Energy Modeling Forum (EMF) and application of AIM/Enduse[Global]

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Energy modeling Forum (EMF)

- Energy modeling forum (1976- at Stanford University)
  - Structured forum for discussing important issues in energy and the environment.
  - A series of ad hoc working groups, each focusing on particular issues.
  - Model comparison, which focuses its discussion by comparing the results of different models.
  - Contribution to the integrated assessment of climate change as witnessed in IPCC reports.
- EMF 27
  - Technology strategies for achieving climate policy objectives
  - Major global models are participating

    AIM/CGE, AIM/Enduse, BET, DNE21+, ENV-Linkages, Farm, IMAGE, MERGE, MESSAGE, Phoenix, POLES, ReMIND, TIAM-World, WITCH

Scenario architecture of EMF 27 study

- Scenarios are specified by combination of technology and policy cases.
- A technology case specifies the availability or the status of key technologies.
- A policy case specifies the emission reductions requirements and the configuration of the international climate policy.

Technology Dimension									
	Default	**Single technologies changed**					**Conventional vs. renewable**		**Frozen technology**
Energy Intensity	Ref	Low	Ref	Ref	Ref	Ref	Ref	Low	Frozen
CCS	On	On	Off	On	On	On	On	Off	Off
Nuclear energy	On	On	On	Off	On	On	On	Off	Frozen
Wind & Solar	Adv	Adv	Adv	Adv	Cons	Adv	Cons	Adv	Frozen
Bioenergy potential	High	High	High	High	High	Low	Low	High	Frozen
Policy Dimension									
Baseline	R2G1	R2G2		R2G3	R2G4	R2G5	R2G6	R2G7	R2G8
450 CO2e	R2G9	R2G10	R2G11	R2G12	R2G13	R2G14	R2G15	R2G16	
550 CO2e	R2G17	R2G18	R2G19	R2G20	R2G21	R2G22	R2G23	R2G24	R2G25
G8	R2G26							R2G27	
Muddling through	R2G28							R2G29	

Overview of AIM/Enduse[Global]

- **Partial equilibrium on energy and non-energy commodity**
- **Dynamic recursive optimization (one-year time step, limited foresight)**

  Minimizing total cost given externally fixed demand for energy and non-energy service such as steel production, passenger transport, agricultural products, etc.
- **Technology rich (About 200 technologies in each region)**
- **Time horizon:** 2005 – 2050
- **Regional coverage:** World 32 regions
- **Gas:** CO_2, CH_4, N_2O, HFC, PFC, SF_6
- **Sectors:**

  Energy end-use: Industry, Residential, Service, Transport, Other

  Energy supply: Power generation, Heat generation, Coal transformation, Oil refinery, Gas transformation, Fuel mining
  Non-energy: Agriculture, Waste, F-gases

Technology options (1)

Sector	Category	Technology options
Power generation	Coal power plant	Pulverised coal combustion(PCC), Supercritical(SC) PCC, Ultrasupercritical(USC) PCC, Integrated gasification combined cycle(IGCC), SC PCC with Carbon capture and storage(CCS), USC PCC with CCS, IGCC with CCS
	Gas power plant	Combined cycle, Advanced combined cycle(ACC), ACC with CCS
	Renewables	Wind power, Photovoltaics, Biomass power plant, Biomass IGCC, Biomass IGCC with CCS
Hydrogen production		Coal, Coal with CCS, Natural gas, Natural gas with CCS, Biomass, Biomass with CCS
Industry	Steel	Large size coke oven, Coke gas recovery, Automatic combustion, Coke dry type quenching, Coal wet adjustment, COG latent heat recovery, Next generation coke oven, Automatic igniter, Coller waste heat recovery, Mainly waste heat recovery, High efficiency igniter, Blast furnace gas recovery, Blast furnace gas recovery with CCS, Wet top pressure recovery turbine, Dry top pressure recovery turbine, Heat recovery of hot blast stove, Coal injection, Dry top pressure gas recovery, LDG recovery, LDG latent heat recovery, Continuous caster, Hot charge rolling, Hot direct rolling, High efficiency heating furnace, Heat furnace with regenerative burner, Continuous annealing lines, DC electric furnace, Scrap pre-heat
	Cement	Ball mill, Tube mill, Vertical mill, Wet kiln, Semi wet/dry kiln, Dry long kiln, Vertical (Shaft) kiln, SP/NSP, Advanced kiln with CCS
	Other industries	High-efficiency boiler (coal, oil, gas), boiler with combustion control (coal, oil, gas), cogeneration (coal, oil, gas), Regenerative gas boiler, High-efficiency industrial furnace (oil, gas), Motor with Inverter control, High efficiency motor

Technology options (2)

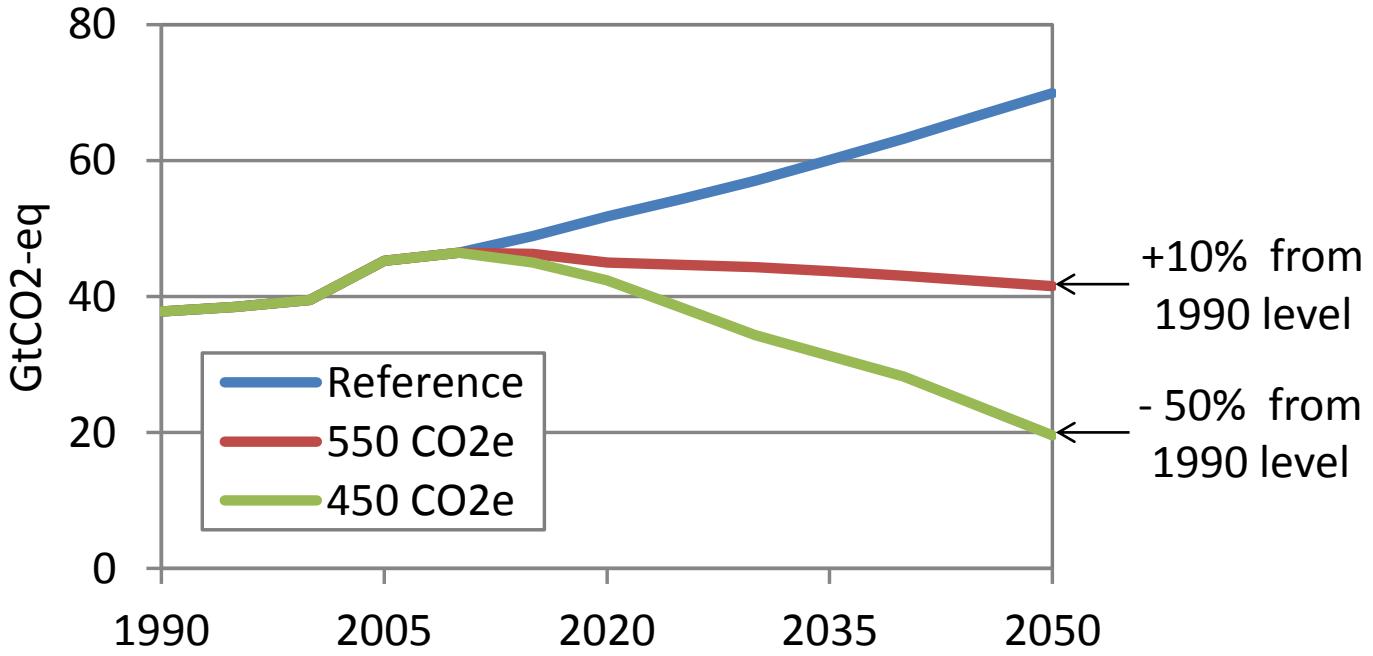
Sector	Category	Technology options
Residential & Commercial	Cooling	High-efficiency Cooler (Sold average in developed countries in 2000, Top Runner, Highest performance)
	Warming	High-efficiency kerosene stove , LPG Stove, Gas Stove, High-efficiency air conditioner (Sold average in developed countries in 2000, Top Runner, Highest performance), Wall insulation for detached house, Wall insulation, Double-glazed Glass with Low-e
	Hot water	High-efficiency kerosene water heater, High-efficiency LPG water heater, Latent Heat Recover LPG Water Heater, Latent Heat Recover Gas Water Heater, CO2 Refrigerant water heater, Solar thermal water heater, Fuel cell
	Cooking	High-efficiency Gas Cooking Stove(LPG, Natural gas)
	Lighting	Fluorescent of incandescent type, Fluorescent with energy saving stabilizer, Inverter type fluorescent, Hf Inverter type fluorescent
	Refrigerator	High-efficiency refrigerator(Sold average in developed countries in 2000, Top Runner , Highest performance)
	TV	High-efficiency TV (Sold average in developed countries in 2000, Top Runner, Highest performance), TV (Liquid crystal display)
Transport	Passenger car	High-efficiency passenger car, Weight reduction, Engine friction reduction, Aerodynamic drag reduction, Rolling resistance reduction, Brake drag reduction, Continuously variable transmission, VVLT & cylinder reactivation, GDI Engine, Hybrid electric vehicle(HEV), Electric vehicle(EV), fuel cell vehicle(FCV), Biofuel
	Truck	High-efficiency truck, Engine improvement, Weight reduction, Aerodynamic drag reduction, Rolling resistance reduction, Natural gas vehicle, Hybrid vehicle, Fuel cell vehicle, Biofuel
	Passenger bus	High-efficiency bus, Rolling resistance reduction for bus, Hybrid engine, Biofuel
	Ship	High-efficiency ship, Biofuel
	Aircraft	High-efficiency aircraft, Biofuel
	Rail	High-efficiency train, Regenerative braking system with VVVF

Technology options (3)

Sector	Category	Technology options
Agriculture	Rice cultivation	Water management (Midseason drainage, Shallow flooding, Alternative flooding/Drainage), fertilizer management (ammonium sulfate), upland rice, Addition of Phosphogypsum, Direct Wet Seeding, Off-season straw, Rice Straw Compost
	Cropland	Reduce fertilization, Nitrogen inhibitor, Fertilizer Free Zone, Optimize distribution geometry, fertilization management (Spreader maintenance, Split fertilization, Sub-optimal fertilizer application), Convert fertilizational tillage to no-till
	Mature management	Anaerobic Digestion (Centralized plant, Farmscale plant), Covered Digester, Covered lagoon, daily spread of manure, Complete mix digester, Plug flow digester, slowing down anaerobic decomposition
	Livestock rumination	Administration of chemical substance (Propionate precursors, Pribiotics), feed management (High Fat Diet, Improved feed intake and genetics, Replace roughage with concentrates)
Waste	Municipal Solid Waste	Biological Treatment, Improved oxidation through improved capping and restoration, Direct Use of Landfill Gas, Electricity and Heat Generation from landfill gas, Flaring Landfill Gas, Upgrade Natural Gas, Anaerobic Digestion, Composting (windrow plant, tunnel plant, hall plant), Incineration, Paper recycling
Fluorinated gases emission	By-product emissions	Thermal Oxidation
	Refrigerants	Alternative system (carbon dioxide, hydrocarbons, hydrocarbons & NH_3), Leakage reduction, Recovery, Decomposition
	Aerosols	Alternative aerosol (Hydrocarbon Aerosol Propellants, Not-in-kind Alternatives), 50% reduction (for Medical applications, General Aerosol Propellants)
	Foam blowing agents	Recovery, Decomposition, Alternative System (Water-blown CO_2 Systems, Liquid CO_2 Foam Blowing, Hydrocarbon Foam Blowing)
	Solvents	Alternative Solvents (NIK Aqueous, NIK Semi-Aqueous), Retrofit Options, 50% reduction
	Manufacturing	Cleaning facility (NF_3 In Situ Clean, NF_3 Remote Clean), Recapture/Destroy, Plasma Abatement, Catalytic Destruction, Thermal Oxidation, Retrofit (PFPB, SWPB, CWPB, VSS, HSS), SO_2 Replacement
	Electrical equipment	Leakage reduction, Device recycle

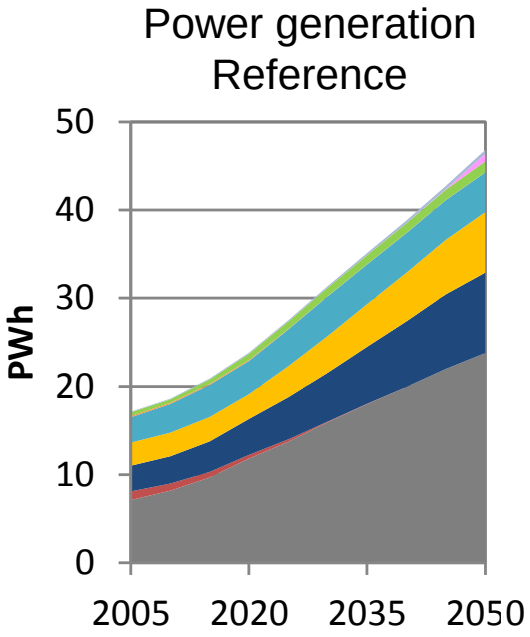
Global GHG emission trajectories

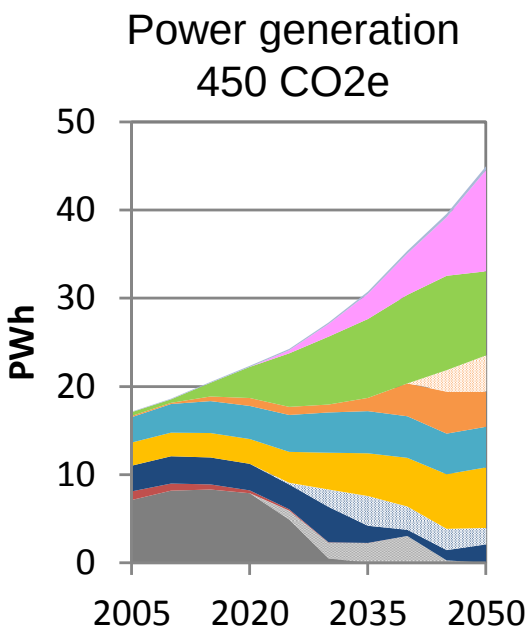
- Global GHG emission trajectories of stabilization scenarios are externally calculated by AIM/Impact[Policy], a dynamic optimization model.
- In 550 scenario, global GHG emissions in 2050 increase by +10% from 1990 level and in 450 scenario they decrease by 50% from 1990 level.
- AIM/Enduse[Global] is used to assess technical feasibility of these GHG emission trajectories.

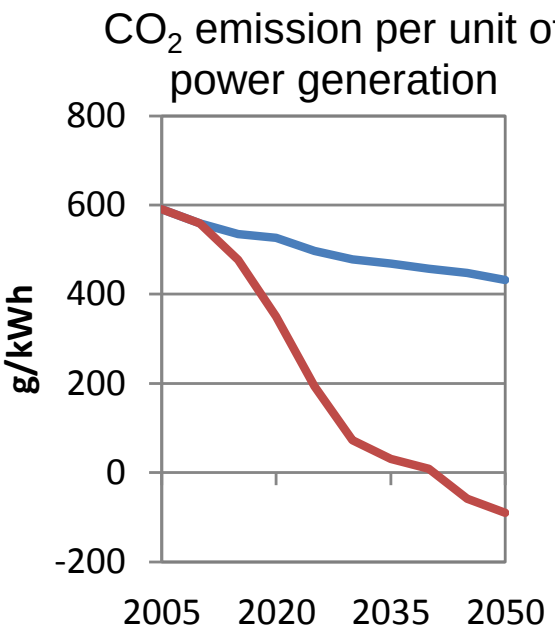


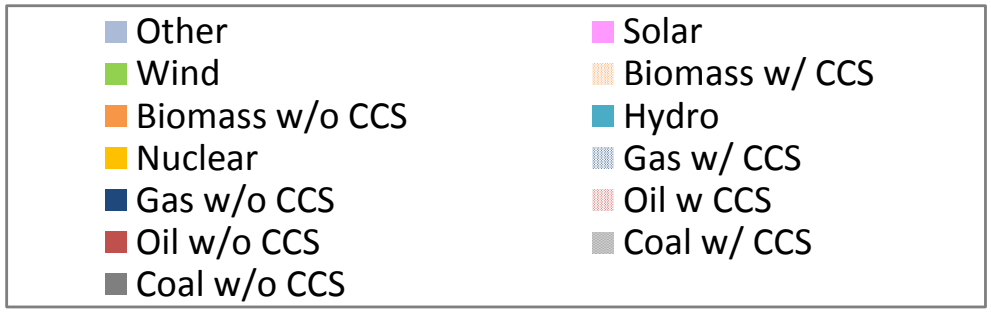
Power sector

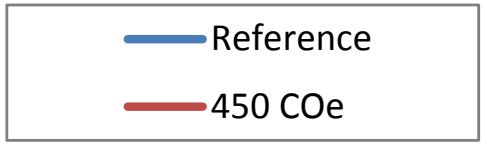
- In 450 scenario, renewable energies account for 75% of total electricity generation in 2050. Biomass with CCS is introduced after 2040.
- As a result, CO_2 emission per unit of power generation become negative after 2040.





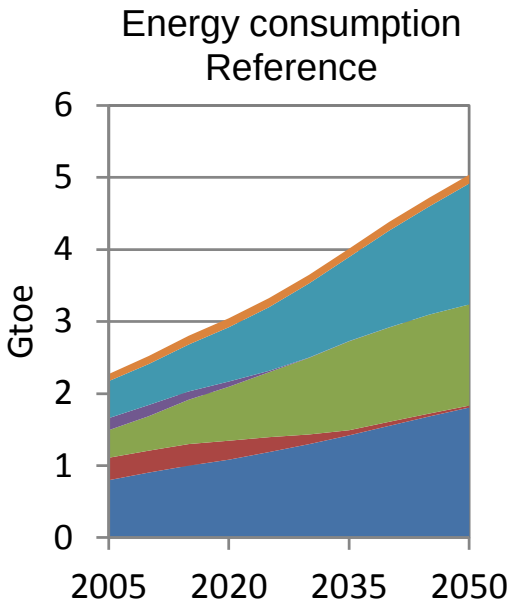


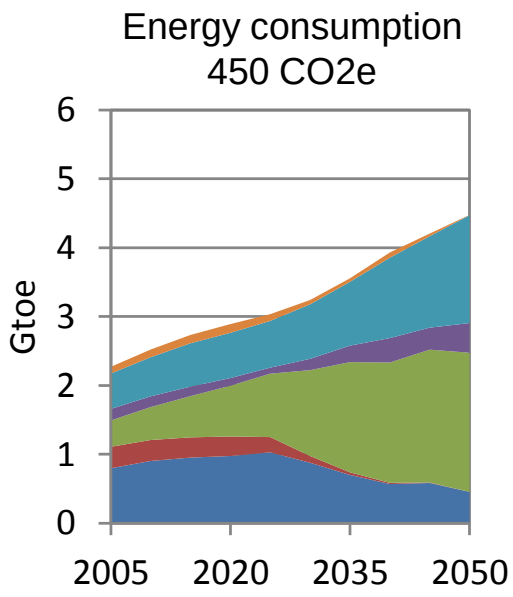


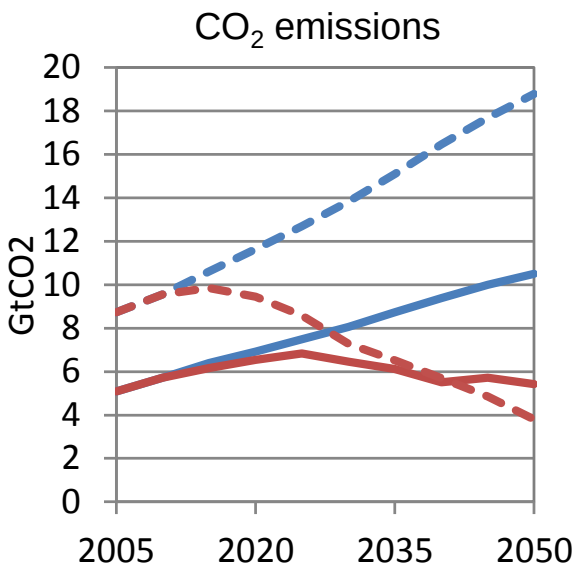


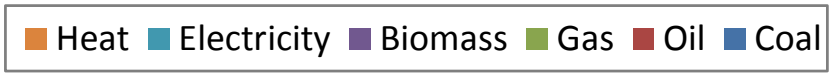
Industrial sector

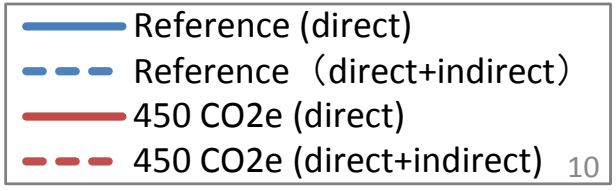
- In 450 scenario, fuel switching from coal to gas takes place.
- Direct CO_2 emissions in 2050 results in the same level as that of 2005.
- Including indirect emissions, CO_2 emissions are reduced more dramatically due to very low CO_2 emission factor of electricity.





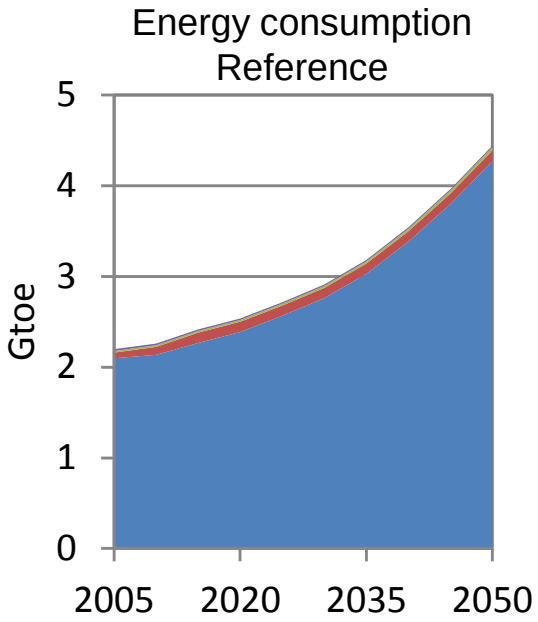


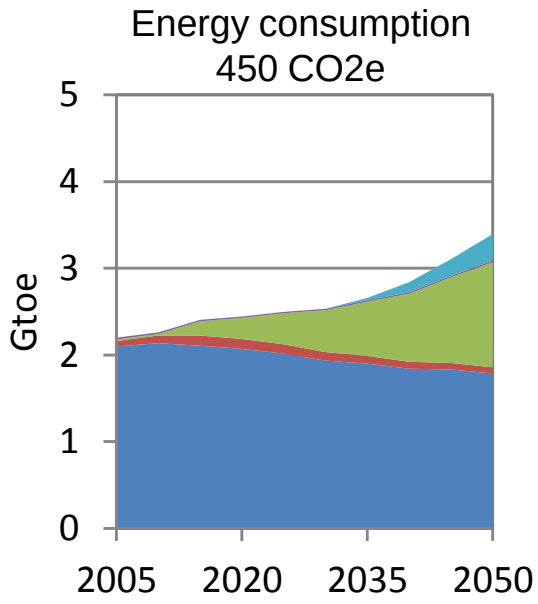


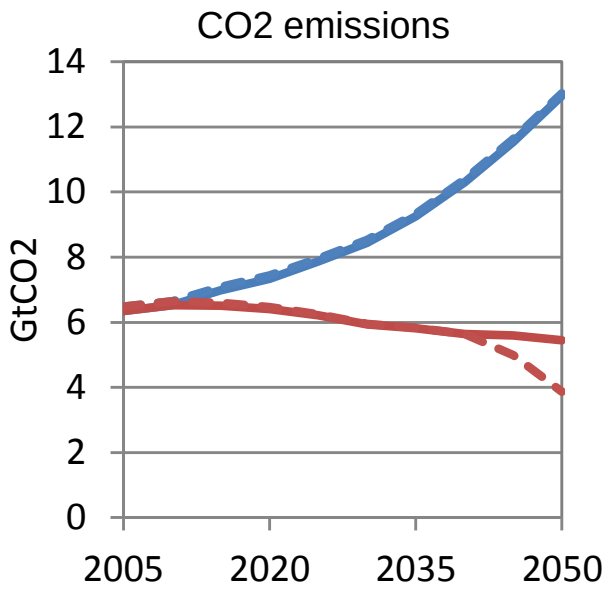


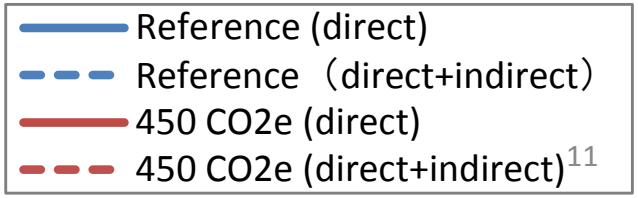
Transportation sector

- In 450 scenario, energy consumption in 2050 is reduced by 25% from reference scenario and biofuel is widely used.
- As a result, direct CO_2 emissions in 2050 is reduced by 15% from 2005 level in 450 scenario.

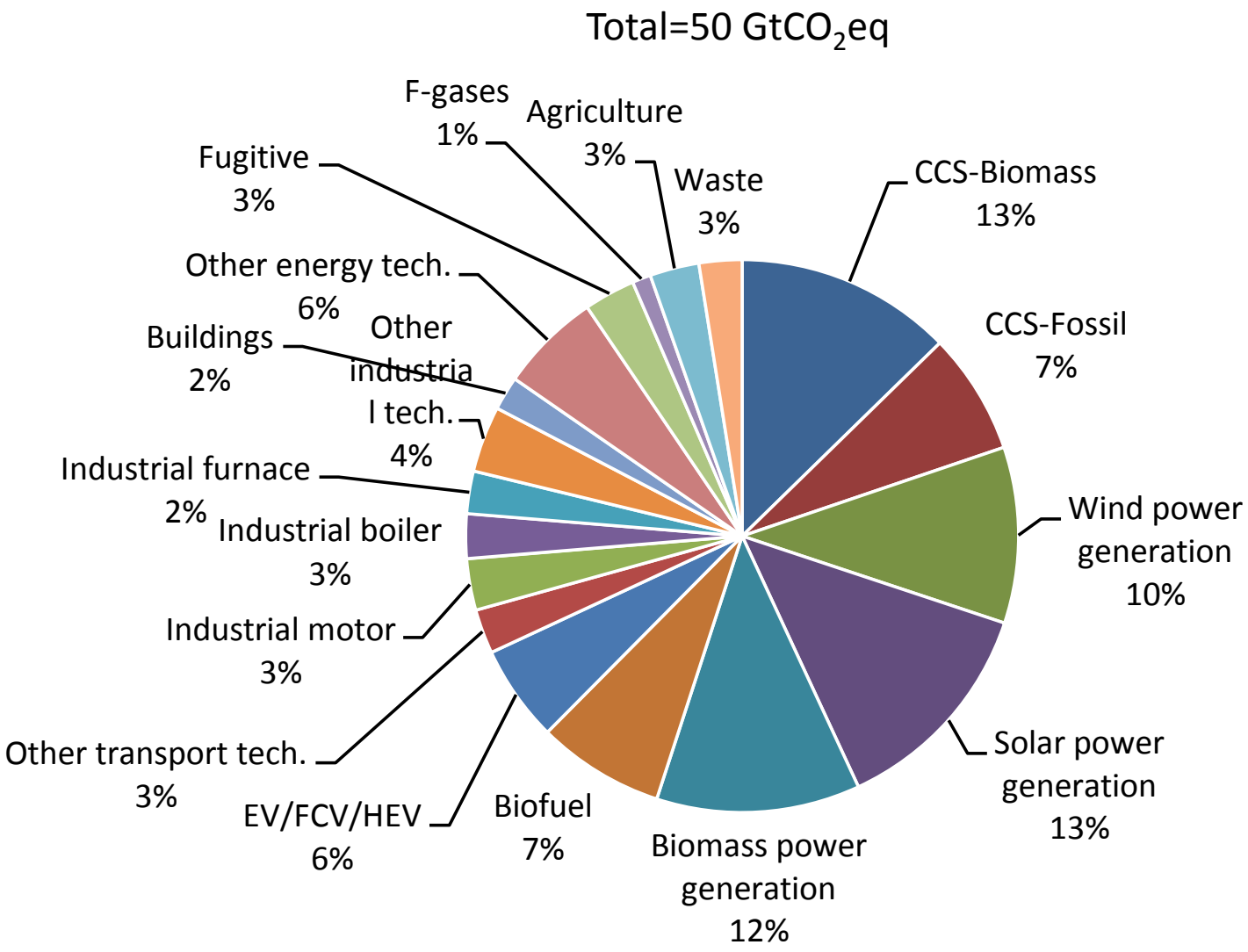








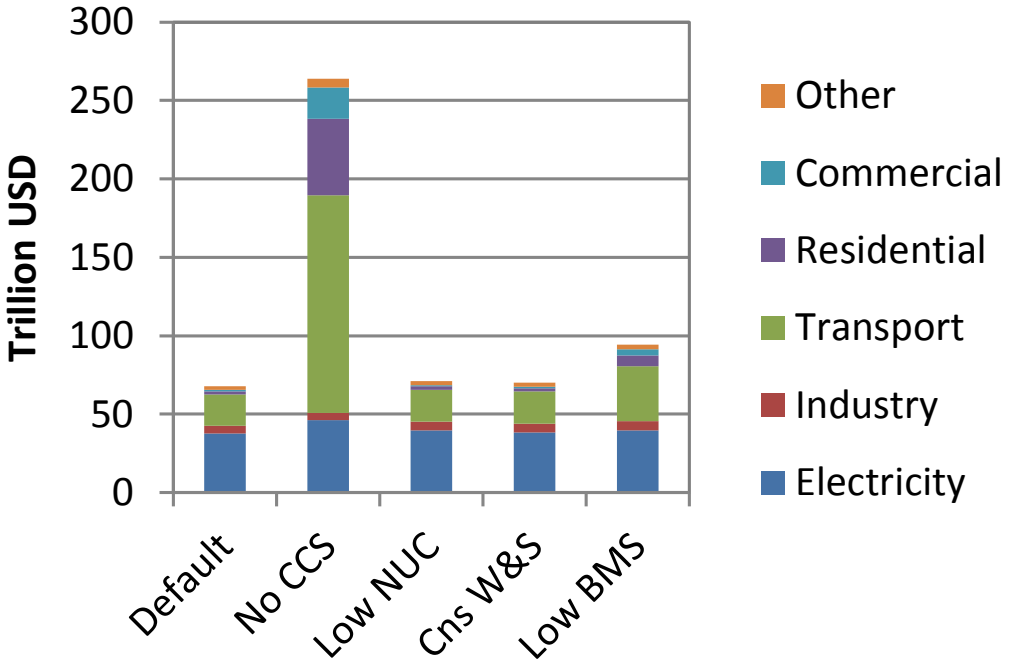
Global GHG emission reduction by technology in 2050 in 450 scenario



Impact of technology limitation

- In all technology cases, 450 scenarios is technically feasible until 2050.
- However, abatement cost increase significantly especially in no CCS scenario.
- This is mainly because introduction of expensive low-carbon technologies in transport and buildings sectors are required to be widely deployed in order to compensate for absence of CCS in power and industry sectors.

Additional cumulative investment cost
in the world in 2005 - 2050

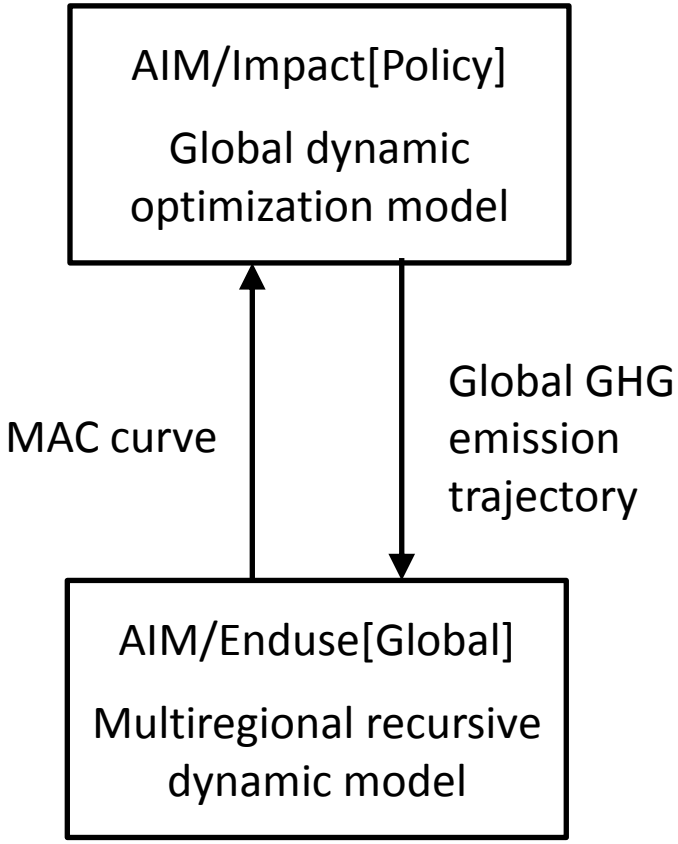


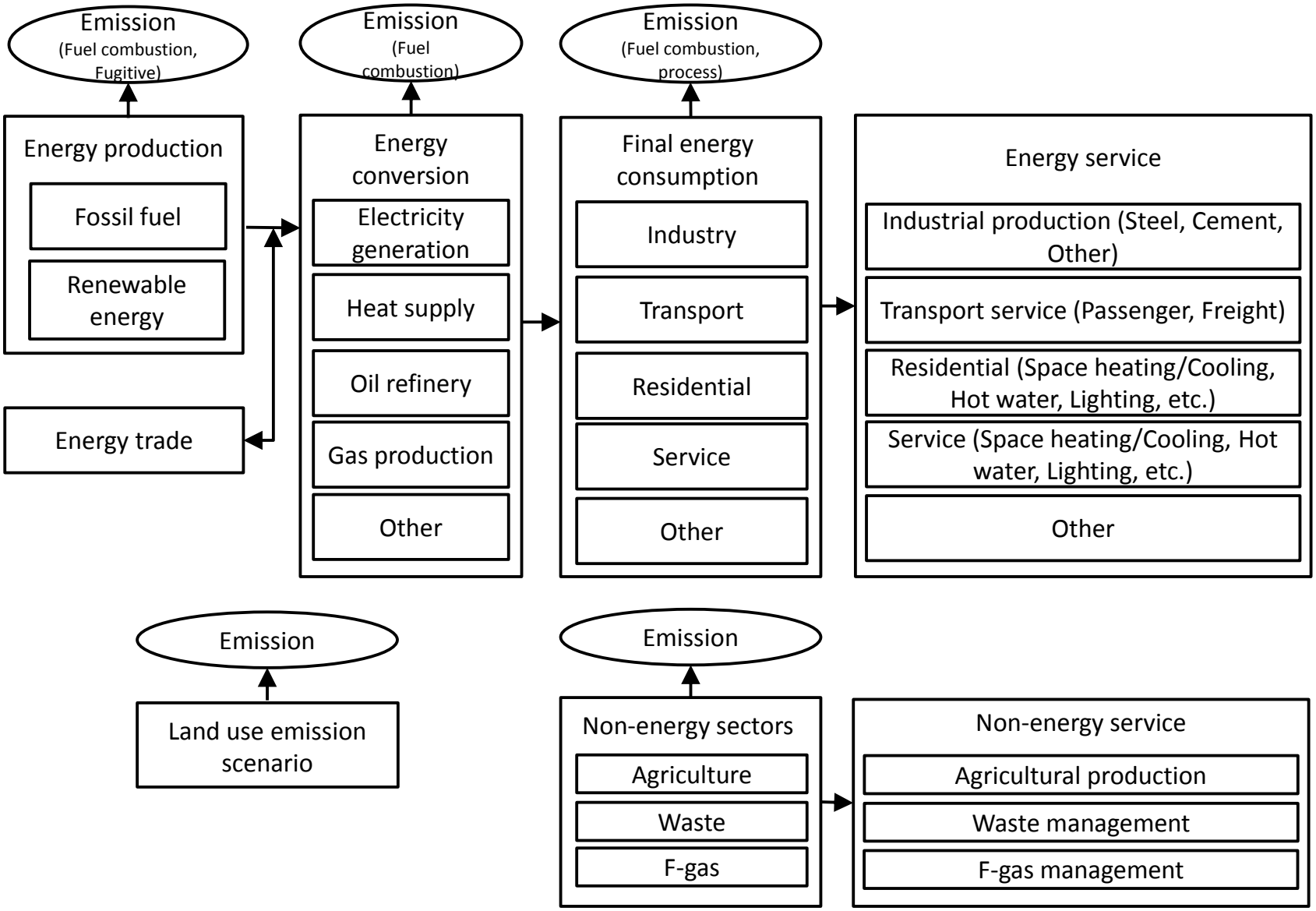
- **No CCS:** No CCS is allowed.
- **Low NUC:** Phase out of nuclear. (No construction of new plants beyond those already under construction or planned.)
- **Cns W&S:** Conservative techno-economic assumption for solar and wind energy technologies
- **Low BMS:** Total global bio-energy supply is limited to 100 EJ.

Summary

- AIM/Enduse[Global] is applied for EMF 27 scenarios.
- Analysis by AIM/Enduse[Global] shows that …
  - 450 ppm CO2e scenario is technically feasible. However, it requires a drastic change in energy systems.
  - The top five key technologies in terms of reduction amount are CCS, solar power generation, wind power generation, biomass power generation and biofuel. These technologies, in total, account for 62% of global GHG emissions reduction in 2050.
  - In all technology cases, 450 scenarios turn out to be technically feasible. However, abatement cost increase significantly especially if CCS in not available.
- These analyses do <u>not</u> consider energy service demand reduction (e.g. reduction of steel products by dematerialization policy, reduction of transportation demand by urban planning, etc.).
- In the next step, we would like to take into account service demand reduction by linking LCS service demand models and CGE model with AIM/Enduse[Global].

Modeling framework




Emission
(Fuel combustion, Fugitive)
Emission
(Fuel combustion)
Emission
(Fuel combustion, process)
Energy production
Fossil fuel
Renewable energy
Energy trade
Energy conversion
Electricity generation
Heat supply
Oil refinery
Gas production
Other
Final energy consumption
Industry
Transport
Residential
Service
Other
Energy service
Industrial production (Steel, Cement, Other)
Transport service (Passenger, Freight)
Residential (Space heating/Cooling, Hot water, Lighting, etc.)
Service (Space heating/Cooling, Hot water, Lighting, etc.)
Other
Emission
Land use emission scenario
Emission
Non-energy sectors
Agriculture
Waste
F-gas
Non-energy service
Agricultural production
Waste management
F-gas management

Residential sector

- There is no significant change in scenario compared to reference scenario.
- However, CO_2 emissions, including direct and indirect emissions, are reduced dramatically due to very low CO2 emission factor of electricity.