Global Environmental Policy

December 08, 2008:
- Overview
- Challenges and strategies towards Deep GHG Reduction

December 15, 2008:
- Reporting and Discussion

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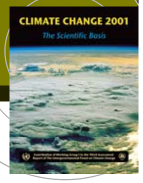
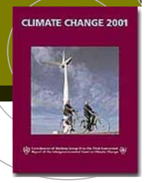
Recent Findings on Climate Change

IPCC 3rd Assessment Report (TAR) Suggestions
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) Suggestions
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

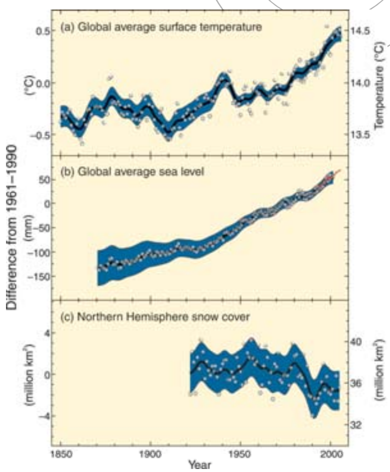
- **Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations.**
  - **This is an advance since the TAR's conclusion that "most of the observed warming over the last 50 years is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

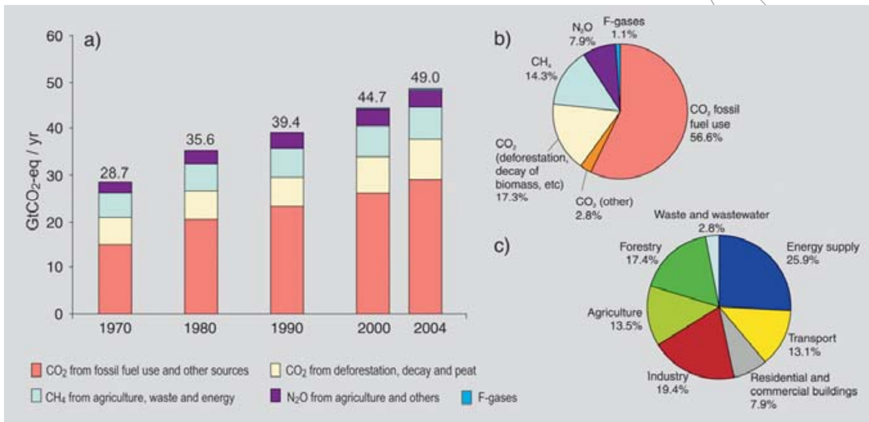
Observations of Climate Change

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

- **GRAPH: Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data; and (c) Northern Hemisphere snow cover for March-April.**
  - All differences are relative to corresponding averages for the period 1961-1990.
  - Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c).

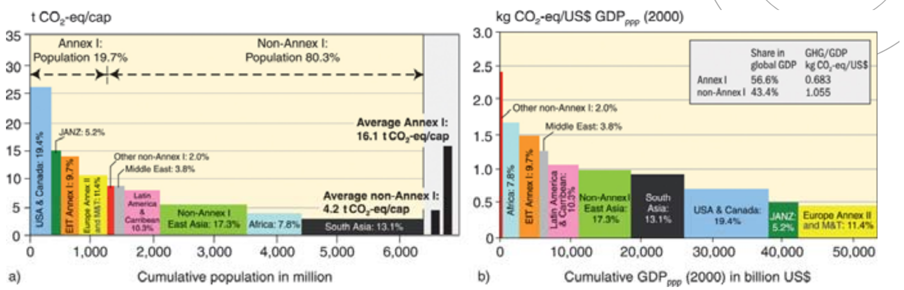


Global Anthropogenic GHG Emissions



- **Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004**

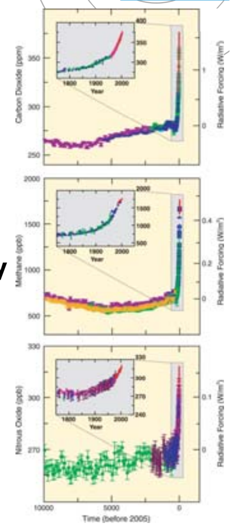
Regional Distribution of GHG Emissions by Population and by GDP



- **Differences in per capita income, per capita emissions and energy intensity among countries remain significant. In 2004, UNFCCC Annex I countries held a 20% share in world population, produced 57% of the world's Gross Domestic Product based on Purchasing Power Parity (GDP_{PPP}) and accounted for 46% of global GHG emissions**

Changes in Atmospheric GHG Concentrations

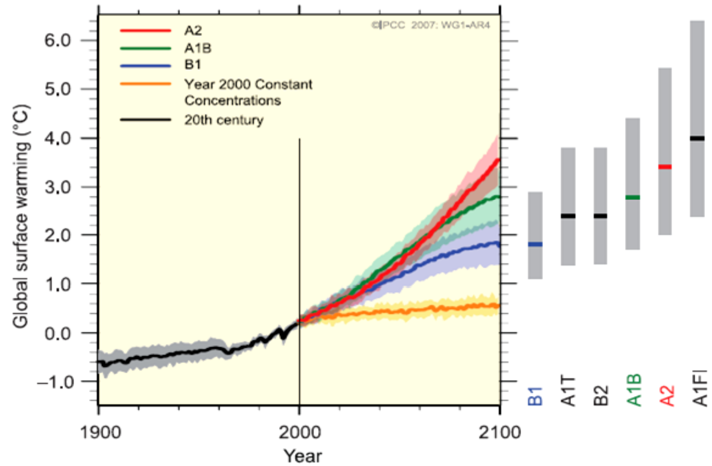
- **Global atmospheric concentrations of CO_2, CH_4 and N_2O have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years.**
- **The atmospheric concentrations of CO_2 and CH_4 in 2005 exceed by far the natural range over the last 650,000 years.**
- **Global increases in CO_2 concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution.**
- **It is *very likely* that the observed increase in CH_4 concentration is predominantly due to agriculture and fossil fuel use.**
- **The increase in N_2O concentration is primarily due to agriculture.**



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.**

Ranges for Predicted Warming



NOTE: Both past and future anthropogenic carbon dioxide emissions will continue to contribute to warming and sea level rise for more than a millennium, due to the time scales required for removal of this gas from the atmosphere and to the slow response of the oceans.

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

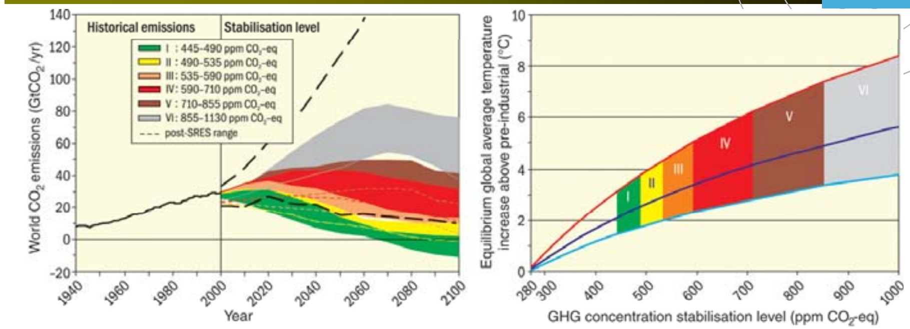
- **Increasing atmospheric carbon dioxide concentrations lead to increasing acidification of the ocean. Projections based on SRES scenarios give reductions in average global surface ocean pH of between 0.14 and 0.35 units over the 21st century, adding to the present decrease of 0.1 units since pre-industrial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

IPCC 4th Assessment Report (AR4)
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

CO_2 Emissions and Equilibrium Temperature Increases for a Range of Stabilisation Levels



- **In order to stabilise the concentration of GHGs in the atmosphere, emissions would need to peak and decline thereafter.**
- **The lower the stabilisation level, the more quickly this peak and decline would need to occur.**
- **Mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels**

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	...	...

Costs of Mitigation

Stabilisation levels (ppm CO_2-eq)	Median GDP reduction[a] (%)		Range of GDP reduction[b] (%)		Reduction of average annual GDP growth rates (percentage points)[c,e]	
	2030	2050	2030	2050	2030	2050
445 – 535[d]	Not available		<3	<5.5	< 0.12	< 0.12
535 – 590	0.6	1.3	0.2 to 2.5	slightly negative to 4	< 0.1	< 0.1
590 – 710	0.2	0.5	-0.6 to 1.2	-1 to 2	< 0.06	< 0.05

Notes: Values given in this table correspond to the full literature across all baselines and mitigation scenarios that provide GDP numbers.
a) Global GDP based on market exchange rates.
b) The 10th and 90th percentile range of the analysed data are given where applicable. Negative values indicate GDP gain. The first row (445-535ppm CO2-eq) gives the upper bound estimate of the literature only.
c) The calculation of the reduction of the annual growth rate is based on the average reduction during the assessed period that would result in the indicated GDP decrease by 2030 and 2050 respectively.
d) The number of studies is relatively small and they generally use low baselines. High emissions baselines generally lead to higher costs.
e) The values correspond to the highest estimate for GDP reduction shown in column three.

- **The macro-economic costs of mitigation generally rise with the stringency of the stabilisation target and are relatively higher when derived from baseline scenarios characterised by high emission levels.**
- **There is *high agreement and medium evidence that in 2050 global* average macro-economic costs for multi-gas mitigation towards stabilisation between 710 and 445ppm CO_2-eq are between a 1% gain to a 5.5% decrease of global GDP**

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);

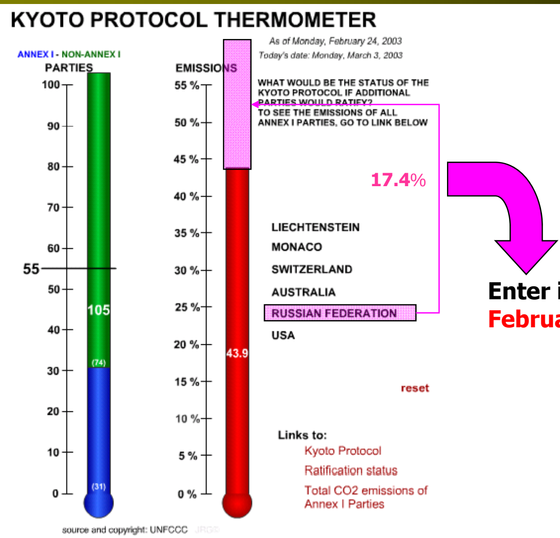
Kyoto Mechanisms

- **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.**

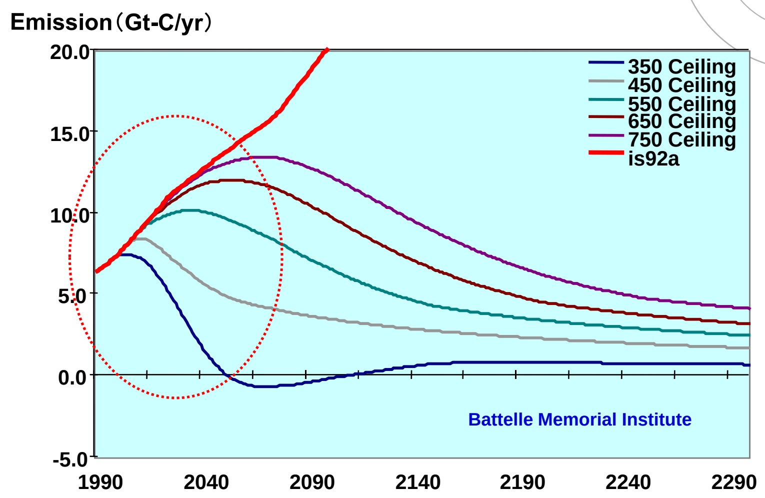
Kyoto Protocol Ratification Status



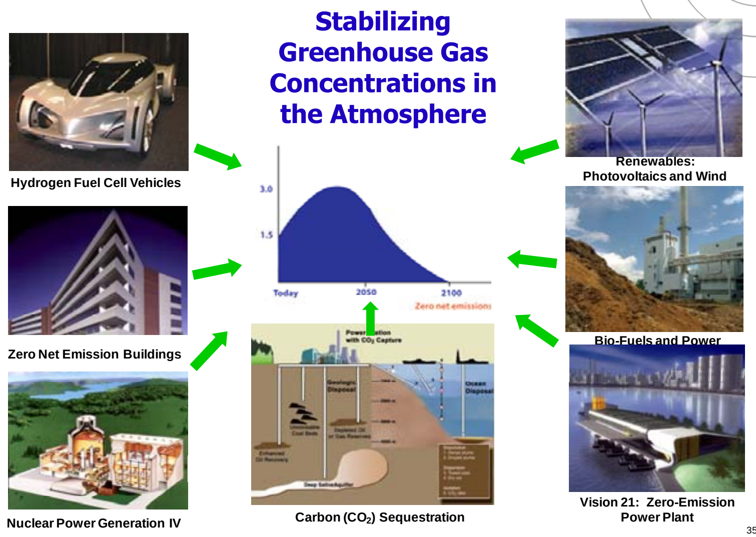
Enter into forth on 16 February 2005

Towards a Deep Reduction of Greenhouse Gas

CO_2 Stabilization Profiles
- Atmospheric Emissions -



The Technology Challenge

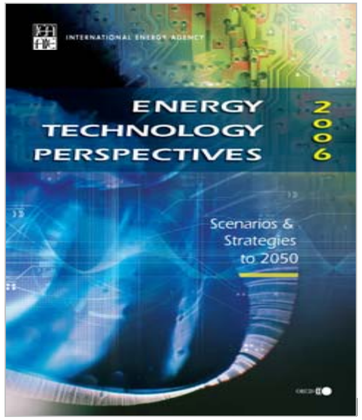


Technological Options for Deep Reduction of GHG Emissions

- 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

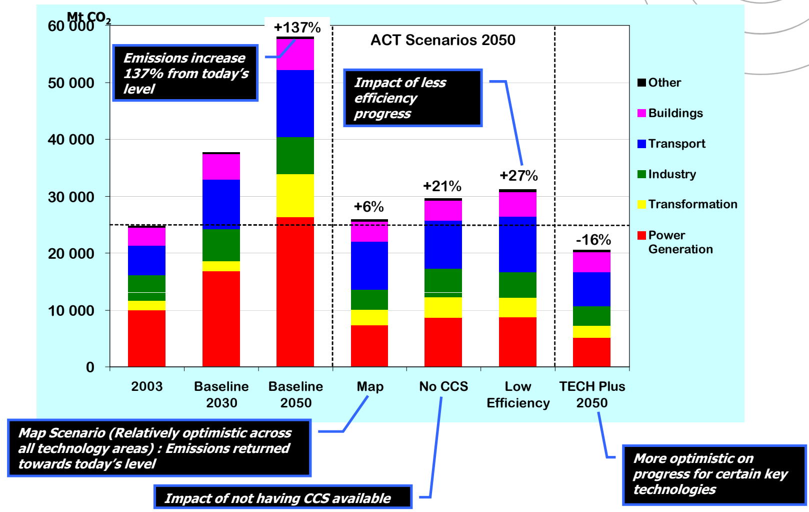
Scenario Analysis

- 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

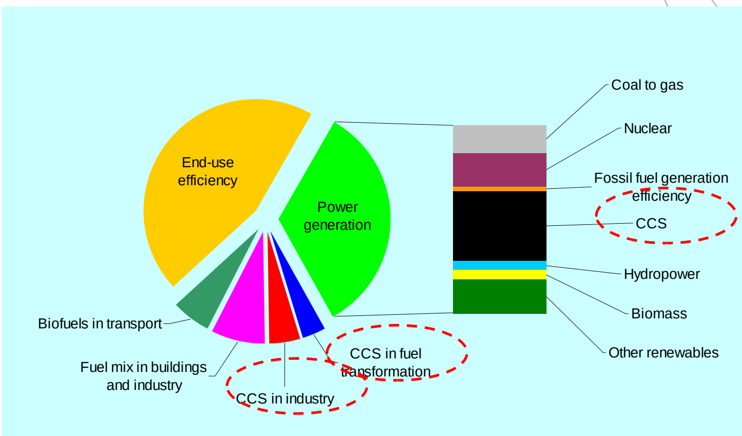
Technology Assumptions

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

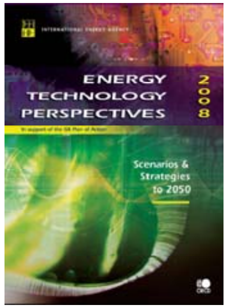


Improved energy efficiency most important contributor to reduced emissions

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**

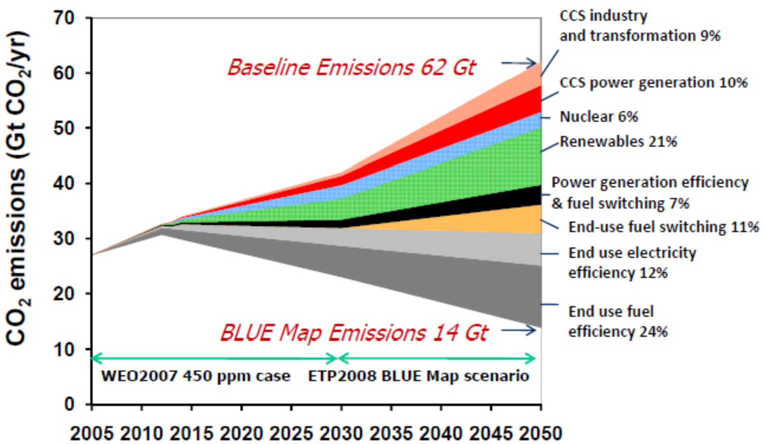
IEA
Energy Technology Perspectives 2008



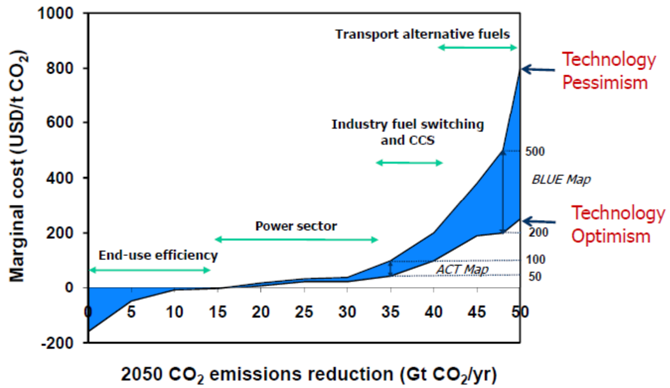
Scenarios in ETP2008

- **ACT Scenarios**
  - Energy CO_2 emissions in 2050 back to the level of 2005
  - Revision of ACT as published in ETP2006
    - Options with a marginal cost up to $50/t$CO_2$ – worldwide (+$20/bbl)
    - Cost estimate has doubled from ETP2006
  - This implies a significantly adjusted energy system
- **BLUE Scenario**
  - -50% energy related CO_2 in 2050, compared to 2005
  - This could be consistent with 450 ppm (depending on post-2050 emissions)
  - Options with a marginal cost of up to $200/t$CO_2$ needed (+$80/bbl)
    - Significantly higher cost with less optimistic assumptions
  - Blue is uncertain, therefore a number of cases needed
  - Blue is only possible if the whole world participates fully
  - This implies a completely different energy system

ETP2008
CO_2 Emission Reduction Scenario



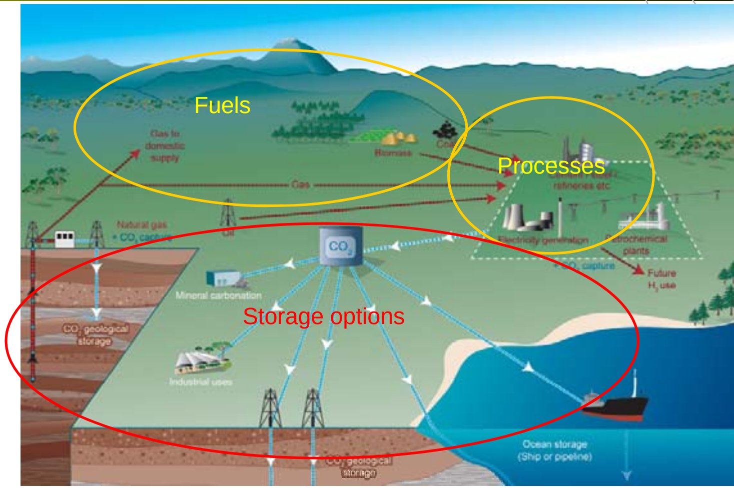
ETP2008
Cost of Emissions Reductions



- To bring emissions back to current levels by 2050 options with a cost up to USD 50/t are needed.
- Reducing emissions by 50% would require options with a cost up to USD 200/t (+80 USD/bbl oil) , possibly even up to USD 500/t CO_2

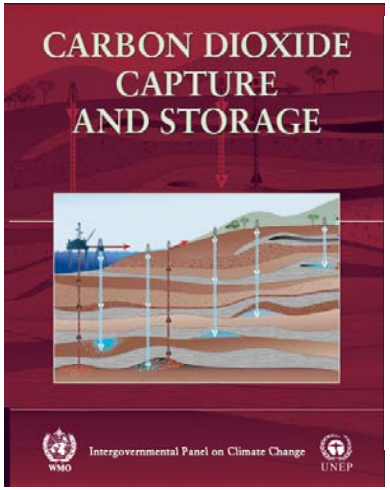
CO_2 Capture and Storage
or
CO_2 Capture and <u>Sequestration</u>
(CCS)

CO_2 Capture and Storage System



Source: IPCC SRCCS

The IPCC Special Report on Carbon Dioxide Capture and Storage



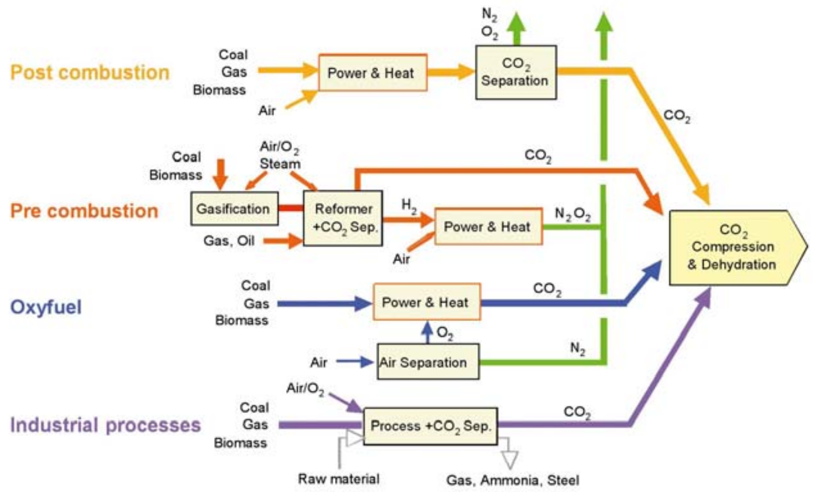
Structure of the Report

1. **Introduction**
2. **Sources of CO_2**
3. **Capture of CO_2**
4. **Transport of CO_2**
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

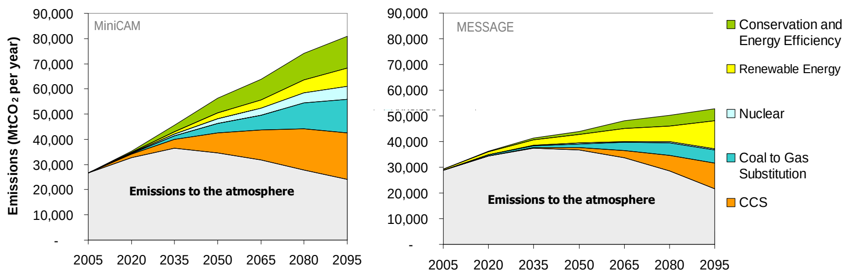


Source: IPCC SRCCS

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



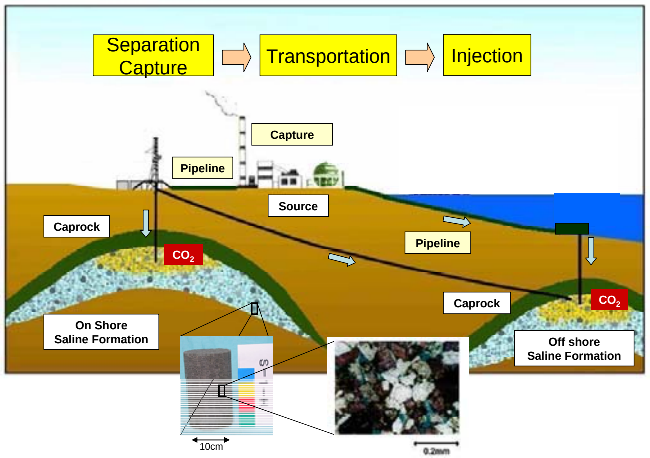
Economic Potential

- 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$/t$CO_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

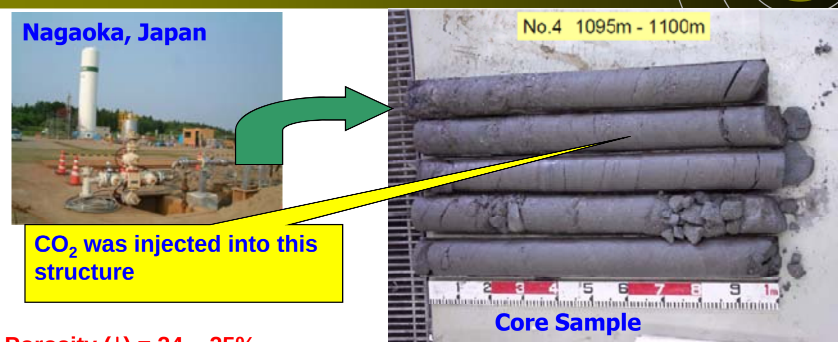
- Geological storage: likely at least about **2,000 GtCO_2** in geological formations
  - *"Likely" is a probability between 66 and 90%.*
  - Oil/gas fields: 675 - 900 GtCO_2
  - Saline formations: 1000 - ~ 104 GtCO_2
  - Coal beds: 3 - 200 GtCO_2
- Ocean storage: on the order of thousands of GtCO_2,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

Schematic of Geological Storage - Saline Formation -



- **CO_2 will not be injected into a cavern!**

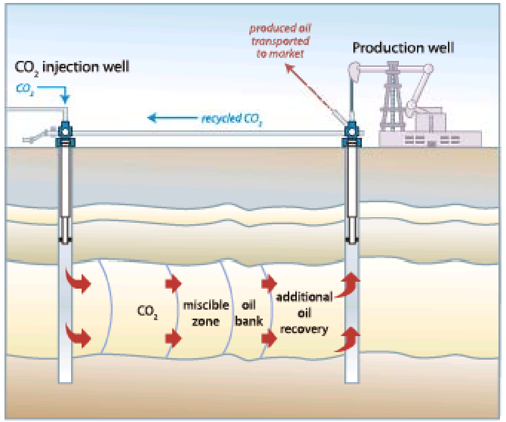
Experimental Site and Core Sample



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

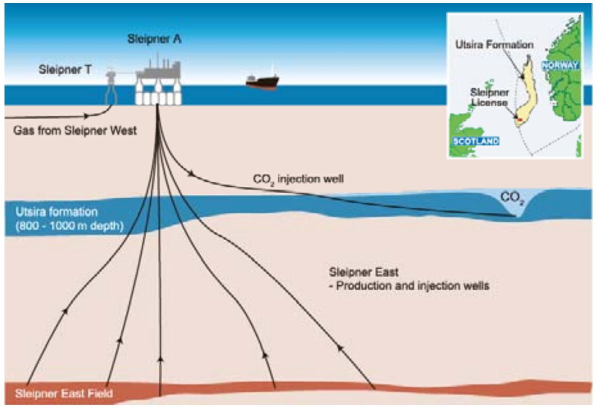
Injection of CO_2 for Enhanced Oil Recovery (EOR)



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.

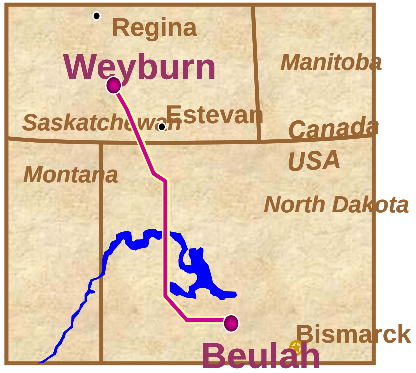
Sleipner CO_2 Storage Project.



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.

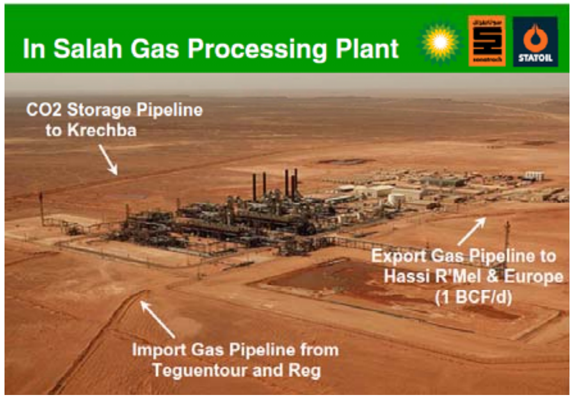


Dakota Gasification.

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.



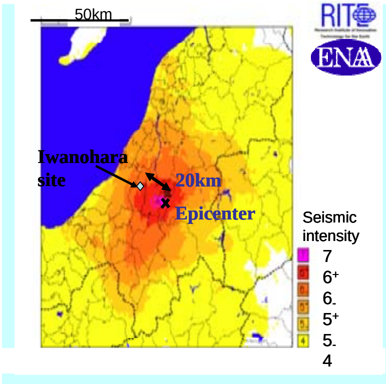
The Krechba Field at In Salah produces natural gas containing up to 10% CO_2 from several geological reservoirs and delivers it to markets in Europe, after processing and stripping the CO_2 to meet commercial specifications.

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

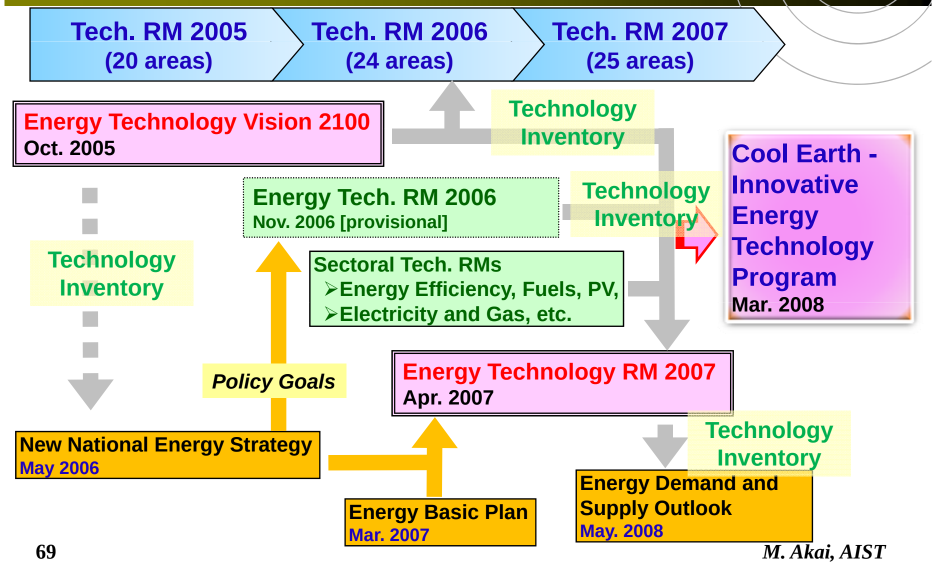
No damage to the project

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…**

Recent Development of Energy Strategy in Japan (METI)

Recent Development in Energy Policy
Energy Technology Roadmapping



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

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):

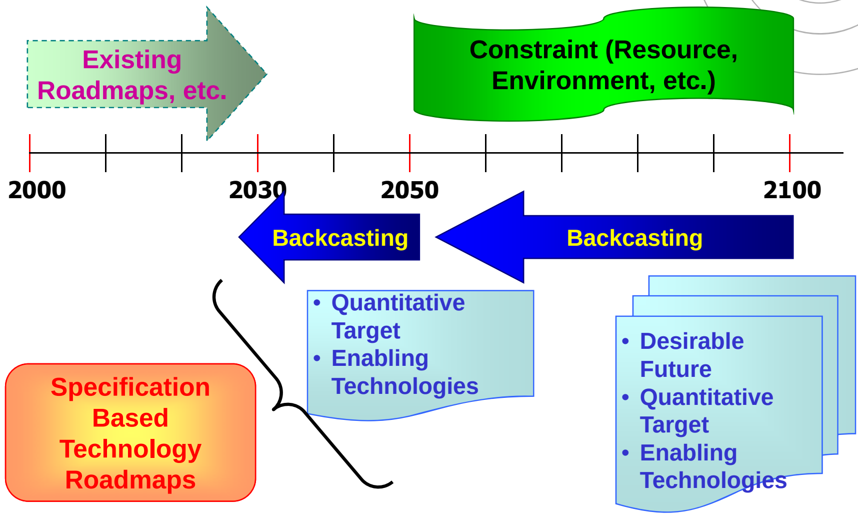
- ***what futures are likely to happen?*** ⇒ ***Forecasting***
  - **starts from today's assured basis of knowledge and is oriented towards the future**

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.**

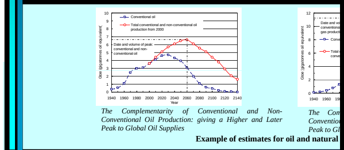
Definition of Desirable Futures

- 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

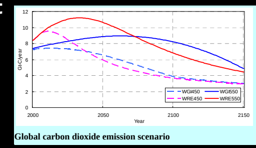
Resource Constraints

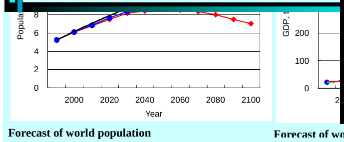
- Although assumption of the future resource constraints includes high degree of uncertainties, the following constraints were assumed
  - Oil production peak at 2050
  - Gas production peak at 2100



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)





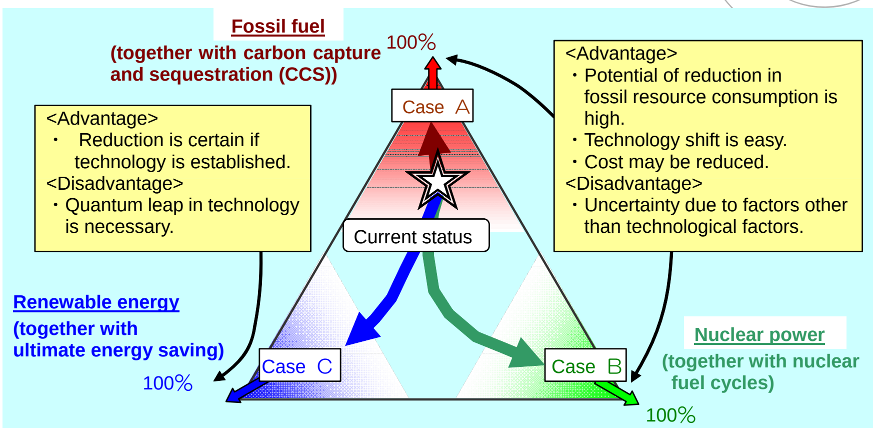
To Overcome Constraints ---

- **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

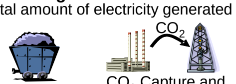
Sketch of Technology Spec. 2100
Extreme Case-A (Fossil + CCS)

- *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



Fossil Fuel

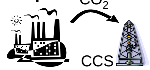
CO_2 Capture and Sequestration (CCS)

Supplying with coal fired power plants with CCS

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

Transport — Res/Com (Residential) — Res/Com (Commercial)

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.*

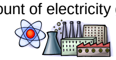
Sketch of Technology Spec. 2100
Extreme Case-B (Nuclear)

- *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



Nuclear Power

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

Transport — Res/Com (Residentila) — Res/Com (Commercial)

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

Renewable Energies

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]

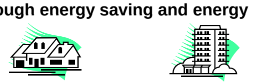
(1) 70% of the energy demand is reduced through energy saving and fuel switching.**

Transport

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.



Res/Com (Residential) — Res/Com (Commercial)

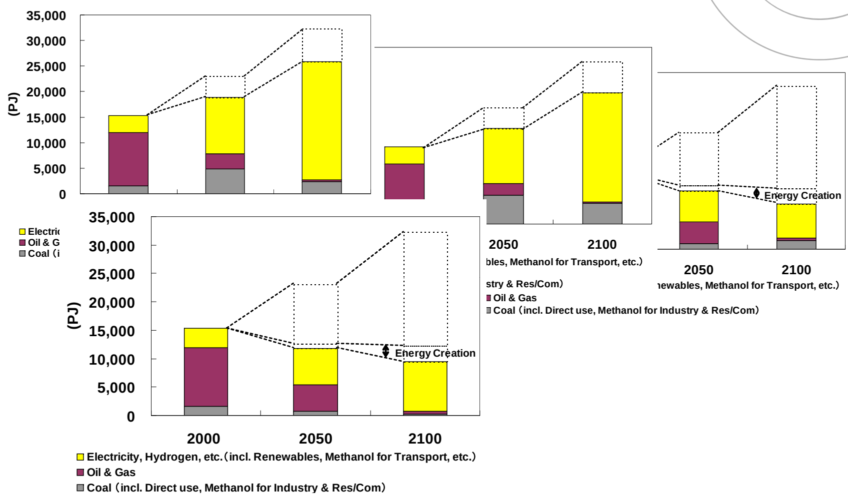
Development of Technology Roadmaps

- **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 -

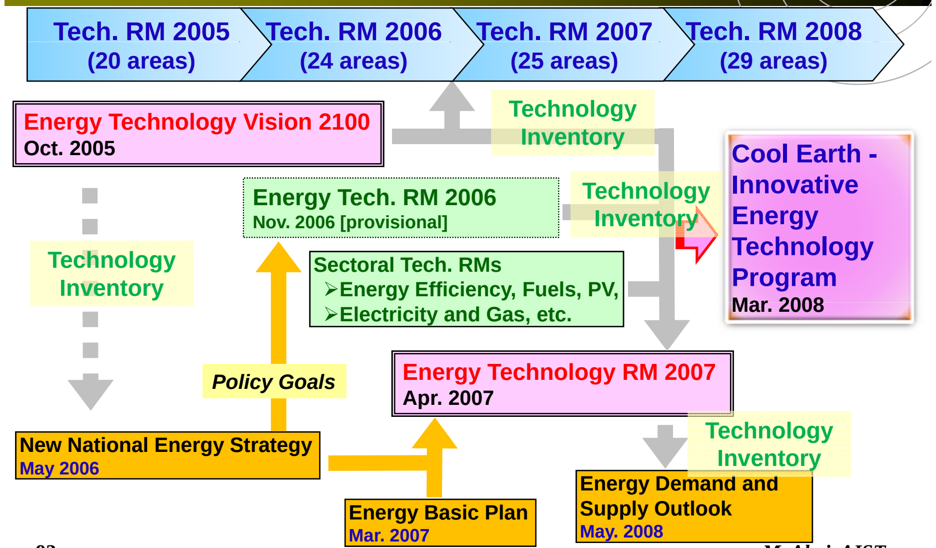
- One of the reasonable solutions for sustainable society is a combination of the case A (in short or middle term, reduce atmospheric CO_2 by CCS), C (in long-term, utilize renewables to the maximum beside ultimate energy-saving) and B (stable operation of nuclear power plants).
- However, appropriate 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.

Cool Earth - Innovative Energy Technology Program

Recent Development in Energy Policy
Energy Technology Roadmapping

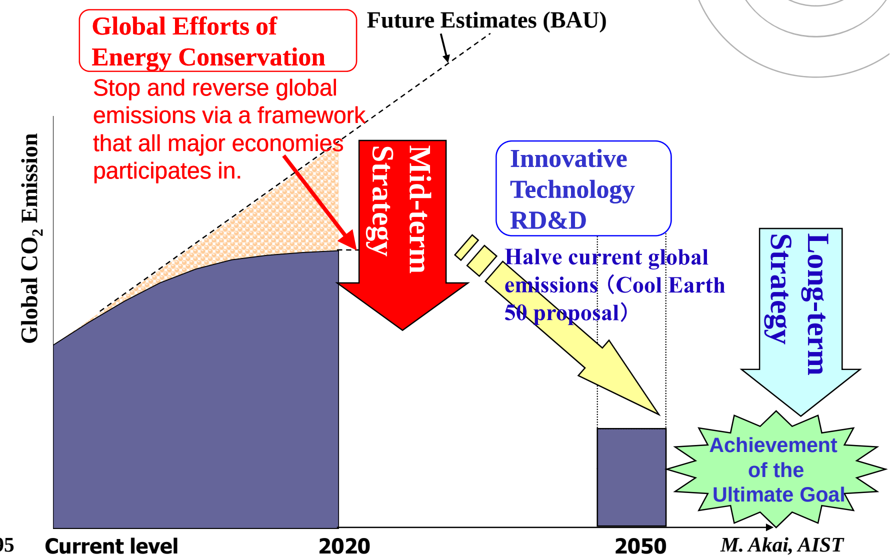


Japan's proposal: Invitation to "Cool Earth 50"

Proposal by Japan's Prime Minister
(May 24, 2007)

1. **Long-term strategy to reduce the emissions of greenhouse gases globally**
   - **Cutting global greenhouse gases emissions by half of the current level by 2050.**
   - **Presenting a long-term vision for developing <u>innovative technologies</u> and building a low-carbon society.**

Long-term Strategy to Reduce GHG Emissions



Japan's proposal: Invitation to "Cool Earth 50"

2. Post-Kyoto framework

- **Three principles to establish a framework**
  1. **All major emitters must participate, thus moving beyond the Kyoto Protocol, leading to global reduction of emissions.**
  2. **The framework must be flexible and diverse, taking into consideration the circumstances of each country.**
  3. **The framework must achieve compatibility between environmental protection and economic growth by <u>utilizing energy conservation and other technologies.</u>**
- **We will create under international cooperation a new financial mechanism to extend support to developing countries with high aspirations**
- **We will expand the endeavor for improving energy efficiency to the entire world. we will promote international efforts to expand the use of nuclear power, as well as providing assistance such as infrastructure development.**
- **We will study methods such as an integrated approach to fight pollution and global warming; emissions trading; and economic incentives.**

Japan's proposal: Invitation to "Cool Earth 50"

3. Launching a national campaign for achieving the Kyoto Protocol target.

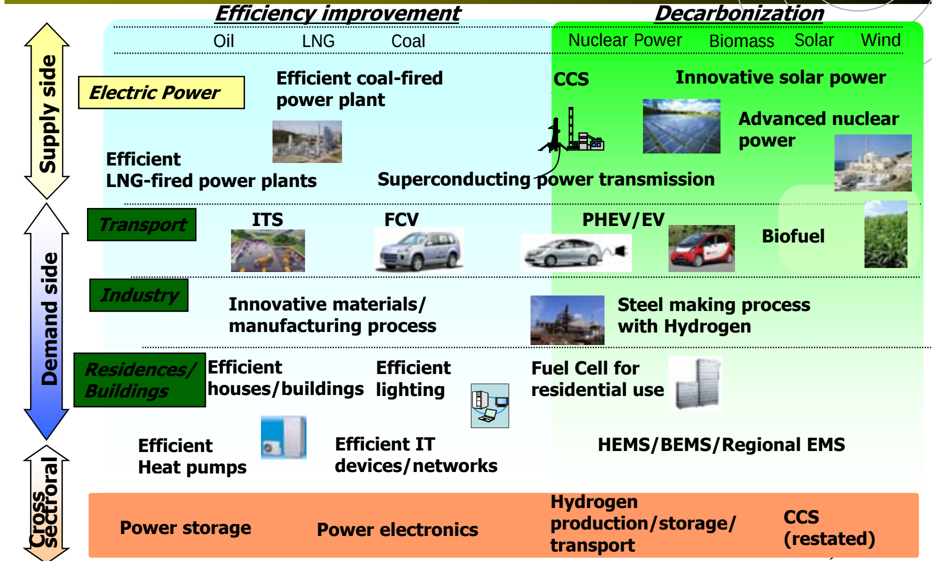
- The Kyoto Protocol Target Achievement Plan will be reviewed to ensure Japan achieves its Kyoto Protocol objective to reduce emissions by 6 %.
- The Government will promote its initiatives and urge municipalities and major business entities to accelerate their actions for reduction of emissions.
- We will launch a national campaign and call for efforts and creative ideas with the motto of reducing greenhouse gases by "1 person, 1day, 1kg." We will solicit and adopt new proposals from the people for expanding the national campaign.

Cool Earth- Innovative Energy Technology Program

METI developed "Cool Earth - Innovative Energy Technology Program" to address substantial GHG reduction in the long-term through innovative energy technologies RD&D. (March 5, 2008)

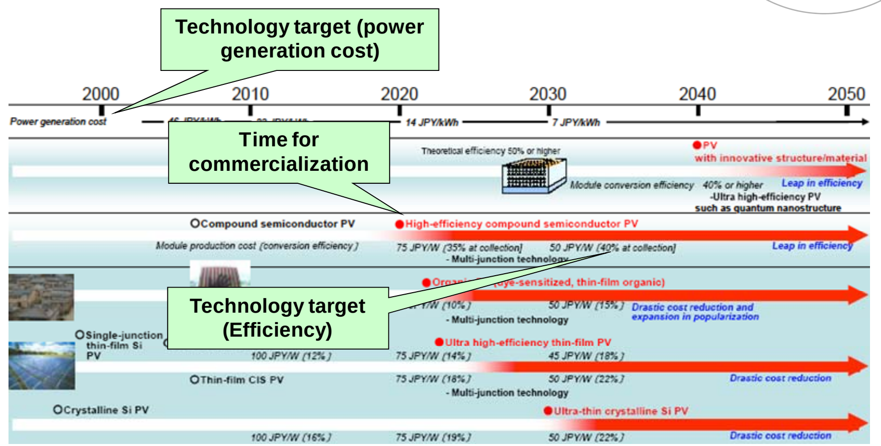
- Identified 21 key energy technologies to be focused on with high priority.
- Formulated technology roadmaps for them, which give RD&D direction and milestones on performance with timelines, and propose further development of global technology roadmaps to monitor global RD&D progress
- Strengthen international cooperation to accelerate innovative technology RD&D.

21 Key Innovative Energy Technologies

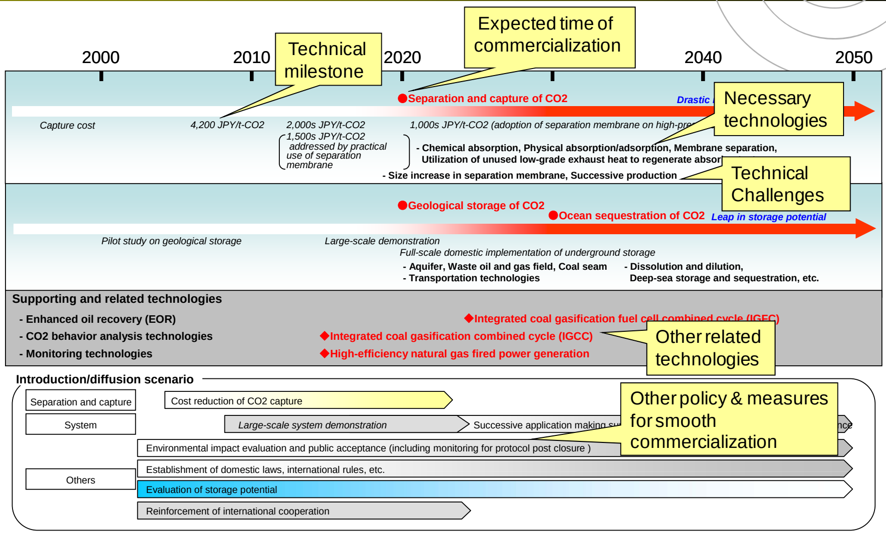


Technology Roadmaps toward 2050
Example on PV

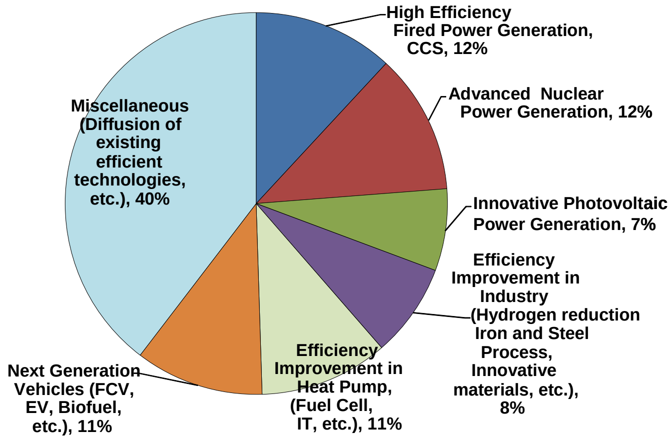
An image of our technology roadmap for innovative PV



Example of Technology Roadmap on CCS



Contribution of Technologies for 50 % Emission Reduction in 2050



Source: Institute of Applied Energy

- 21 innovative technologies contribute to nearly 60% of the necessary reductions for the 50% of emission reduction.
- Technologies for power generation and transportation sectors have relatively large contributions, but it is necessary to address all sectors.

Need for International Action

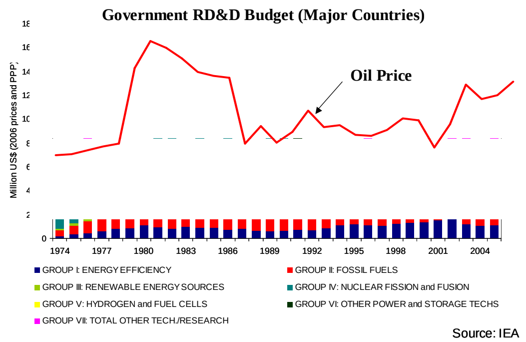
1. **Expanding RD&D investment by developed countries**
   - Urging developed countries to expand investment for research, development and deployment (RD&D) of innovative technologies
2. **Developing and sharing technology roadmaps**
   - Developing and sharing technology development roadmaps for key innovative energy technologies with the support of the IEA, in order to accelerate their RD&D systematically with making use of strengths of each country
3. **Strengthening international cooperation in each technology**
   - Strengthening existing international RD&D for several technology fields, and exploring new fields, with sharing the progress of each technological development

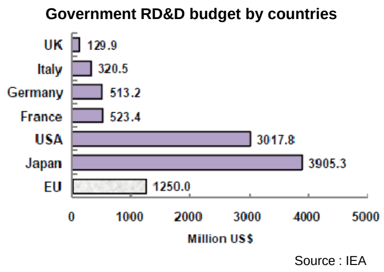
Outcome of G8 Meetings
Innovative Energy Technologies

- Energy Ministers Meeting of G8, The People's Republic of China, India and The Republic of Korea
  - We should collectively endeavor to increase energy RD&D according to national circumstances
  - Those of us interested will take the initiative to accelerate efficient and lower carbon technology RD&D by using relevant structures within the IEA and the technology development roadmaps for key technologies prepared by the IEA and countries; assessing the current status of existing international partnerships for technology cooperation; and exploring the need for additional ones, along with the IEA non-Member partners and other entities and relevant partnerships, and invite interested major economies to join in these efforts.
- G8 Toyako Summit on 7-9 July 2008
  - G8 members have so far pledged over the next several years over US$10 billion annually in direct government-funded R&D
  - We will establish an international initiative with the support of the IEA to develop roadmaps for innovative technologies and cooperate upon existing and new partnerships

RD&D investment

- **Public RD&D spending in the energy field has been stagnating recently, so it is essential to secure substantial investment for innovative technologies.**
- **Global efforts are needed to secure investment**





Expanding RD&D investment

- **G8 countries**
  - **We should collectively endeavor to increase energy RD&D according to national circumstances (G8+3 energy ministerial meeting)**
  - **G8 members have so far pledged over the next several years over US$10 billion annually in direct government-funded R&D (G8 summit)**
- **Japan**
  - **Japan will invest $30 Billion for 5 years in environment and energy technology R&D (Prime Minister's speech in January 2008)**
  - **METI invest $600 Million for R&D of 21 innovative technologies in FY2008 and is asking $1 billion for that purpose in FY2009**

Accelerating Global RD&D Technology Roadmapping

The EU, U.S. and Japan have already taken substantial steps:

Europe Strategic Energy Technology Plan (2007)
Climate Change Technology Plan (2006)
Energy Technology Strategy (2007)
Cool Earth -Innovative Energy Technology Program (2008)
Energy Technology Perspective 2008"

<u>Sharing of the long-term roadmaps of energy technologies</u>

- To ensure global efforts and promote steady progress through reviewing technology progress based on the common roadmaps
- To identify areas of focus where further global efforts or cooperation is needed, by clarifying the gap between what has been done and what is needed, based on common roadmaps
- To strengthen existing international cooperation and establish new international cooperation, if needed

Developing and Sharing Technology Roadmaps

- **Initial action:**

IEA Workshop on
Energy Technology Roadmaps
15 - 16 May 2008
International Energy Agency, Paris

- **Activities will be undertaken through the meeting of CERT(Committee of Energy Research and Technology) and Expert group for R&D priority setting of IEA from to deepen our consideration for common technology roadmaps, and develop roadmaps we can share globally by 2010 as Energy Technology Perspective 2010.**

Enhancing International Cooperation

- **Building upon existing partnerships**
  - CCS: CSLF, APP
  - Nuclear: GNEP, GIF
  - Fuel cells: IPHE
  - Others: Implementing agreements in IEA
- **Promoting further collaboration (Examples)**
  - CCS
    - Promote CCS demonstration under international cooperation, enhance cross-linking among international partnerships (launched China-Japan CCS-EOR project & Callide A project between Australia and Japan)
  - Innovative steel making: Participate in IISI program, joint programs in the EU
  - Innovative PV: International COE program for 3rd Generation PV
  - Green IT: Holding an international symposium, sharing information on R&D

Example: Enhancing Cooperation with EU

- **Ministerial agreement between Mr. Potočnik and Mr. Amari (June 16, 2008)**
  - To enhance cooperation on innovative energy technology
  - To hold a workshop in Japan in March 2009 to share technology roadmaps, exchange information on energy technology R&D, and deepen dialogue to explore further cooperation
- **Potential cooperative projects include:**
  - CCS, 3rd generation PV and Power storage

Political Will and R&D Challenge

- **Political Will as a key driver**
  - To set desirable target for the future
  - To develop roadmaps
  - To promote R&D activities

    ≈ **Implementation of Roadmaps**
  - To design and promote socio-economic system to challenge policy goals such as energy security, climate change, etc.
- **Available science and technologies, coupled with proper assessments, to drive Policies**

In pursuit of "Japan as a Low-carbon Society"
Speech by Prime Minister at the Japan Press Club
9 June 2008

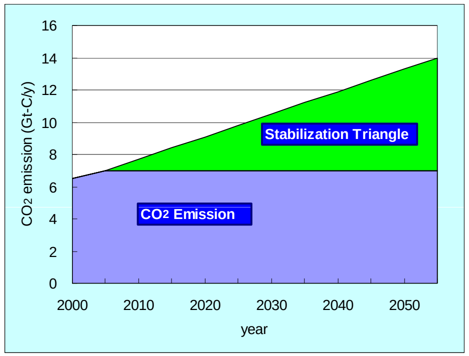
- … we must halve global CO_2 emissions by the year 2050. This reduction target forms the crux of the "Cool Earth Programme" which Japan has proposed to the world. I aim to have this goal shared by the G8 and other major economies.
- It is impossible to meet this goal unless *all* countries tackle the issue of global warming one way or another, not just the main carbon emitters.
- … Japan will set a long-term goal of reducing, by 2050, 60-80% of its current level of emissions, …
- … Japan recently announced that it is possible for it to achieve a further reduction of 14% (by 2020) from the current level, a reduction of the same order as that to be made by the EU.

Summary - Challenges

- **To implement Cool Earth – Innovative Energy Technology Program and Roadmaps**
  - **Example: Addressing necessary regulatory framework, financing mechanism, incentives, etc. for CCS as well as investment to RD&D**
- **To develop Roadmap to achieve domestic goal of deep GHG reduction**
  - **Example: Acceleration of "Energy Technology Vision 2100" which depicts a scenario of 80% reduction in 2100**

Simple Consideration on Deep Reduction Strategy

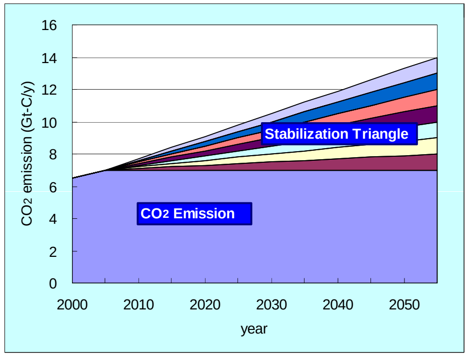
Stabilization Triangle



- **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.**

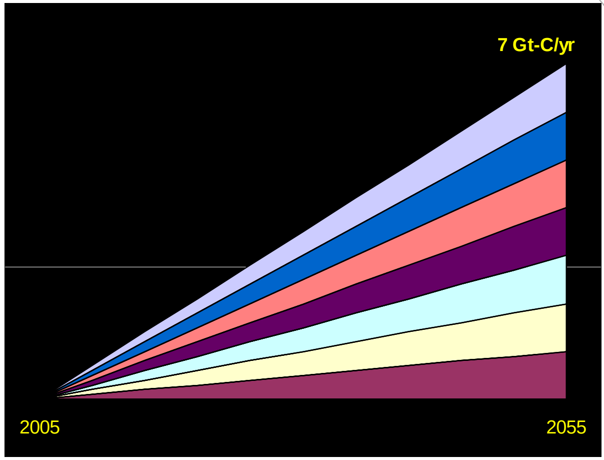
Robert H. Socolow (Princeton Univ.)

Stabilization Wedges



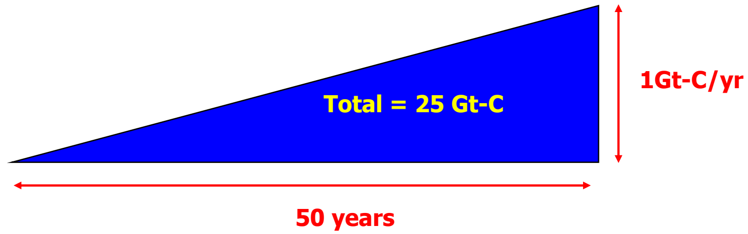
- **To introduce a new physical unit, the wedge, as a unit for describing 50-year strategies.**
- **To explain the strategy is, roughly, a seven-wedge problem.**

Seven Wedges to Fill the Triangle

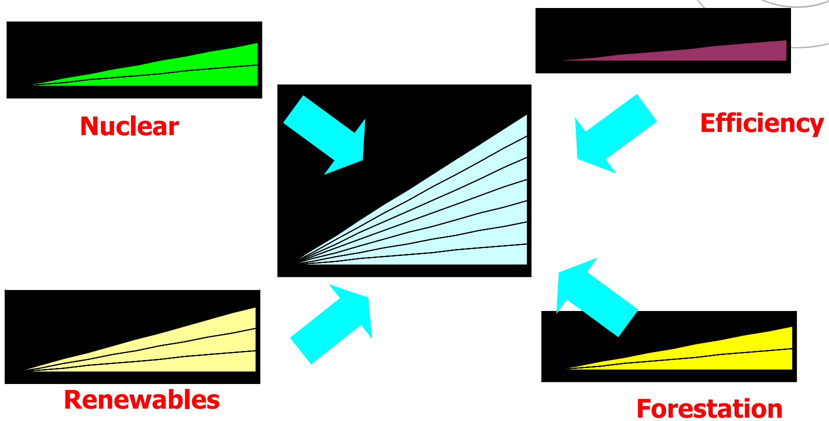


What is a "Wedge"?

- **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)**

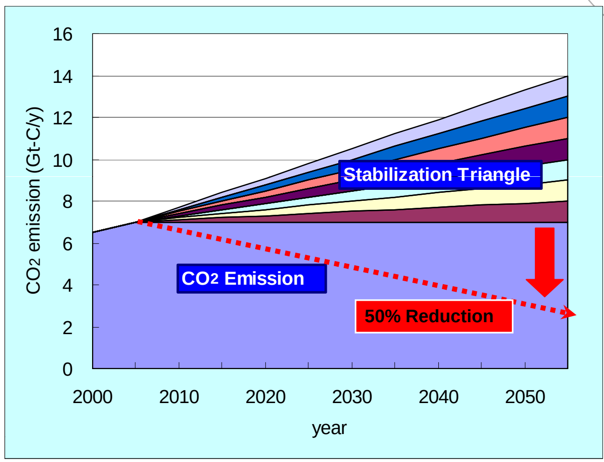
Reporting Subject

- **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),**
  - **……**

Discussion Subject

- **Consider possible combinations of developed wedges to achieve 50% reduction of CO_2 emission by 2050 both in global scale and in Japan.**
  - **NOT for the "emission stabilization"**
- **Identify barriers to achive the target in relation to the consideration on wedges.**

Reduction Wedges to Stabilize Atmospheric CO_2 Concentration



Thank you!

Documents related to "Cool Earth - Innovative Energy Technology Program" are available from the following URLs:

Japanese: http://www.enecho.meti.go.jp/policy/coolearth_energy/index.htm

English: http://www.meti.go.jp/english/newtopics/data/nBackIssue20080305_04.html