Global Environmental Policy

Makoto Akai

National Institute of Advanced Industrial Science and Technology (AIST)

Lecture Plan

- **May 23: Overview**
- **May 30: Challenges and strategies towards Deep GHG Reduction**
  - **Discussion on Stabilization Wedge**
- **June 06: ???**

Public Perception on Global Warming Mitigation Measures

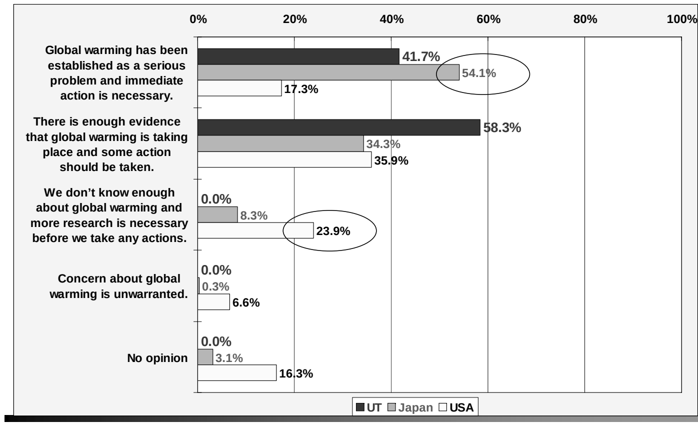
US-Japan Study

+ Multinational Study

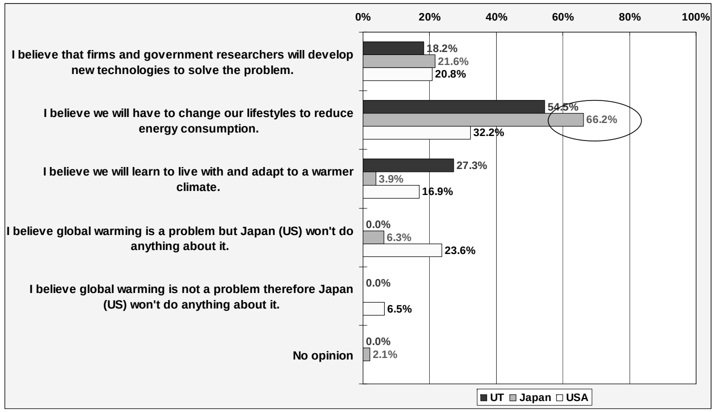
Summary of the Survey

	Japan (AIST)	USA (MIT)
Survey period	Dec. 2003	Oct. 2003
Sample size	1006	1205
Female percentage	50.6%	Average
Average age	47.3	Average
Place of residence	Tokyo (50%) & Sapporo (50%)	Nation wide
Response rate	64%	70%

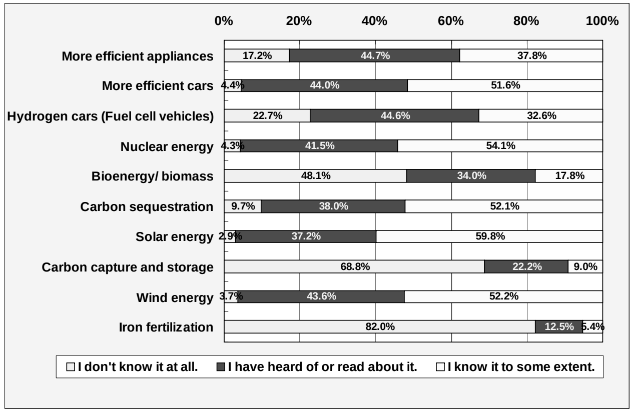
From what you know about global warming, which of the following statements comes closest to your opinion?



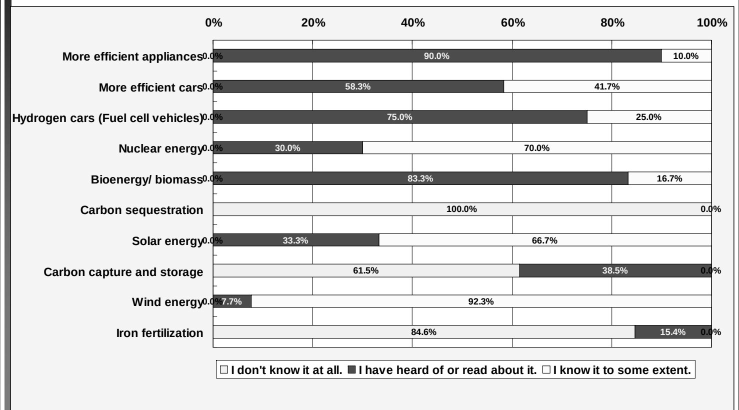
Assuming that global warming is a problem, what do you think the Japan (US) is likely to do about it?



Have you heard of or read about any of the following in the past year? (Japanese Results)

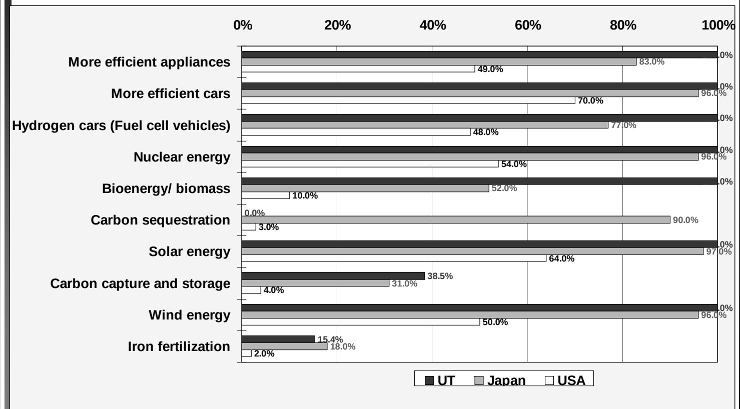


Have you heard of or read about any of the following in the past year? (UT Results)

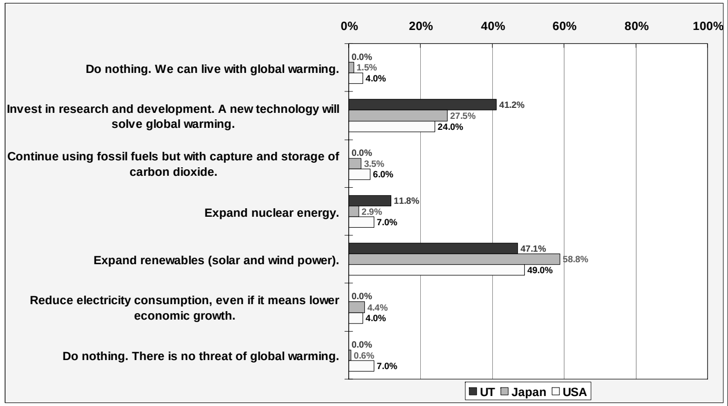


Comparison of Recognition for Global Warming Mitigation Measures

("I've heard of or read about it" + "I know it to some extent")



How do you feel we can best address the issue of global warming as it relates to electricity production?



Public Understanding for GHG Mitigation

A multinational Comparison Study

	US	UK	Sweden	Japan
Survey distribution	Knowledge Networks	YouGov	Statistics Sweden	Mizuho Inst. & NAIST
Research partner	MIT	Cambridge	Chalmers	Mizuho Inst.
Methodology	Internet	Internet	Written	Written
# of responses	1,205	1,056	742	1,006
Response rate	70%	40%	49%	64%
Date of survey	Oct 2003	Sept 2004	Dec 2004	Dec 2003
Questions	20 multiple choice	20 multiple choice	20 multiple choice	5 written + 66 multiple Choice

Howard J Herzog, MIT Laboratory for Energy and the Environment

What are the Three Most Important Issues Facing the US Today?

Rank	Issue	%	Rank	Issue	%
1	Terrorism	42	12	Taxes	11
2	Health Care	35	13	Environment	9
3	Economy	35	14	Poverty	8
4	Unemployment	30	15	Aging Population	5
5	Family Values	20	16	Income Inequality	4
6	Education	19	17	AIDS	4
7	Federal Budget Deficit	15	18	Abortion	4
8	Foreign Policy	14	19	Racism	4
9	Crime	14	20	Welfare	3
10	Social Security	13	21	Inflation	3
11	Drugs	12	22	Stock Market	2

Howard J Herzog, MIT Laboratory for Energy and the Environment

What are the Three Most Important Issues Facing the UK Today?

Rank	Issue	%	Rank	Issue	%
1	Asylum seekers	42	14	Introducing € / Keeping £	7
2	Terrorism	39	15	Poverty	7
3	Crime	31	16	Welfare	6
4	Health care	26	17	Unemployment	5
5	Education	17	18	Income inequality	5
6	Drugs	16	19	Racism	4
7	Aging population	15	20	Social exclusion	4
8	Environment	13	21	Inflation	2
9	Taxes	13	22	Budget deficit	1
10	European Union	11	23	AIDS	1
11	Economy	10	24	Abortion	1
12	Family values	10	25	Stock market	0
13	Foreign policy/Influence	10	26	None of these	1

Howard J Herzog, MIT Laboratory for Energy and the Environment

What are the Three Most Important Issues Facing Sweden Today?

Rank	Issue	%
1	Health care	57
2	Unemployment	44
3	Education	41
4	Crime	28
5	Environment	24
6	Economy of the state	21
7	Income inequity	14
8	Welfare	14
9	Aging population	11
10	Taxes	8

Rank	Issue	%
11	Drugs	7
12	Budget deficit	5
13	Racism	4
14	Poverty	4
15	Foreign policy	2
16	Inflation	2
17	Terrorism	2
18	AIDS	1
19	Stock market	1
	Other	4

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How Should We Address Global Warming?

Answer	US	UK	Sweden	Japan
Global warming has been established as a serious problem and immediate action is necessary	17	41	35	54
There is enough evidence that global warming is taking place and some action should be taken	36	33	45	34
We don't know enough about global warming and more research is necessary before we take any actions	24	18	13	8
Concern about global warming is unwarranted	7	4	2	0
Not sure	16	4	3	3

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How Will We Address Global Warming?

Answer	US	UK	Sweden	Japan
I believe that firms and government researchers will develop new technologies to solve the problem	21	26	37	22
I believe we will have to change our lifestyles to reduce energy consumption	32	27	22	66
I believe we will learn to live with and adapt to a warmer climate	17	13	19	4
I believe global warming is a problem but [my country] won't do anything about it	24	21	14	6
I believe we will do nothing since global warming is not a problem	7	3	2	NA
Not sure	NA	10	6	2

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Simple Consideration on Deep Reduction Strategy

Stabilization Wedges

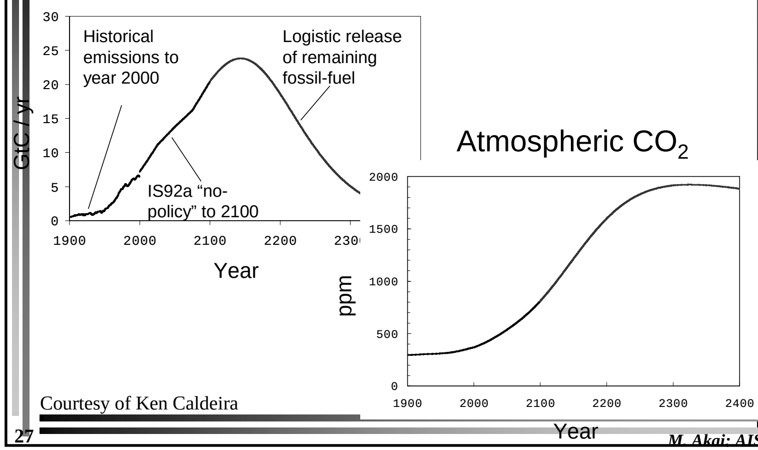
Towards a Deep Reduction

IPCC TAR Recommendations

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.**

What happens if we do nothing?



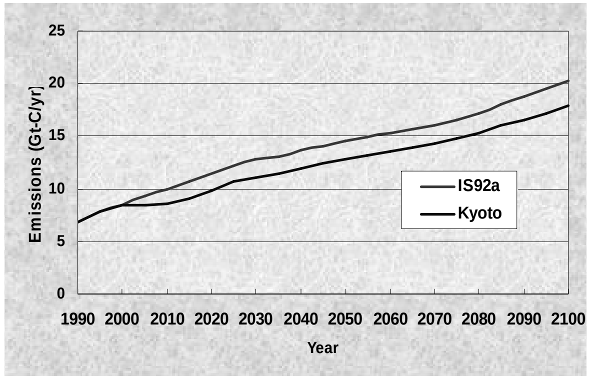
Courtesy of Ken Caldeira

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);**

Effect of Kyoto Protocol

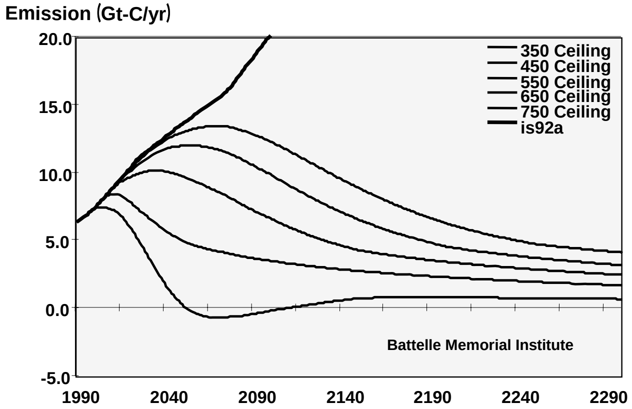
It's just an entrance to a sustainable society



(Pacific Northwest National Laboratory)

CO_2 Stabilization Profiles

- Atmospheric Emissions -



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.

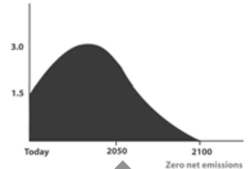
The Technology Challenge

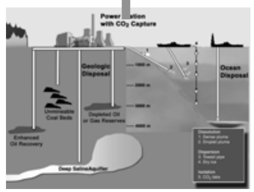
Stabilizing Greenhouse Gas Concentrations in the Atmosphere

Hydrogen Fuel Cell Vehicles

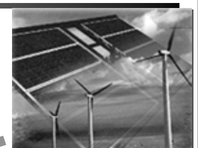
Zero Net Emission Buildings

Nuclear Power Generation IV



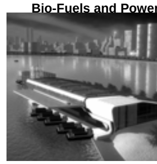


Carbon (CO_2) Sequestration



Renewables: Photovoltaics and Wind

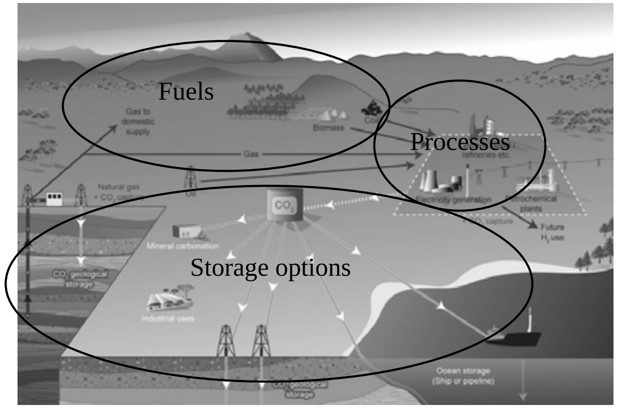
Bio-Fuels and Power



Vision 21: Zero-Emission Power Plant

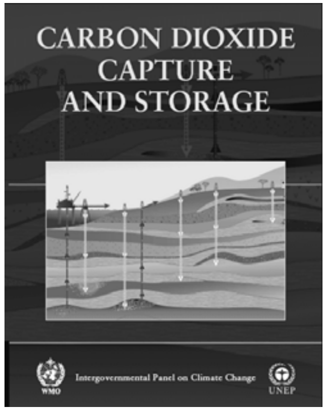
CO_2 Capture and Storage
or
CO_2 Capture and <u>Sequestration</u>
(CCS)

CO_2 Capture and Storage System



Source: IPCC SRCCS

The IPCC Special Report on Carbon Dioxide Capture and Storage



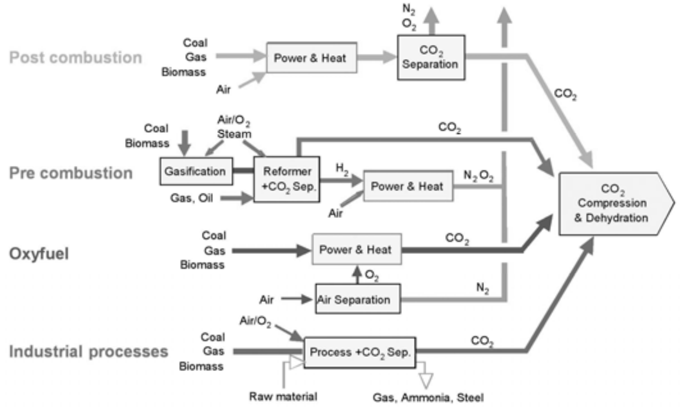
Structure of the Report

1. Introduction
2. Sources of 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

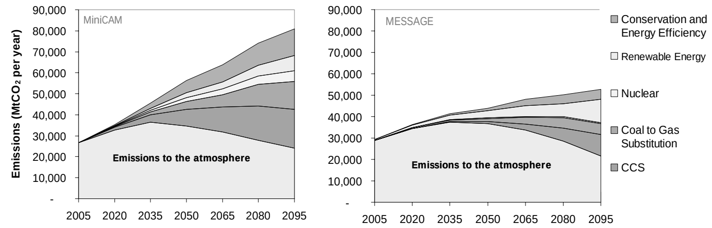


Source: IPCC SRCCS

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



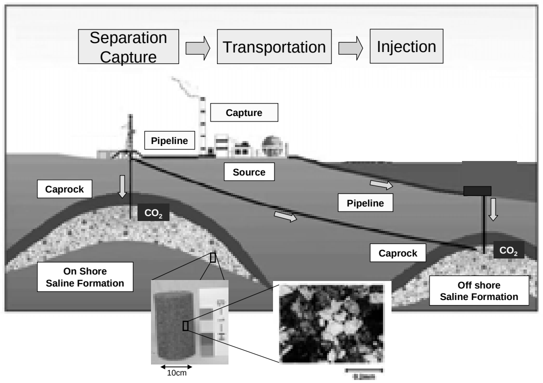
Economic Potential

- 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$/t$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

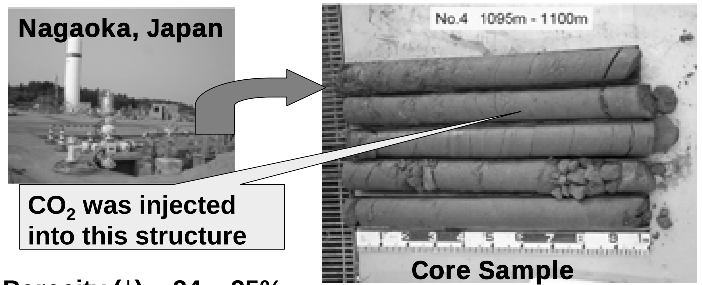
- Geological storage: likely at least about 2,000 GtCO_2 in geological formations
  - *"Likely" is a probability between 66 and 90%.*
  - Oil/gas fields: 675 - 900 GtCO_2
  - Saline formations: 1000 - ~ 104 GtCO_2
  - Coal beds: 3 - 200 GtCO_2
- Ocean storage: on the order of thousands of GtCO_2, depending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

Schematic of Geological Storage
- Saline Formation -



- CO_2 will not be injected into a cavern!

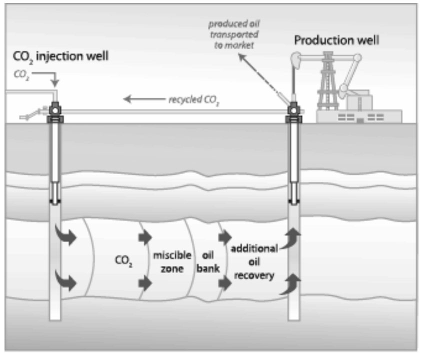
Experimental Site and Core Sample



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

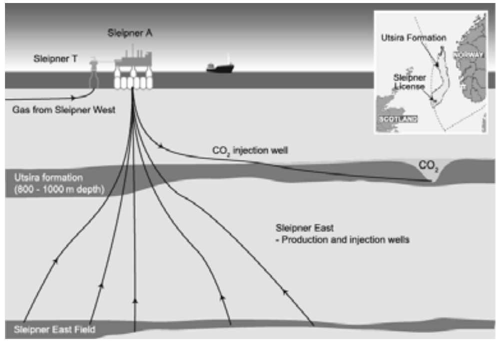
Injection of CO_2 for Enhanced Oil Recovery (EOR)



- 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.

From IPCC SRCCS

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.

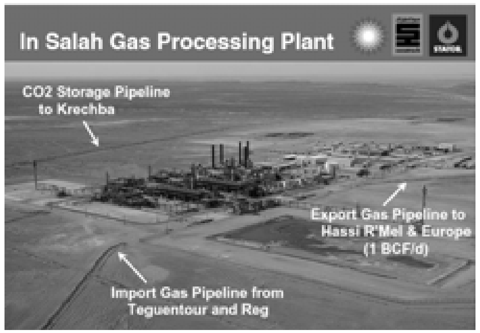
Weyburn CO_2-EOR Project.

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.

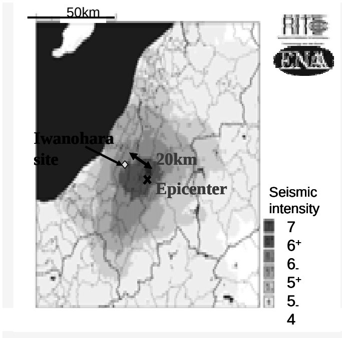
The project involves re-injecting the CO_2 up to 1.2 $MtCO_2$/yr into a sandstone reservoir at a depth of 1800 m. Injection started in April 2004 and it is estimated that 17 $MtCO_2$ will be stored over the life of the project.

Big Earthquake and Nagaoka Project

Niigata Chuetsu Earthquake

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

Injection was automatically stopped at the main shock.



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

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

Access road to the injection site

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 and Global Environmental Policies in Several Nations

United Kingdom

Key Points in UK Policy (1/2)

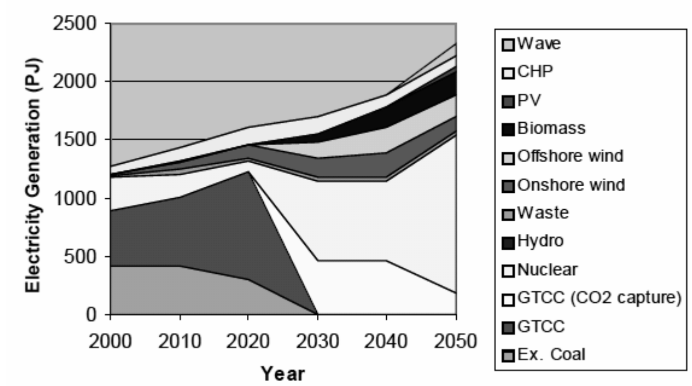
- UK Energy White Paper : environment issues at heart of Energy Policy - desire to put UK on a path to reduce CO_2 levels by 60% in 2050 (compared to 1990 levels)
- No one single winning technology; broad portfolio approach required
- Clean use of fossil fuels world-wide becoming increasingly recognized as a key transitional issue in getting to a sustainable energy future

Key Points in UK Policy (2/2)

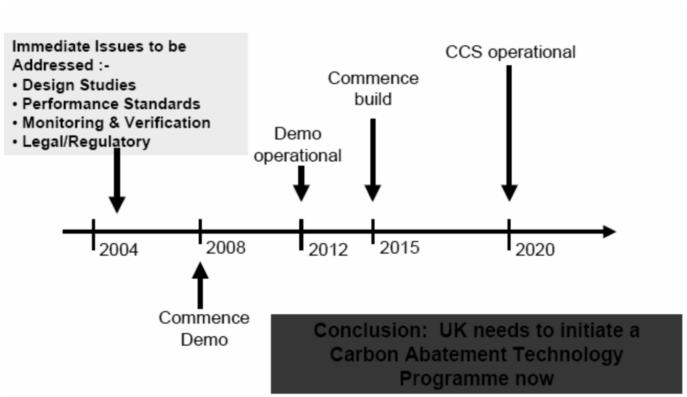
- Desire for a Carbon Abatement Strategy that includes fossil fuels
- CCS considered as one key element in such a strategy; recognized link to "hydrogen economy" needs
- International co-operation recognised as an essential element

UK Fuel Mix in Electricity Generation

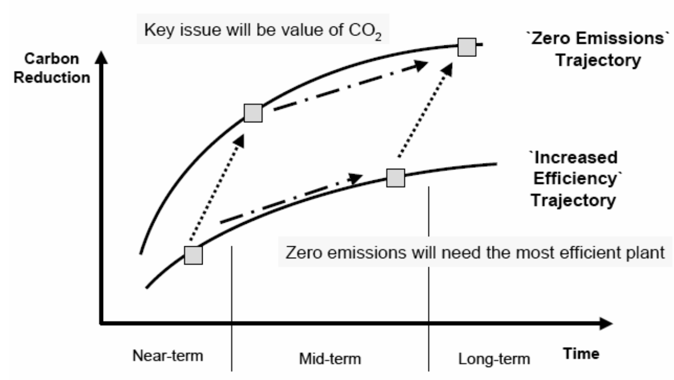
60% CO_2 Reduction in 2050 (limited Energy Efficiency)



UK Roadmap for Carbon Capture and Sequestration



UK Strategy Trajectories

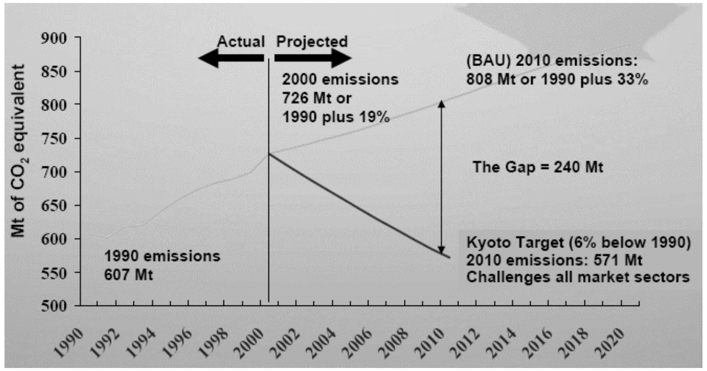


Canada

The Canadian Context

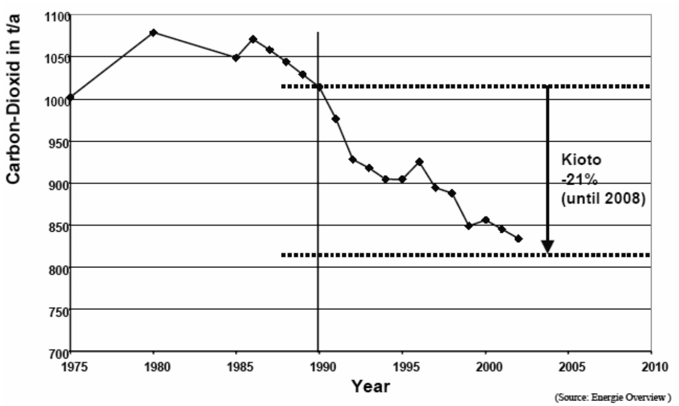
- Canadian energy policy is framed within the context of Sustainable Development
- Sustainable development – pursuit of a balanced portfolio of environmental, economic and social goals
- For energy, sustainable development aims to:
  - Reduce energy use, intensity (and carbon content), emissions
- A major driver is climate change
- CO_2 capture and storage is the natural evolution of leading Canadian initiatives in AGI and EOR in place since the 1980's

Canada's Kyoto Challenge

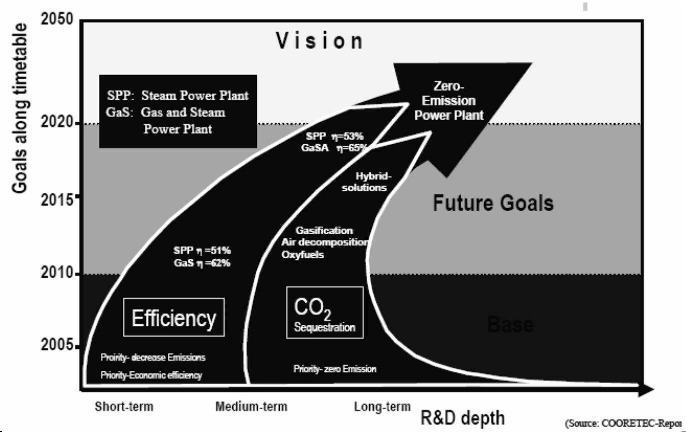


Germany

CO_2 Emissions in Germany



Emission Reduction Roadmap



Italy

GHG Emissions in Italy

- **Italy committed to reduce its total GHG emissions by 6.5% in 2008-2012 compared to 1990 levels**
  - 93 million tonnes by 2010 from the projected level in 2010 without any measures
- **Energy-related CO_2 emissions have been growing gradually and were 6.5% above the 1990 level in 2001 reaching 437 Mt-CO_2**
  - Power sector: 155 Mt-CO_2 (1/3 total)
- **Italian Carbon intensity: 0.35 kg-CO_2/$GDP in 2000 (IEA av. 0.43, EU av. 0.37)**

⇓

- ➢ **Policy measures (voluntary agreements, carbon tax, regulations, international agreements, …)**
- ➢ **R&D initiatives**

Three Horses of the “Troika”

- **Energy efficiency**
- **Renewable energy**
- **Emission free fossil fuels**

Sometimes operate simultaneously

⇓

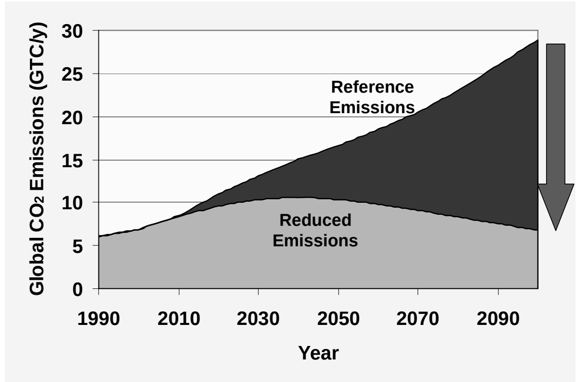
- **Carbon Capture and Storage (CCS), is a crucial issue in energy policy: as the third horse of the troika**

United States

President's Key Policy Addresses:

- **June 11, 2001**
  - Committed U.S. to Work Within UN Framework
  - Directed U.S.G. to Develop Flexible, Science-Based Response
  - Supported UNFCCC to Stabilize GHG Concentrations
  - Established National Climate Change Technology Initiative
  - Established Climate Change Research Initiative
- **February 14, 2002**
  - Reaffirmed Long-Term UNFCCC Central Goal
  - Established U.S Goal to Reduce GHG Intensity by 18% by 2012
  - Encouraged Business Challenges and Voluntary Reporting
  - Directed Improvements to the EPACT Emissions Registry
  - Supported Transferable Credits
  - Valued GHG Avoidances by Supporting Financial Incentives

Global Climate Change – The Role for DOE and New Technology



Technology Pathways

#1: Closing the Loop on Carbon
- Introduction of Carbon Sequestration and Hydrogen Technologies Augment the Standard Suite of Energy Technologies

#2: Renewables and Nuclear Succeed
- Major Technological Advances in Renewable and Hydrogen Technologies are Coupled with a New Generation of Nuclear Reactors

#3: Beyond the Standard Suite
- Dramatic Breakthroughs in "New and Advanced Technologies – e.g., Fusion, Bio-X" – Create a Fundamentally Changed Energy System

Japan

Energy Technology Vision 2100

(METI)

Development of "Energy Technology Vision 2100"

Purpose

- To establish METI strategic energy R&D plan
  - To consider optimum R&D resource allocation.
  - To prioritize energy R&D programs and specific project of METI.
- To prepare strategy for post-Kyoto and further deep reduction of GHG
- To develop technology roadmap to be reflected in METI's energy, environmental and industrial policy

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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
  - Infrastructure development
  - Stock turnover time (10s yrs)

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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

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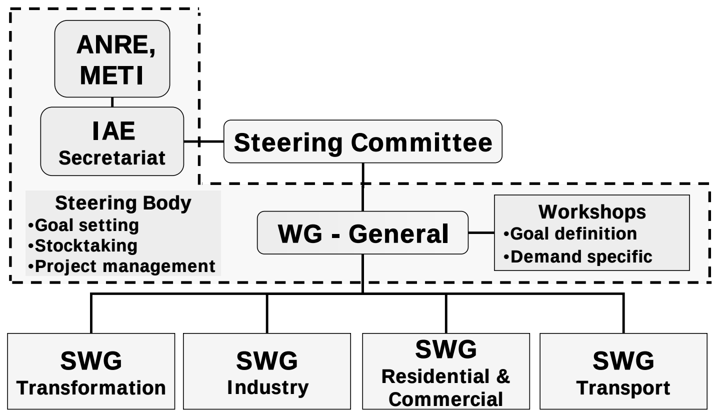
Work Structure

Development of "Technology Vision"



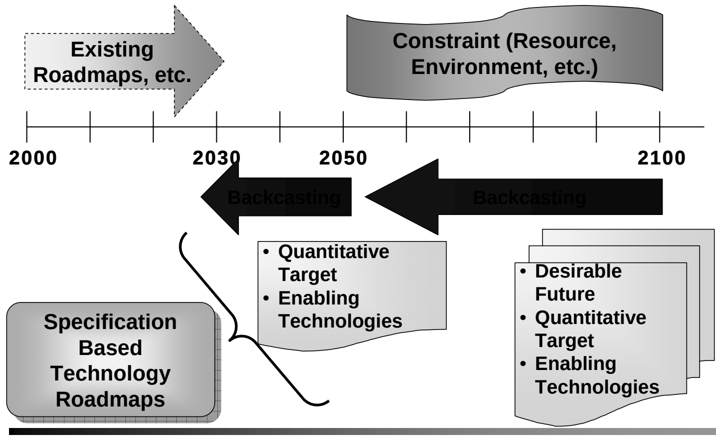
Methodology - Backcasting

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



Basic Recognition on the Energy Sector

- **Constraints on energy connect directly to the level of human utility (quantity of economic activity, quality of life).**
- **Consideration of future energy structure should take into account both resource and environmental constraints.**
- **The key to achieve a truly sustainable future is technology.**
- **However, there is great uncertainty because various kinds of options are selected in the actual society.**

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.**
- **<u>Not to set preference to specific technology such as hydrogen, distributed system, biomass, etc.</u>**

Assumptions

Developing a Challenging Technology Portfolio

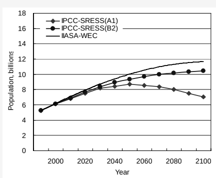
- The effect of modal shift or changing of lifestyle were not expected.
- Although the assumption of the future resource and environmental constraints includes high uncertainties, rigorous constraints were assumed as "preparations".
- To set excessive conditions about energy structure to identify the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

Desirable Futures

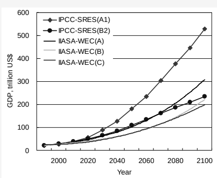
- Society where the economy grows and the quality of life improves
- Society where necessary energy can be quantitatively and stably secured
- Society where the global environment is maintained
- Society where technological innovation and utilization of advanced technology are promoted through international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

Assumptions towards 2100

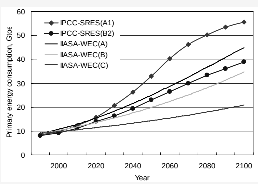
- Population and economy
  - To increase continuously
- Energy consumption
  - To increase following the increase in population and GDP



Forecast of world population



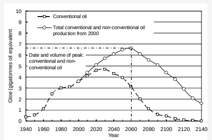
Forecast of world GDP



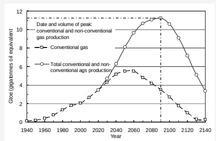
Forecast of energy consumption

Resource Constraints

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



The Complementarity of Conventional and Non-Conventional Oil Production: giving a Higher and Later Peak to Global Oil Supplies

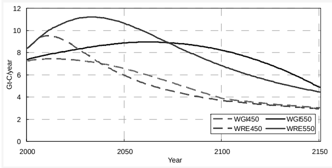


The Complementarity of Conventional and Non-Conventional Gas Production: giving a Higher and Later Peak to Global Gas Supplies

Example of estimates for oil and natural gas production

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

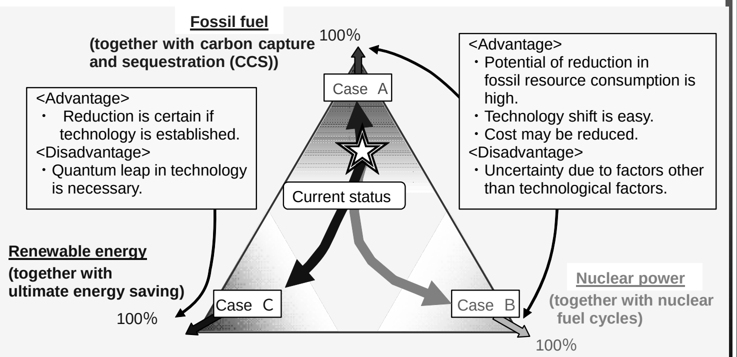
To Overcome Constraints ---

- 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

Basic Approach to Achieve the Desirable Future