長聴第１－２号

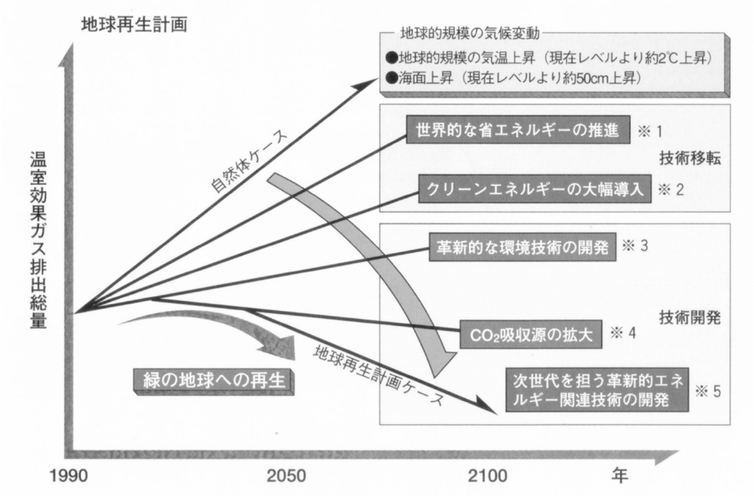
地球温暖化対策における原子力の意義
ー定量的政策評価の事例としてー

For 原子力委員会

By 山地憲治,040128

- ・地球再生計画」のモデル解析
- 大気中CO_2濃度安定化への長期戦略
- 地球温暖化対策における原子力の役割
  - 原子力とバイオマス
  - 核燃料サイクルの効果
  - CO_2規制の不確実性の影響
- 政策的含意

「地球再生計画」の概念図



※１　総合的な省エネルギーの推進、フロンの廃止等

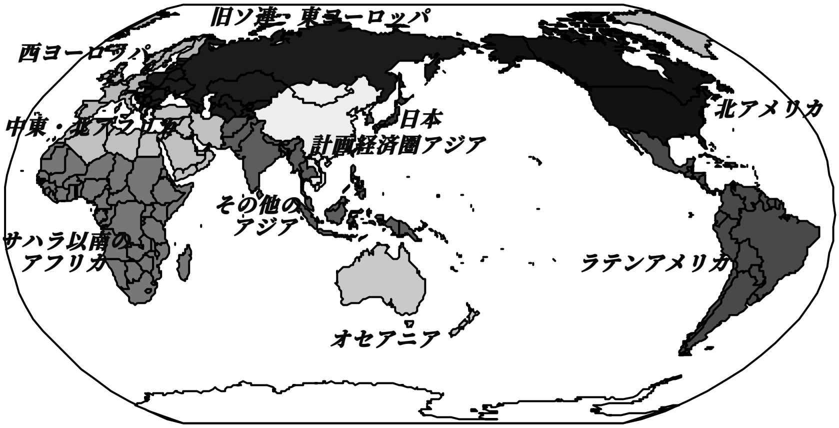
※２　太陽光発電・燃料電池など新・再生可能エネルギーの技術開発・導入、安全性確保に十分配慮した原子力の導入促進等

※３　CO_2固定化・有効利用技術開発、生分解性プラスチック、新世代冷媒開発、環境調和型生産プロセス技術開発、CO_2海洋隔離技術開発等

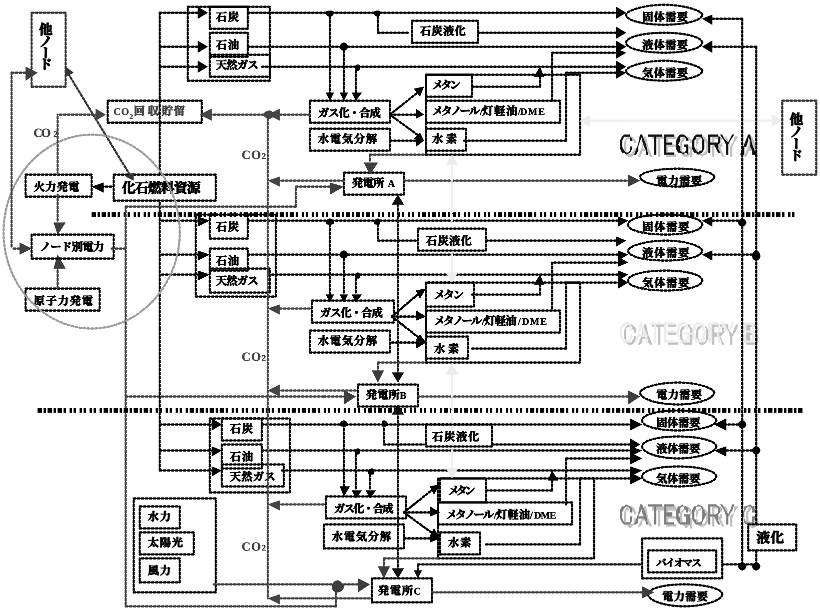
※４　植林・森林保全、砂漠緑化、海洋のCO_2固定能力の強化等

※５　宇宙太陽発電技術・核融合技術の開発等

DNE21モデルの世界地域分割



世界地域細分化モデルのエネルギー変換過程の想定



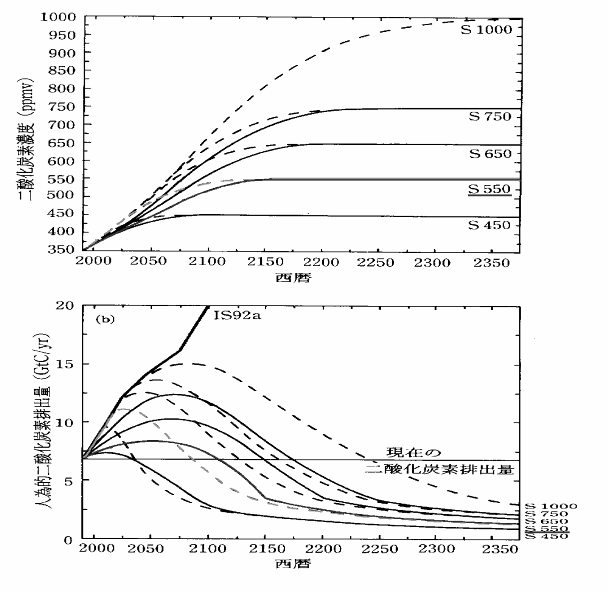
大気中CO$_2$濃度安定化への長期戦略

- グローバルモデルが示す最適経路
- 京都議定書の意義 :排出削減目標、柔軟性措置
- 途上国の参加
- 技術の役割

省エネ、天然ガス、自然エネルギー、原子力

CO$_2$回収 ·貯留

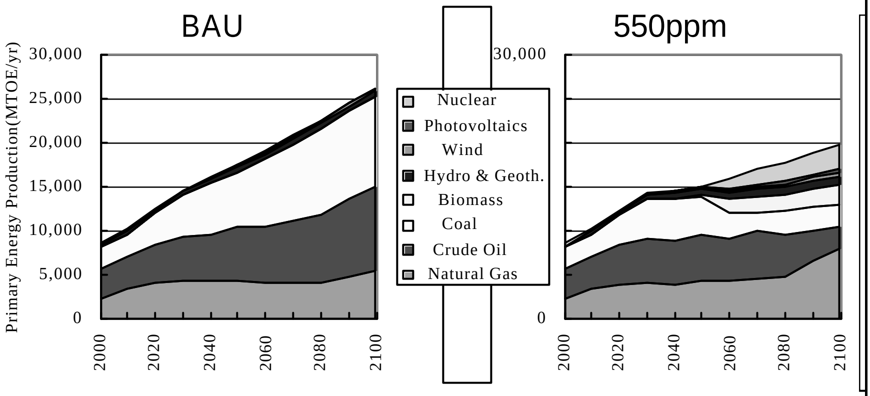
大気中CO2濃度安定化の経路



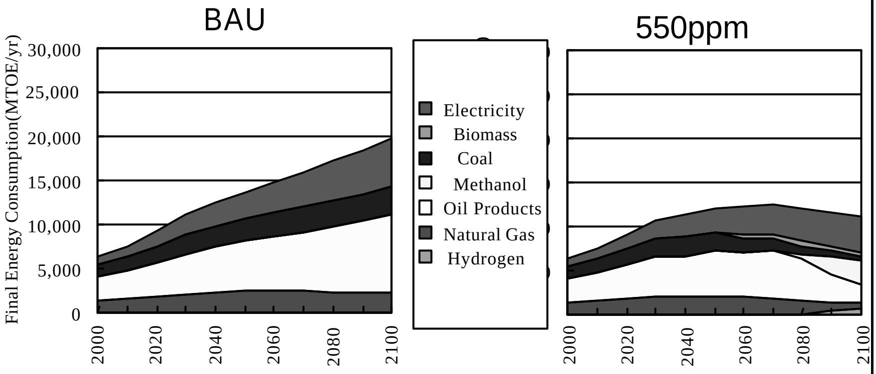
Simulation cases

	Case	CO2 constraints
1	BAU	free
2	550ppm	Global atmospheric CO2 concentration at 550ppm in 2100
3	COP3 forever	COP3 forever in Annex1 after 2010
4	300%	2010: COP3 after 2020: Annex1:80% CO2 emissions at 1990 non-Annex1: 300% CO2 emissions at 1990

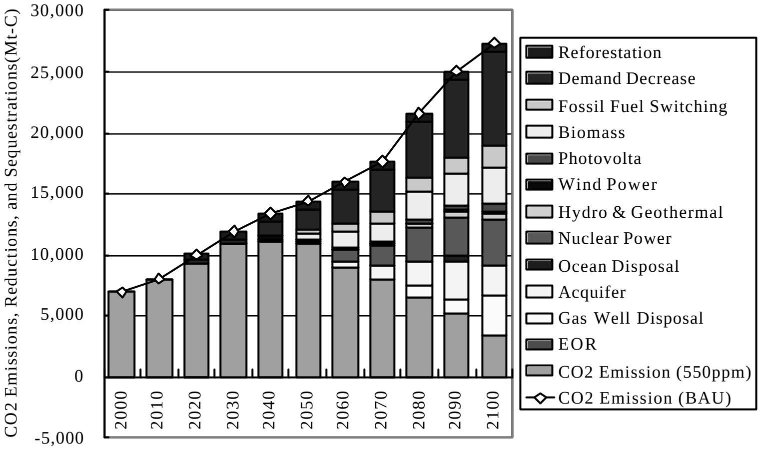
Primary energy production



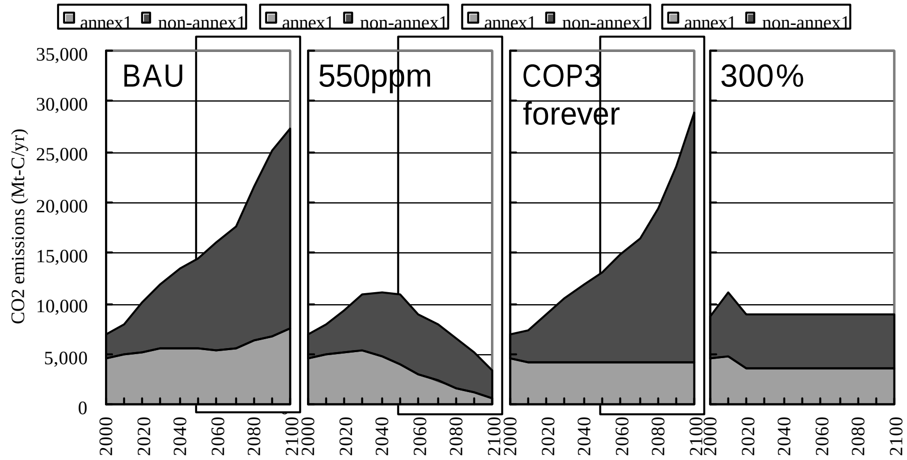
Final energy consumption



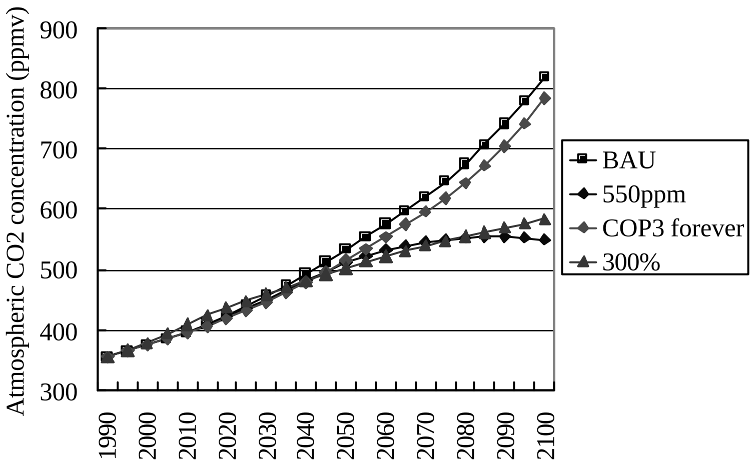
Contributions of each technological option



CO2 emissions



Atmospheric CO2 concentration



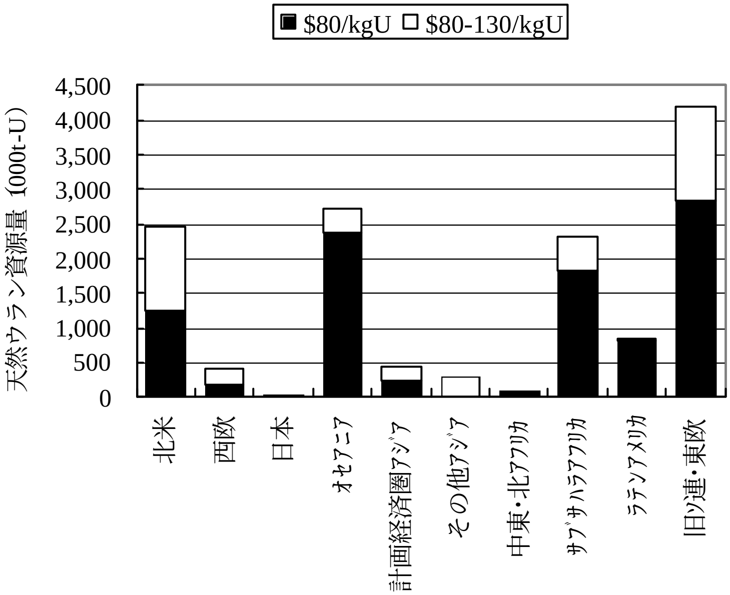
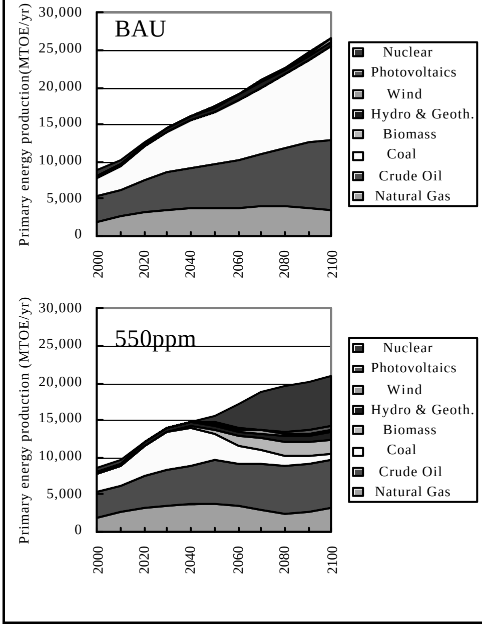
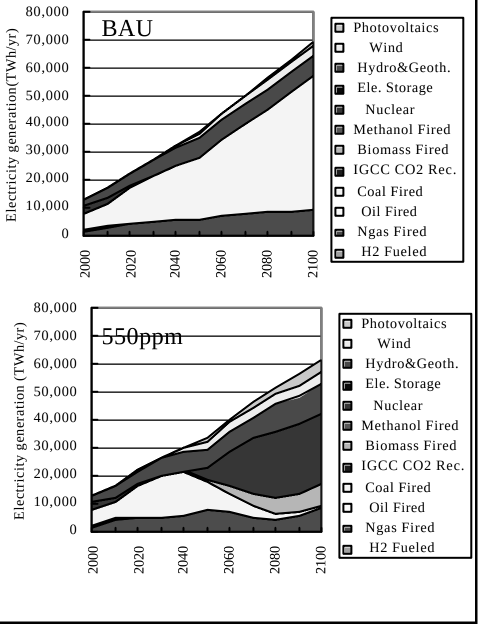


図5-16　ウラン資源量

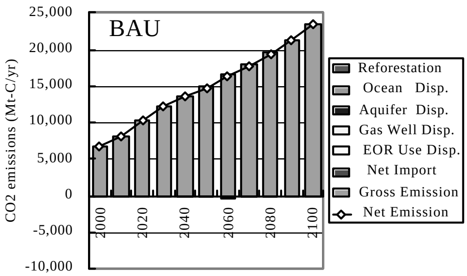
一次エネルギー生産量

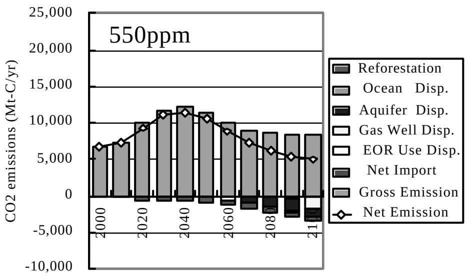
発電量

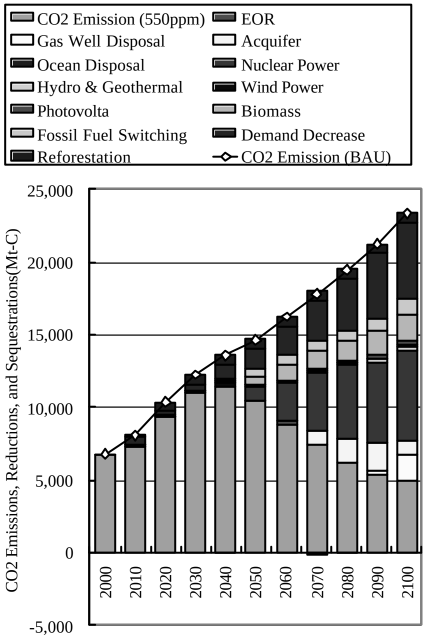




CO2排出量　CO2排出削減効果

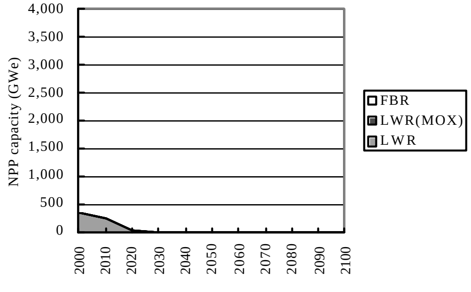




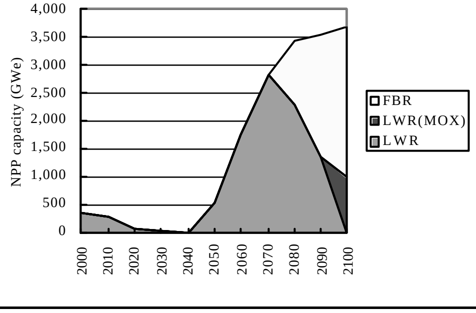


核燃料サイクル :原子力設備容量

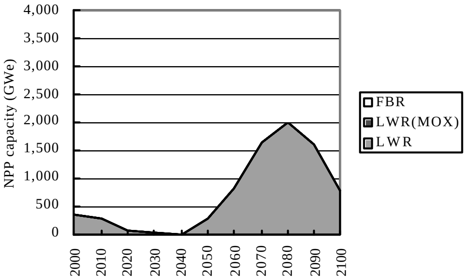
BAU



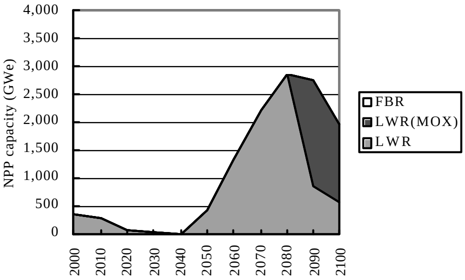
550ppm



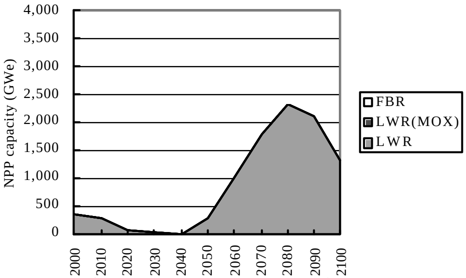
バックエンドの効果解析（550ppm）



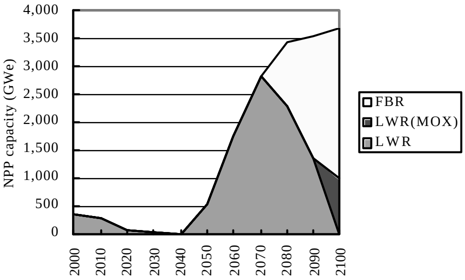
バックエンド無



LWR(MOX)可



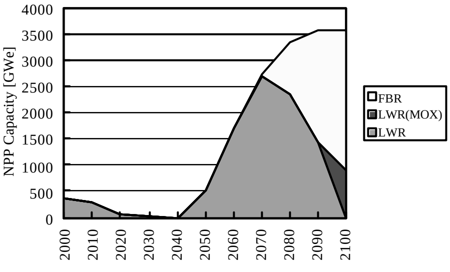
再処理による回収ウラン利用可



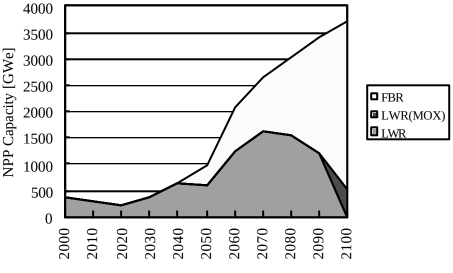
FBR可

割引率の効果　（550ppm）

割引率 5%

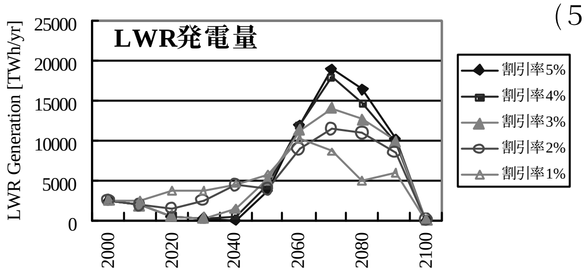


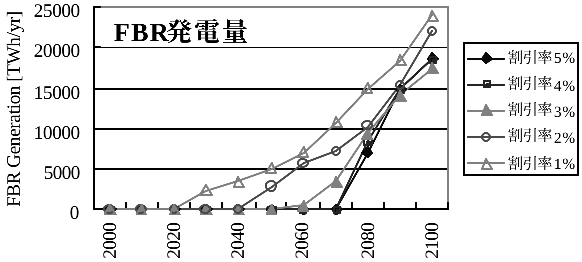
割引率 2%



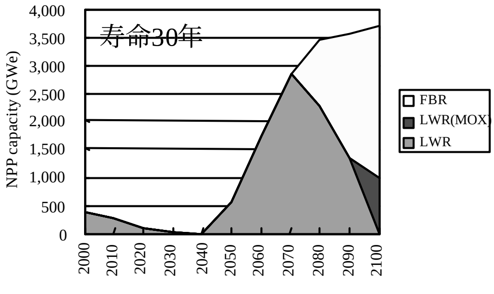
LWR , FBR導入に関する割引率の感度解析

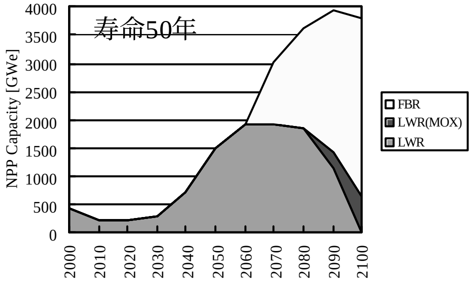
（550ppm）





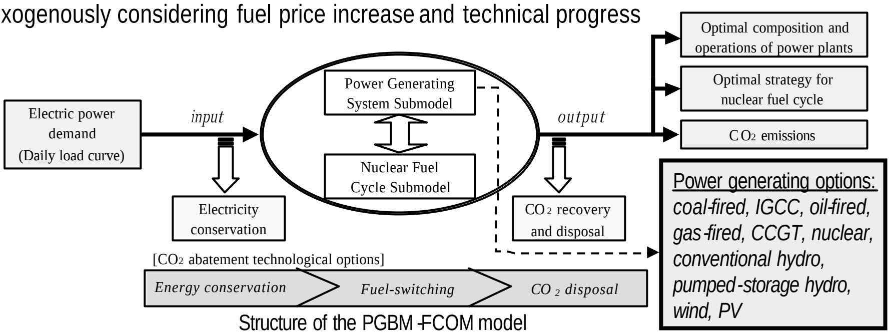
原子炉寿命の効果（550 ppm）





Overview of the PGBM-FCOM Model

- Long-term dynamic LP model called the PGBM-FCOM model
  (Power Generation Best Mix Model interactively combined with the Fuel Cycle Optimization Model)
- Detailed description of the Japanese electric power and fuel cycle sectors to determine the optimal fuel cycle strategy **in line with** the optimal power system management
- **Region**: Japan, **Time horizon**: 2000-2100 (10-year intervals), **Discount rate**: 5%
- **Objective**: minimizing the total discounted cost (fixed and variable costs)
- **Constraints**: supply-demand balance, supplying capacity, capacity balance, operating capacity, load following capacity, growth rate of the plant capacity, CO_2 emissions, operation of pumped-storage plants, new renewables, and CO_2 disposal system, fuel cycle-related constraints, etc.
- Exogenously considering fuel price increase and technical progress

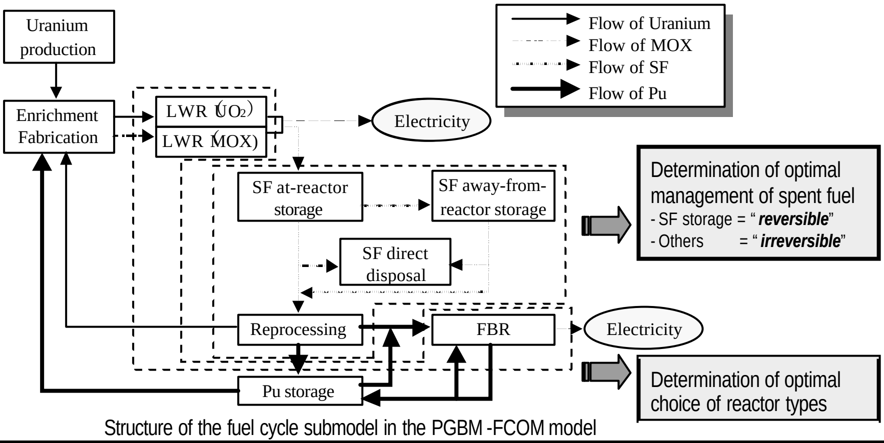


Power generating options:
coal-fired, IGCC, oil-fired, gas-fired, CCGT, nuclear, conventional hydro, pumped-storage hydro, wind, PV

Structure of the PGBM-FCOM model

Overview of the Fuel Cycle Submodel

- Detailed description of the process of the fuel cycle to determine the optimal fuel cycle strategy in line with the optimal power system management among various alternatives
- Dynamic LP model minimizing the discounted cost associated with fuel cycle sector under the following constraints: supply-demand balance of nuclear power, uranium resource availability, availability of FBR and SF direct disposal (from 2030), material balance, AR SF storage capacity, etc.
- Final decision between reprocessing and direct disposal made within the simulation period



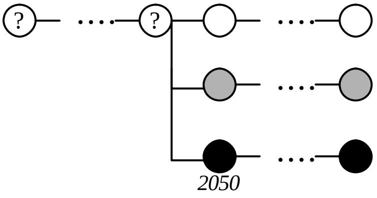
Determination of optimal management of spent fuel
- SF storage = "***reversible***"
- Others = "***irreversible***"

Determination of optimal choice of reactor types

Structure of the fuel cycle submodel in the PGBM-FCOM model

3-Branch Scenario Tree for Uncertain CO_2 Limits

- 3 possible future regulation on CO_2 emissions is assumed to begin from 2050, considering knowledge accumulation and inertia in the energy system (based on Akimoto et al. (1998))
- Scenarios are set as follows: (based on Manne and Richels (1992))
  - **Baseline scenario**: **60%**
    = No CO_2 emissions constraint is imposed
  - **Moderate CO_2 emissions constraint scenario**: **24%**
    = Average annual CO_2 emissions during 2050-2100 is constrained to 20% below 1990 level
    + Available uranium resources are constrained to 20% below the baseline scenario
  - **Strict CO_2 emissions constraint scenario**: **16%**
    = Average annual CO_2 emissions during 2050-2100 is constrained to 50% below 1990 level
    + Available uranium resources are constrained to 50% below the baseline scenario



Baseline scenario
（No CO_2 emissions constraint imposed）

Moderate CO_2 emissions constraint scenario
（Moderate constraints imposed on cumulative CO_2 emissions and available uranium resources）

Strict CO_2 emissions constraint scenario
（Strict constraints imposed on cumulative CO_2 emissions and available uranium resources）

3-branch scenario tree representing uncertainty about the future regulation on CO_2 emissions

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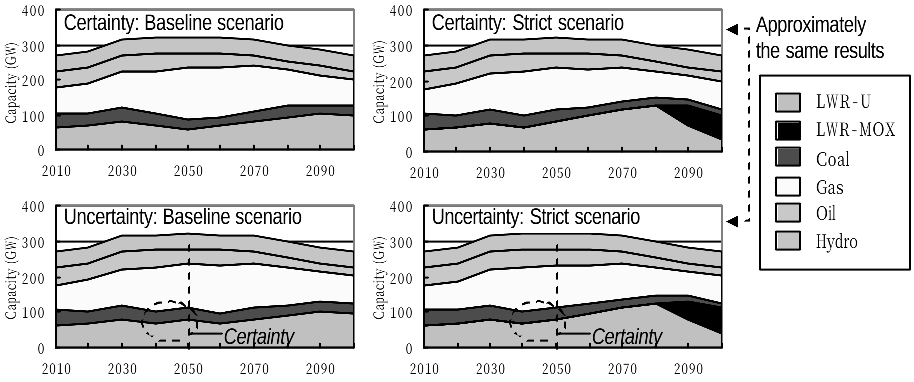
Optimal Strategy under Uncertain CO_2 Limits (1)

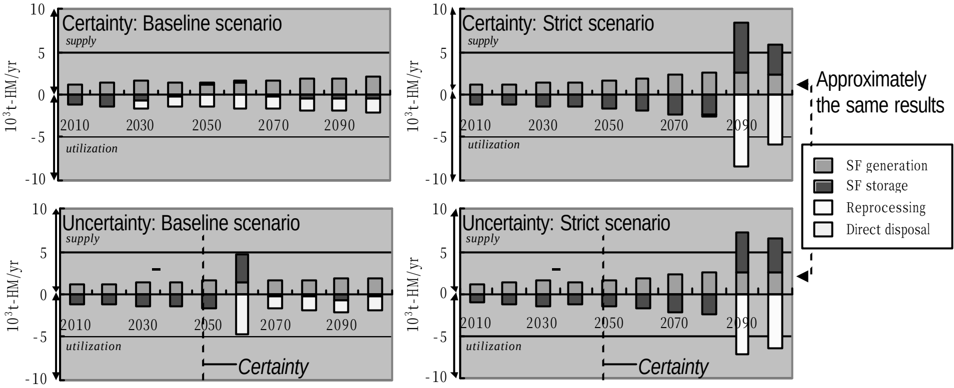
- **Optimal choice of reactor types under certainty**
  - No Pu utilization is chosen in the baseline and moderate constraint scenarios
  - LWR-MOX is chosen in the strict constraint scenario due to the insufficiency of available uranium resources for large-scale introduction of nuclear power to satisfy strict CO_2 emissions constraint
- **Optimal choice of reactor types under uncertainty**
  - Optimal strategy under uncertainty is the same as that in the strict scenario under certainty
  - Precautionary strategy of making decisions **to prepare for the most pessimistic scenario**



Optimal composition of power plants under certainty and uncertainty about the future regulation on CO_2 emissions

Optimal Strategy under Uncertain CO_2 Limits (2)

- **Optimal spent fuel management under certainty**
  - Direct disposal is chosen in the case of no Pu utilization
  - All the SF is stored and then reprocessed according to the Pu demand in the case of Pu utilization
- **Optimal spent fuel management under uncertainty**
  - **Precautionary strategy of storing all the SF** with several options kept open until uncertainty resolution **to prepare for the most pessimistic scenario** and then acting accordingly
  - Such precautionary strategy makes it possible to **address uncertainty in a flexible manner**



Optimal SF flow balance under certainty and uncertainty about the future regulation on CO_2 emissions

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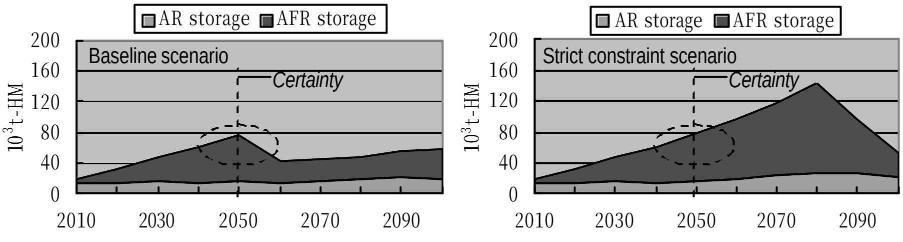
Optimal Strategy under Uncertain CO_2 Limits (3)

- AFR interim SF storage makes it possible to manage SF and Pu in a rational way so that their desirable supply-demand balances will be achieved
  - AFR storage for receiving excess SF at reactors until it is disposed of or reprocessed
  - AFR storage for receiving excess SF to carry out reprocessing according to the demand for Pu
  - This contrasts sharply with the current back-end fuel cycle policy management in Japan
- **AFR interim SF storage** plays an important role in precautionary strategy under uncertainty
  - More AFR SF storage capacity is required for adopting the sensible hedging strategy



Optimal SF storage stocks under uncertainty about the future regulation on CO_2 emissions

政策的含意

- 地球温暖化対策という外部性を考慮しないと、原子力には市場競争力がない。

- 大気中CO_2濃度安定化という地球温暖化対策の究極目標を考慮すると、２１世紀後半には原子力の大幅な拡大が望まれる。

- 21世紀中の天然ウラン資源の利用可能量が現在の既知資源の３倍程度だとすると､地球温暖化対策のため、ＦＢＲによるＰｕの本格的利用が２１世紀後半に必要になる。

- CO_2削減規制の不確実性を考慮すると､当面は使用済み燃料の中間貯蔵を選択し､将来に備えて再処理と使用済み燃料直接処分の両方の選択肢を確保する必要がある。