Circular Carbon Economy and Decarbonized Use of Fossil Fuels

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4R technologies to manage carbon

Major 4R technologies

Reduce	Reuse	Recycle	Remove
Reducing the amount of carbon entering the system	Reusing carbon without chemical conversion	Recycling carbon with chemical conversion	Removing carbon from the system
• Energy and materials efficiency • Renewable energy, including hybrid use with fossil fuel • Nuclear energy, including hybrid use with fossil fuel • Advanced ultra-super-critical technologies for coal power plants • Hydrogen (blue/green) fuel cells for long-distance heavy-duty vehicles • Ammonia produced from zero-carbon hydrogen (blue/green) for power generation and ships • Direct reduction in steel making by using CO_2 free hydrogen (blue/green)	• Carbon capture and utilization (CCU) • Use CO_2 at carbon utilization facilities, such as at greenhouses for enhancing crops • Bio-jet fuels with reed beds • Algal synthesis	• CCU • Artificial photosynthesis • Bioenergy recycle in the pulp and paper industry • Bioenergy with carbon capture and storage • Carbamide (urea production using CO_2 as feedstock) • Coal ash concrete curing with absorbing CO_2 • Electrochemical reduction of CO_2 • Fine chemicals with innovative manufacturing processes and carbon recycling • Fischer-Tropsch exothermic of carbon dioxide with hydrogen syngas • Hydrogenation to formic acid • Oil sludge pyrolysis • Sabatier synthesis (CO_2 methanation: exothermic of carbon dioxide with blue/green hydrogen) • Thermal pyrolysis	• CCS • Direct air capture (DAC) • Carbon dioxide removal • Fossil fuels-based blue hydrogen

Source : Mansouri, N. Y. *et al.*(2020) “A Carbon Management System of Innovation: Towards a Circular Carbon Economy”

A critical element of “4R” categorizations in CCE is neutrality to emissions reduction technologies.

The concept of 4R highlights the importance of Reuse and Recycle technologies that regard carbon as a resource.

Base scenarios of IEEJ Outlook

	Reference Scenario	Advanced Technologies Scenario (ATS)
	Reflects past trends with technology progress and current energy policies, without any aggressive policies for low-carbon measures.	**Assumes introduction of powerful policies** to address energy security and climate change issues with the utmost penetration of low-carbon technologies.
Social-economy structure	Stable growth led by developing economies despite slower population growth. Rapid diffusion of energy consuming appliances and vehicles due to higher income.	
International energy price	**Oil** supply cost increases along with demand growth. **Gas** price convergences among Europe, North America and Asia markets. **Coal** keeps unchanged with today's level.	Slower price increase due to lower demand growth (coal price decreases).
	[LNG in Asia] Higher/lower price cases	
Energy policies	Gradual reinforcement of low-carbon policies with past pace.	Further reinforcement of domestic policies along with international collaboration.
Energy technologies	Improving efficiency and declining cost of existing technology with past pace.	Further declining cost of existing and promising technology.

Assumptions of CCE Scenario

❖ Assumed adoptions of 4R technologies in CCE scenario

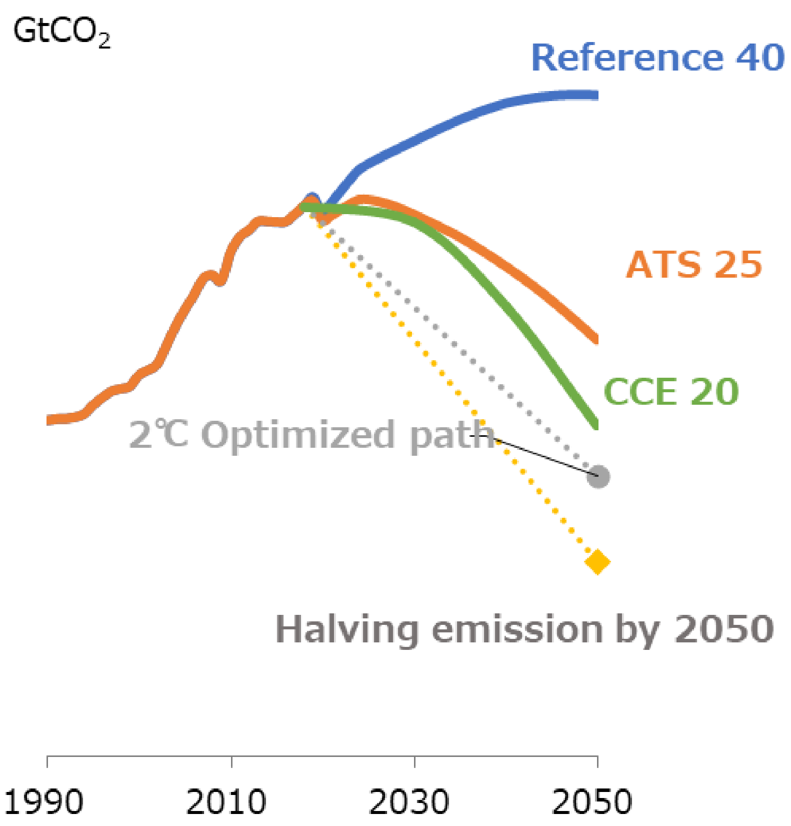
4R	Technology	Assumption
Reduce	Blue hydrogen* for power generation	Adopt blue hydrogen power generation (including ammonia produced from blue hydrogen) for 50% of coal-fired power plants without CCS facility as of 2050 in Advanced Technologies Scenario (ATS)
	Blue hydrogen for transportation	Adopt blue hydrogen (mainly as fuel cell vehicle) to 20% of road transportation demand as of 2050
	Direct reduction in steel making by blue hydrogen	Adopt direct reduction technology utilizing blue hydrogen to 25% of crude steel production in OECD, China, and India as of 2050
	Reduction of cement production	Reduction of cement production by 25% utilizing coal ash and limestone and calcined clay as of 2050
Reuse	Algae synthesis to produce biofuel	Increase algae-based bio-diesel by 50% from ATS
Recycle	Concrete curing capturing CO_2	Adopt concrete curing capturing CO_2 technology to 50% of the world concrete production as of 2050
	Synthetic methane	Replace natural gas with synthetic methane (produced from and green hydrogen** and green hydrogen) for 50% of gas-fired power plants without CCS facility as of 2050 in ATS
Remove	Carbon capture and storage	CCS for blue hydrogen production

*Blue hydrogen : Hydrogen produced from fossil fuels with CCS
**Green hydrogen : Hydrogen produced by electrolysis utilizing electricity from renewable power generation

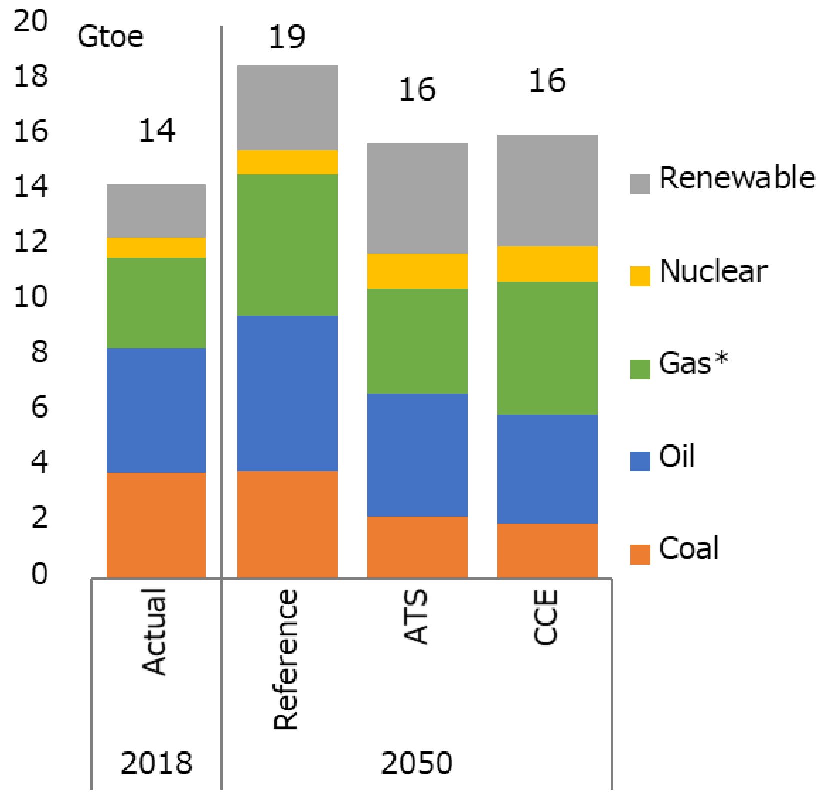
In addition to the assumptions to ATS, CCE scenario assumes the utmost adoptions of 4R technologies to decarbonize fossil fuel use.

Emissions reduced while keeping using fossil fuels

World CO_2 Emissions



Total Primary Energy Demand of the World



*Gas in CCE scenario includes synthetic methane

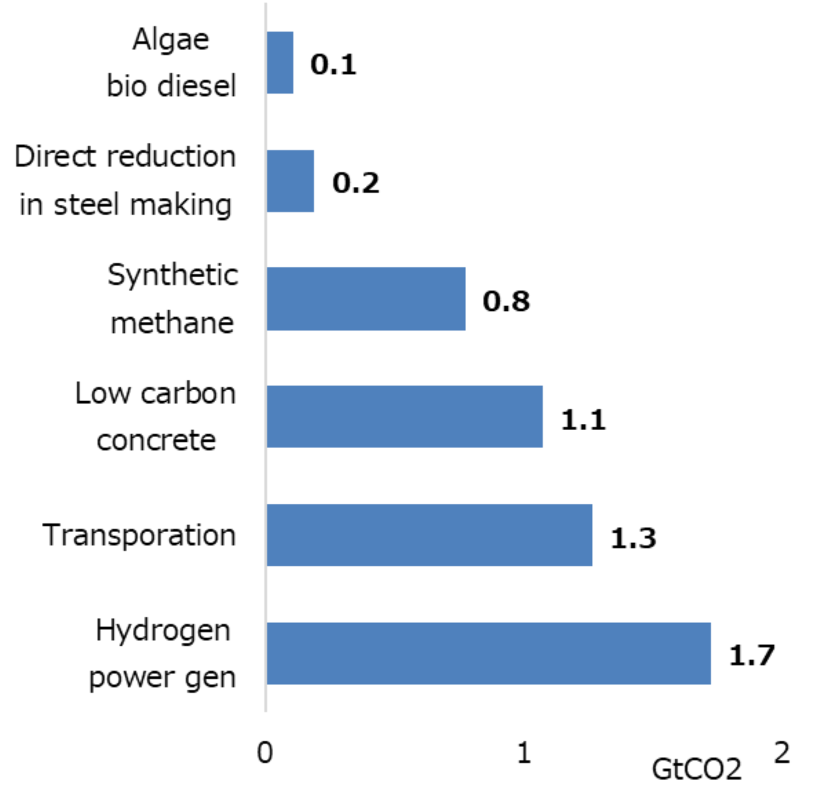
CO_2 emissions are reduced by 5Gt from ATS and approaches 2℃ optimized path.

While the share of fossil fuels of CCE scenario is almost same as ATS', the mix of fossil fuels shifts from coal and oil to natural gas as a primary feedstock of blue hydrogen.

CO_2 emissions significantly reduced while the consumption of fossil fuel unchanged.

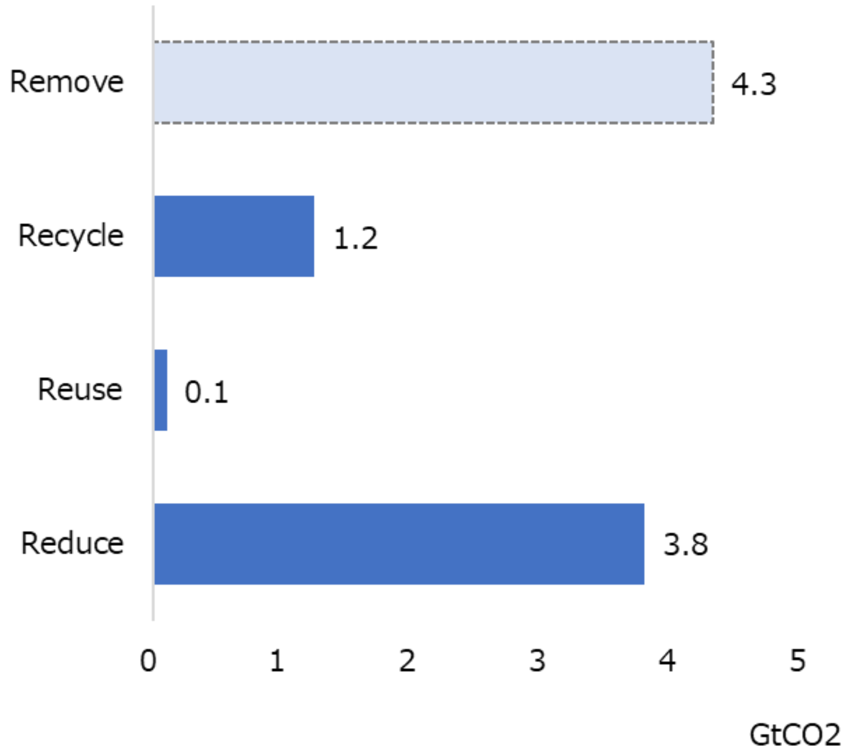
Power and transport sectors have large reduction potential.

❖ CO_2 emissions reduction by technology



* The amount of Low carbon concrete is the sum of reduced volume of cement production reduction and concrete curing absorbing CO_2.

❖ CO_2 emissions reduction by 4R



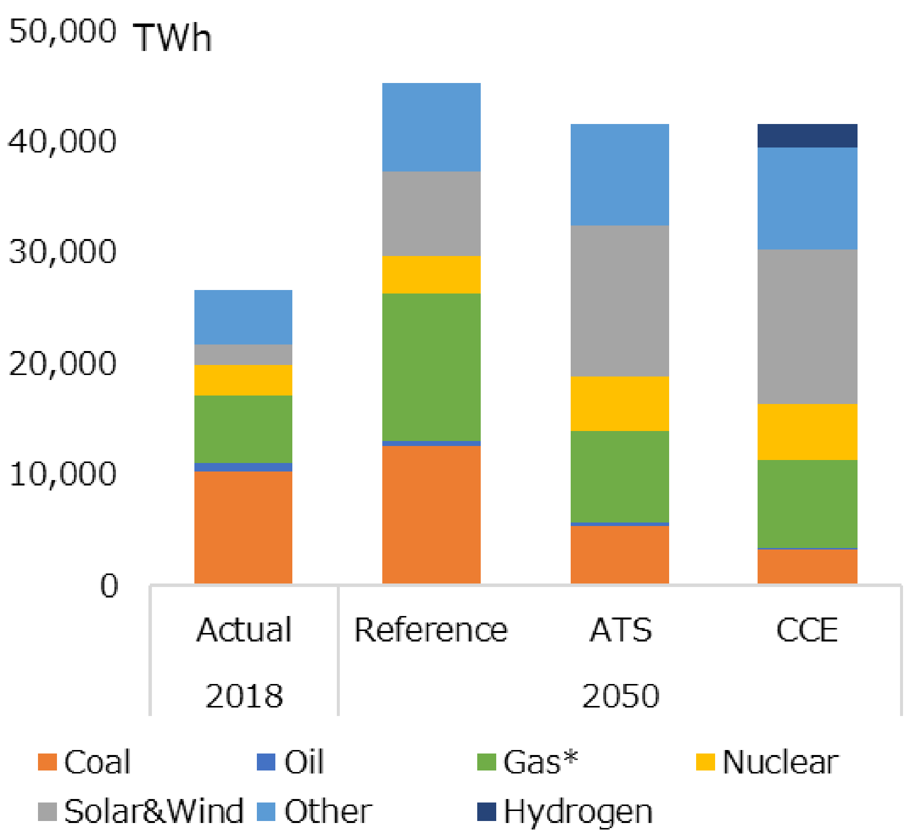
Reduce: Hydrogen power generation, hydrogen for transportation, cement production reduction, direct reduction of steel making
Reuse : Algae biodiesel
Recycle : CO_2 absorbing concrete, synthetic methane
Remove: CCS（also counted in Reduce and Recycle technologies)

Power and transportation sectors have high potential of emissions reduction in CCE scenario. Blue hydrogen plays a significant role in both sectors.

Reduce technologies contributes the reduction most while the Reuse and Recycle’s contributions are relatively small.

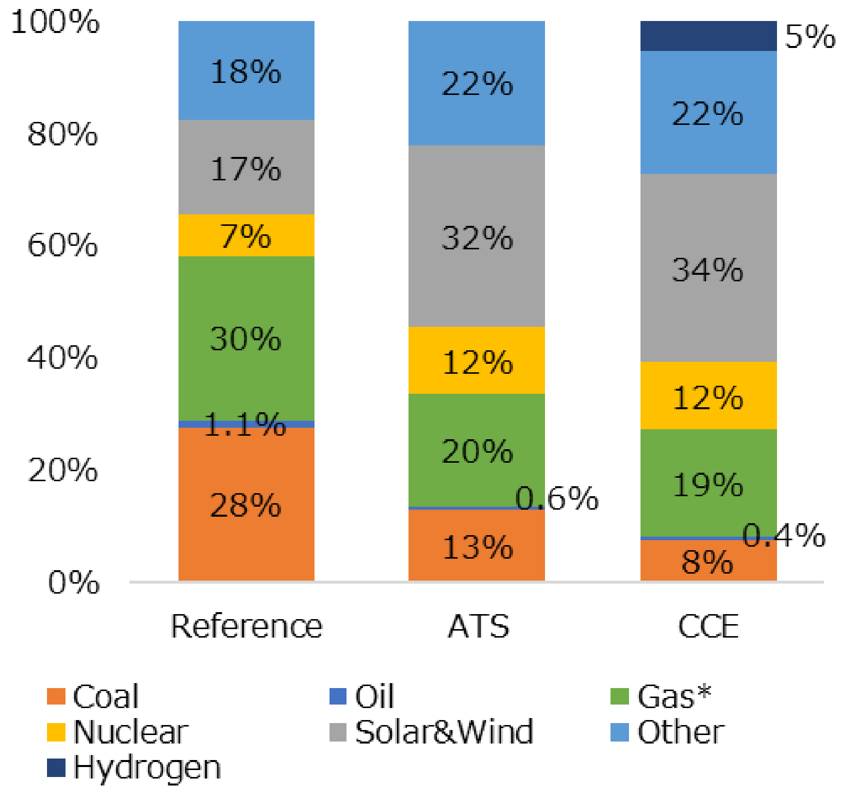
Coal-fired power is partially replaced with H_2.

❖ Electricity generation (World)



*CCE scenario includes synthetic methane.

❖ Power generation mix (World as of 2050)

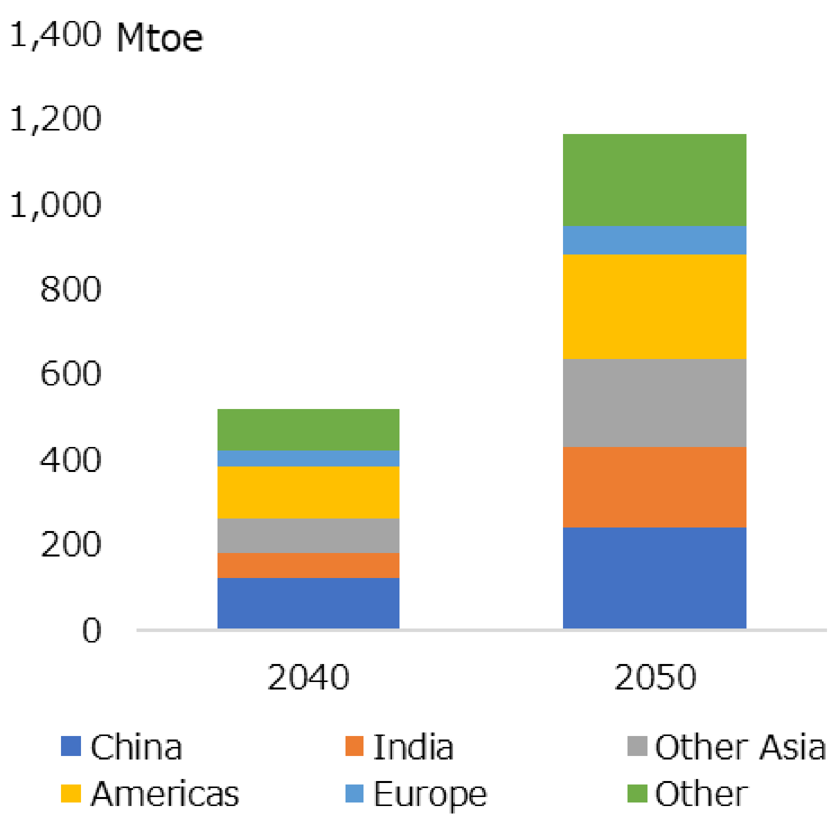


*CCE scenario includes synthetic methane.

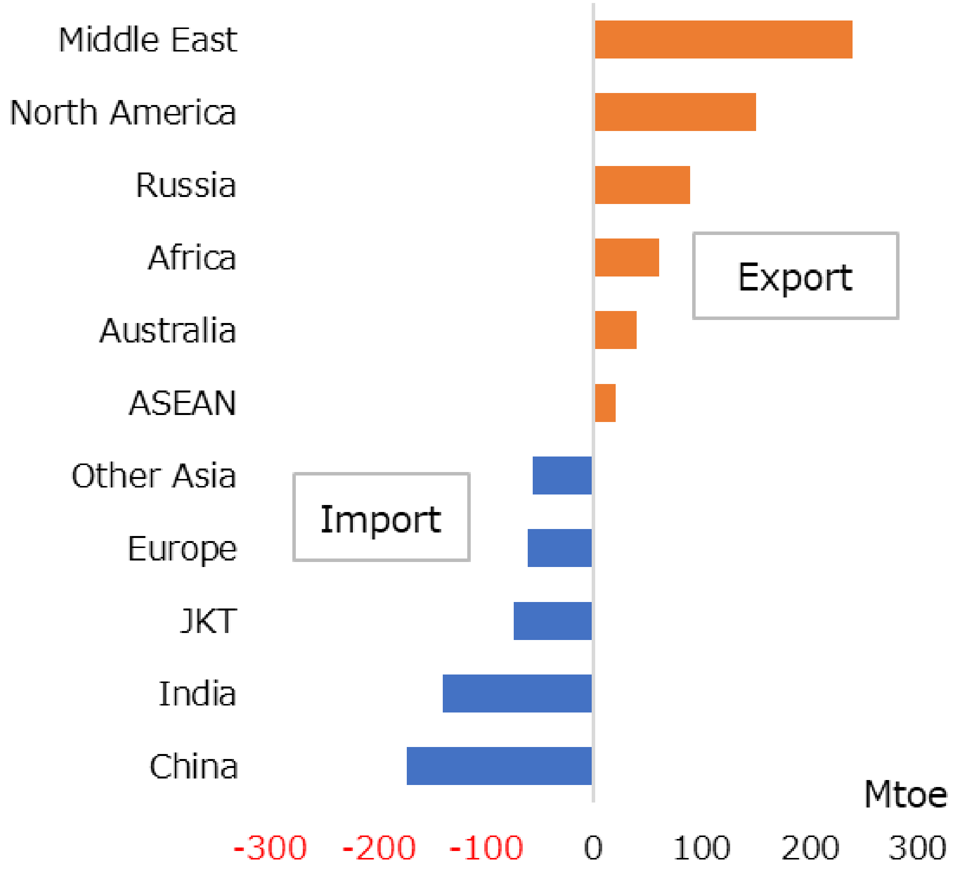
Share of fossil fuels will decline from 34% to 27% in CCE scenario.
Share of hydrogen power will be 5% as of 2050.

Hydrogen demand will grow in Asia.

❖ World hydrogen demand



❖ Hydrogen export/import balance (2050)

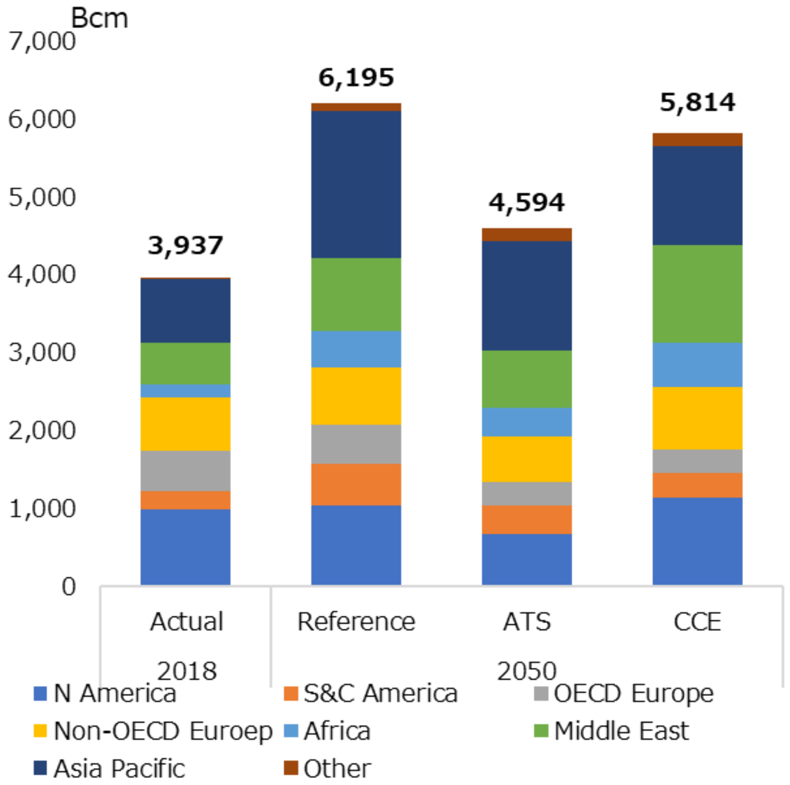


World hydrogen demand is expected to grow mainly in Asia in CCE scenario.

Countries without blue hydrogen production capability will need to import blue hydrogen from countries with low cost and abundant fossil fuel resources with CCS capability.

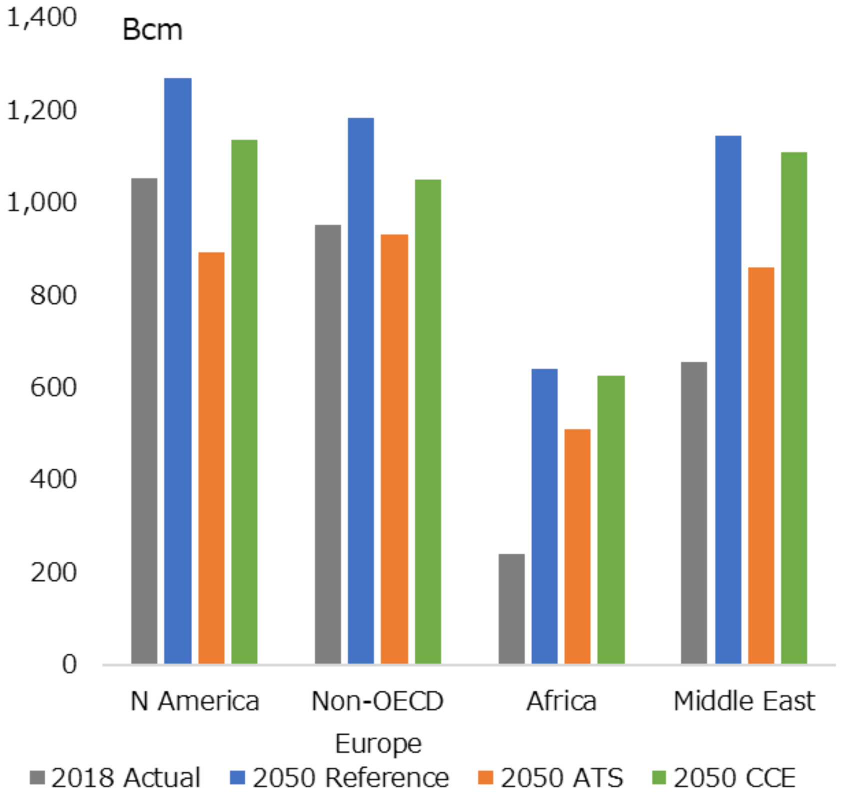
New natural gas demand will emerge.

❖ Natural gad demand* (World)



*Includes synthetic methane

❖ Natural gas production (as of 2050)



Natural gas demand will grow by 27% in CCE scenario as of 2050 because of the additional feedstock demand for blue hydrogen.*

Major gas producing countries are required to increase their production although the volume of production will not exceed the reference scenario.

***This scenario assumes 80% of blue hydrogen will be produced by natural gas.**

Implications

- By intensively adopting technologies to decarbonize fossil fuels, carbon emissions can further be reduced while keeping using fossil fuels.

- Blue hydrogen will play a key role in CCE scenario. Reduction of its production cost and infrastructure developments need to be accelerated.

- The concept of Circular Carbon Economy brings useful implications by highlighting the importance of neutrality to technologies and more options to pursue carbon emissions reduction.