal shift or changing of lifestyle were not expected.
- Although the assumption of the future resource and environmental constraints includes high uncertainties, rigorous constraints were assumed as "preparations".
- To set excessive conditions about energy structure to identify the most severe technological specifications.
  - As a result, if all of them are achieved, the constraints are excessively achieved.

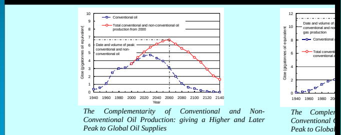
Definition of Desirable Futures

- Society where the economy grows and the quality of life improves
- Society where necessary energy can be quantitatively and stably secured
- Society where the global environment is maintained
- Society where technological innovation and utilization of advanced technology are promoted through international cooperation
- Society with flexible choices depend on national and regional characteristics

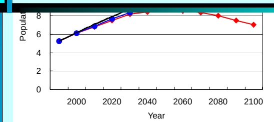
Assumptions towards 2100

Resource Constraints

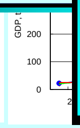
- Although assumption of the future resource constraints includes high de... uncertainties, the following constraints were assumed a...
  - Oil production peak at 2050
  - Gas production peak at 2100



Example of estimates for oil and natural gas



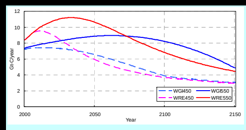
Forecast of world population



Forecast of world GDP

Environmental Constraints

- CO_2 emission intensity (CO_2/GDP) should be improved to stabilize atmospheric CO_2 concentration
  - 1/3 in 2050
  - Less than 1/10 in 2100 (further improvement after 2100)



Global carbon dioxide emission scenario

Forecast of energy consumption

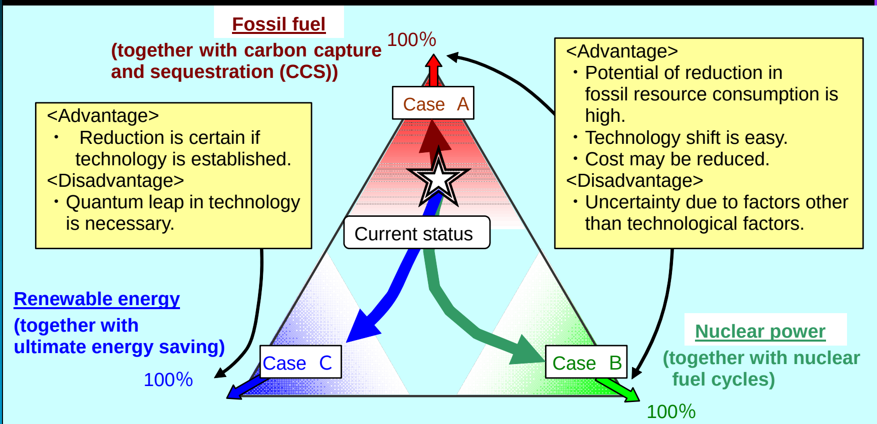
To Overcome Constraints ---

- Sector specific consideration
  - Residential/Commercial
  - Transport
  - Industry
  - Transformation (Elec. & H_2 production)
- Definition of goal in terms of sector or sub-sector specific CO_2 emission intensity.
- Identification of necessary technologies and their targets

Demand sectors and their typical CO_2 emission intensity

Industry	:	t-C/production volume	=	t-C/MJ	×	MJ/production volume
Commercial	:	t-C/floor space	=	t-C/MJ	×	MJ/floor space
Residential	:	t-C/household	=	t-C/MJ	×	MJ/household
Transport	:	t-C/distance	=	t-C/MJ	×	MJ/distance
(*Transformation sector*: t-C/MJ)				Conversion efficiency		Single unit and equipment efficiency

Three Extreme Cases and Possible Pathway to Achieve the Goal



- Cases A & C assume least dependency on energy saving

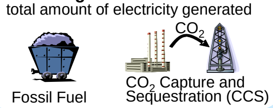
Sketch of Technology Spec. 2100
Extreme Case-A (Fossil + CCS)

- Case A assumes a situation where we cannot heavily rely on energy saving.
- The increase of the share of electricity and hydrogen is considered.

** Values are relative to those in 2000, otherwise stated*

[Target in the Transformation Sector]

(1) Production of Electricity and Hydrogen
About eight times* the current total amount of electricity generated



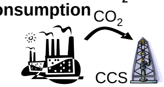
Supplying with coal fired power plants with CCS

Total amount of CO_2 captured and sequestered in transformation and industry sector becomes approximately 4.0 billion t-CO_2/year.
*** Additional energy required for the CCS process is not included.*

Electricity or Hydrogen

[Target in the Industry Sector]

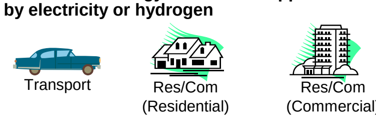
(1) CCS it applied to over 80% of CO_2 emissions from fossil fuel consumption



(2) Over 65% of the energy demand is supplied by electricity or hydrogen from the transformation sector

[Target in the Transport and Res/Com Sectors]

(1)100% of the energy demand is supplied by electricity or hydrogen



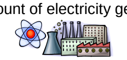
Sketch of Technology Spec. 2100
Extreme Case-B (Nuclear)

- Case B assumes a situation where we cannot heavily rely on energy saving.
- The increase of the share of electricity and hydrogen is considered.

** Values are relative to those in 2000, otherwise stated*

[Target in the Transformation Sector]

(1) Production of Electricity and Hydrogen
About eight times* the current total amount of electricity generated



Supplying by nuclear power

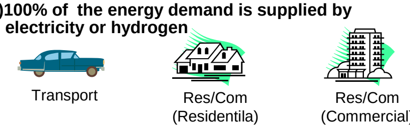
Electricity or Hydrogen

[Target in the Industry Sector]

(1) All the energy demand is supplied with electricity or hydrogen with the exception of feedstocks and reductants

[Target in the Transport and Res/Com Sectors]

(1)100% of the energy demand is supplied by electricity or hydrogen



Sketch of Technology Spec. 2100
Extreme Case-C (Renewable + Ultimate Energy Saving)

** Values are relative to those in 2000, otherwise stated*
*** Per unit utility*

[Target in the Transformation Sector]

(1) Production of Electricity and Hydrogen
About twice* of the current total electricity generated

Supplying by renewable energies

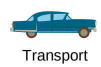
Electricity, Hydrogen or Biomass

[Target in the Industry Sector]

Energy demand to be reduced by 70%**
(1) 50% of the production energy intensity is reduced.
(2) Making the rate of material energy regeneration to 80%
(3) Improvement of functions such as strength by factor 4

[Target in the Transport Sector]

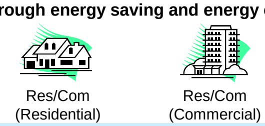
(1) 70% of the energy demand is reduced through energy saving and fuel switching.**



For automobile, 80% is reduced

[Target in the Res/Com Sector]

(1) Energy demand to be reduced by 80% through energy saving and energy creation.



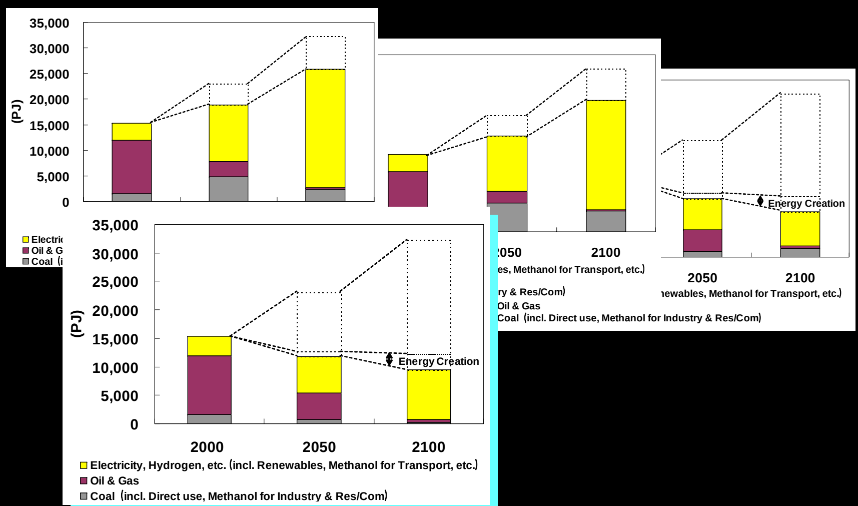
Development of Technology Roadmaps

- Target sectors:
  - Residential and Commercial
  - Transportation
  - Industry
  - Transformation (Energy supply)
- Summary roadmap
  - Target specifications and milestones
  - Typical technologies
- Detailed roadmaps
  - Technology breakdown for sub-sectors

Important Cross-Boundary Technologies

- Once a cross-boundary technology is established, it can work effectively in a wide range of applications. Here, the following technologies are identified:
  - Energy-saving technologies
  - Energy storage technologies
  - Power electronics technologies
  - Gasification technologies
  - Energy management technologies

Verification by Scenario Analysis using Energy Models



Possible Solution with the Combination of Three Cases (2/2)

- ... combination of these cases can vary according to situations in the future. It is **important to prepare technologies** through R&D for social and economic changes at various occasions in the future.
- As a result, we can acquire an optimal and robust energy system structure...
- Also, if we prepare for the three extreme cases ..., their synergy effect enables the reduction of fossil resources consumption and CO_2 emissions...

Implications on Specific Technology Areas

- Hydrogen
  - Important as an energy storage medium, especially when energy supply dominated by renewable resources.
- Biomass
  - Contribution to transformation sector (power generation and hydrogen production) is relatively small.
  - Mainly used in industrial sector as a carbon free resource containing carbon.
- CO_2 Capture and Sequestration (CCS)
  - Important as a short or mid-term option (fossil power plants, industries, hydrogen production) by increasing the flexibility of energy supply and demand structure with moderate cost.

Possible Solution with the Combination of Three Cases (1/2)

- … capacity for geological sequestration is considered to have limitations. We have to consider ocean sequestration to satisfy the required capacity …
- Case A (fossil + CCS) cannot be a long-term solution due to the limitation of fossil resources. Therefore, the combination of case C (renewable + energy-saving) and case B (nuclear) is desirable … on a long-term basis, by avoiding rapid climate change by CCS as required on a mid-term basis.

Possible ETV 2100 Scenario

- Combination of 3 Cases -

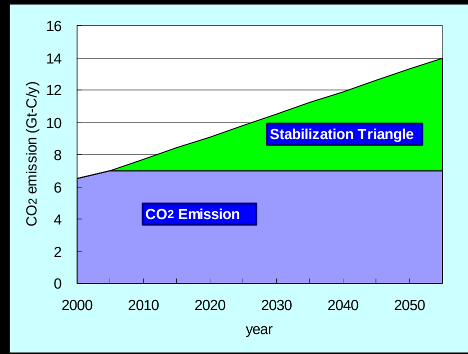
- One of the reasonable solutions for sustainable society is a combination of the case A (in short or middle term, reduce atmospheric CO_2 by CCS), C (in long-term, utilize renewables to the maximum beside ultimate energy-saving) and B (stable operation of nuclear power plants).
- However, appropriate combination of each case may change according to the future situation, so it is important to judge R&D priority based on the future social and economical situation or status of technology progress.

Implications on Future Scenario

- Energy efficiency is the key!
- Case-A “Fossil + CCS” would contribute to deep reduction of CO_2 and hydrogen economy but might not be a truly sustainable option from the viewpoint of resource depletion.
- Nuclear and CCS, especially as a mid-term option, would increase the flexibility of energy supply and demand structure with moderate cost.

Simple Consideration on Deep Reduction Strategy

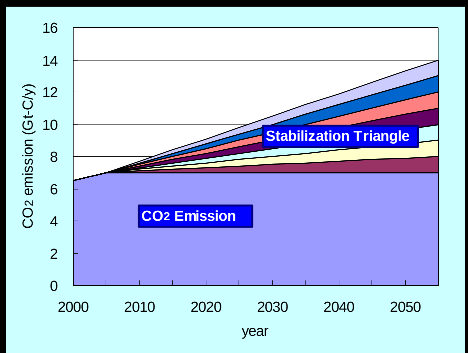
Stabilization Triangle



- Restrict attention to 50 years
- Use only straight lines! Take the goal to be flat emissions and the baseline to be doubling linearly in 50 years.

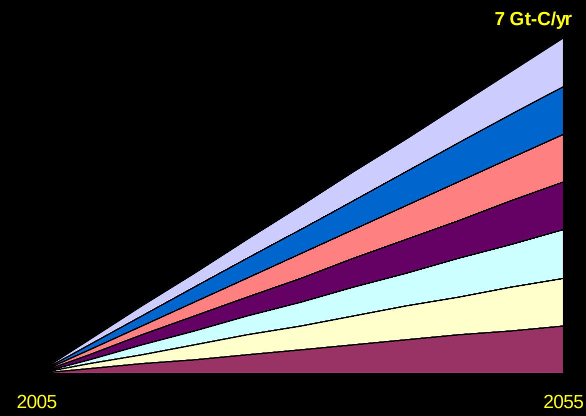
Robert H. Socolow (Princeton Univ.)

Stabilization Wedges



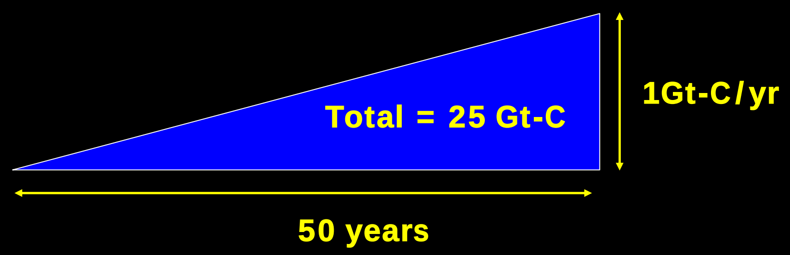
- To introduce a new physical unit, the wedge, as a unit for describing 50-year strategies.
- To explain the strategy is, roughly, a seven-wedge problem.

Seven Wedges to Fill the Triangle

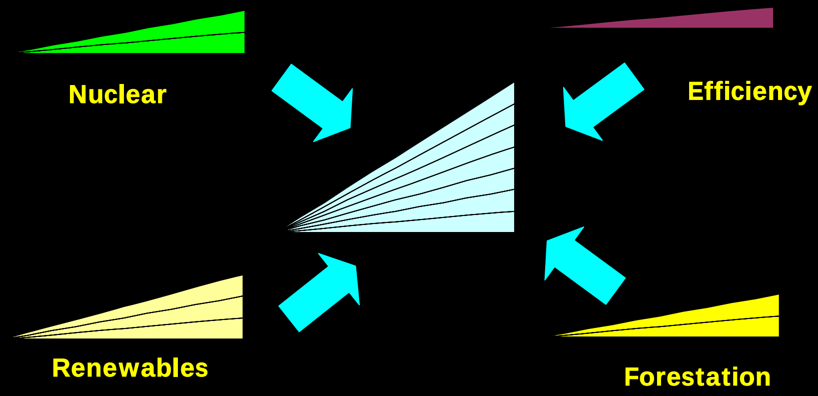


What is a "Wedge"?

- A "wedge" is an activity reducing the rate of carbon build-up in the atmosphere that grows in 50 years from zero to 1.0 Gt-C/yr.



Filling the Stabilization Triangle



- Many candidate wedges are available

Example of a Wedge - Nuclear -

- Displacement of coal fired power plant
  - CO_2 emission from 1GW coal fired plant:
    - Specific emission: 0.887 kg/kWh
    - Availability: 80%

      $1\times10^6\times24\times365\times0.8\times0.887=6.22\times10^6$ (t-CO_2/yr)

      $=6.22\times10^6\times12/44 = 1.70\times10^6$ (t-C/yr)
  - To reduce 1Gt-C:
    - 1×10^9 (t-C/yr) / 1.70×10^6 (t-C/yr) = 590
- Effort needed to 1 wedge:
  - Add 590 GW that displaces coal (~1.7×current capacity)

Reporting Subject

- Develop a wedge with explanation of
  - Estimation procedures
  - Comparison of current market scale, etc.
- Candidate technologies include:
  - CO_2 capture and sequestration,
  - Renewables (Solar, Wind, etc.),
  - Efficiency improvement (Vehicles, etc.),
  - Shifting to low carbon fuel (Natural gas),
  - ......