Co-firing of Clean Ammonia for Decarbonization in Asia

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Tatsuya Terazawa
Chairman & CEO
The Institute of Energy Economics, Japan (IEEJ)

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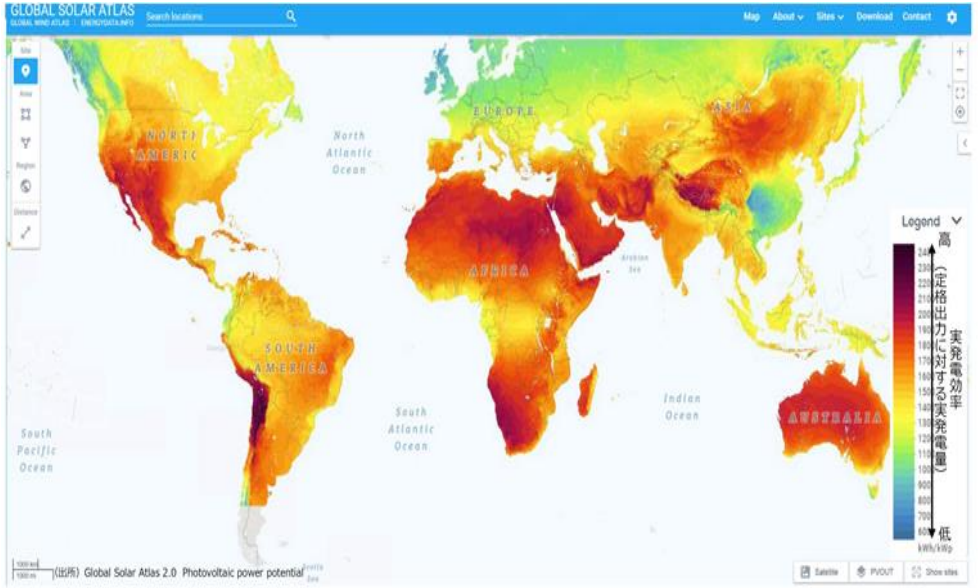
Renewable energy resources in Asia are limited.

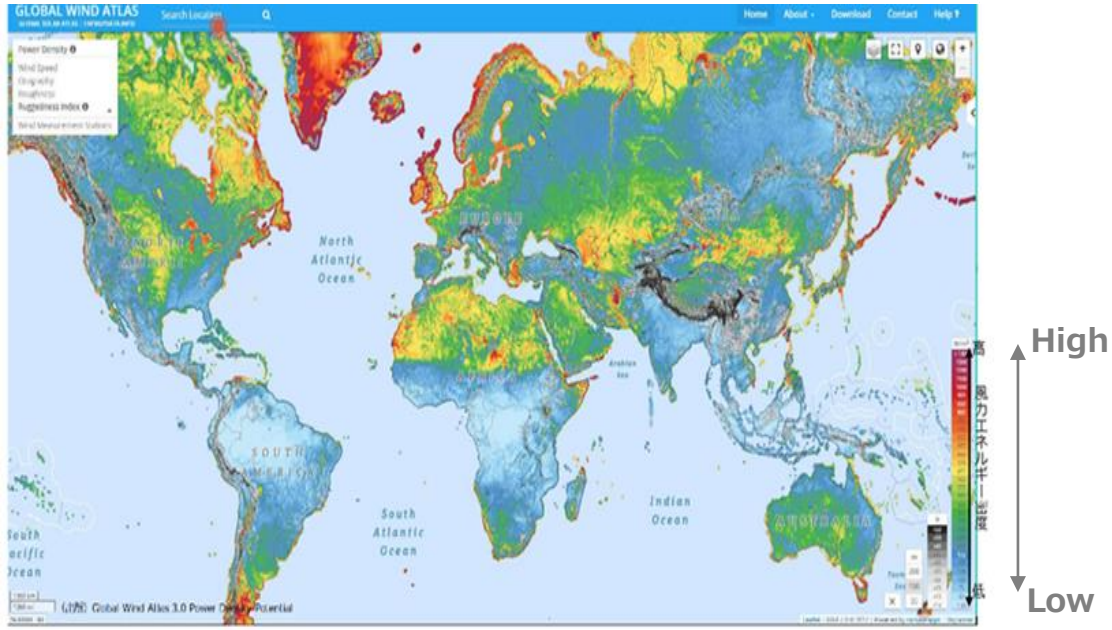
- Being the growth center of the global economy, Asia's energy demand will continue to grow.
- Renewable (solar and power) resources in Asia, however, are limited to meet the growing energy demand.

Solar power potential



(Source) Global Solar Atlas

Wind energy density



(Source) Global Wind Atlas

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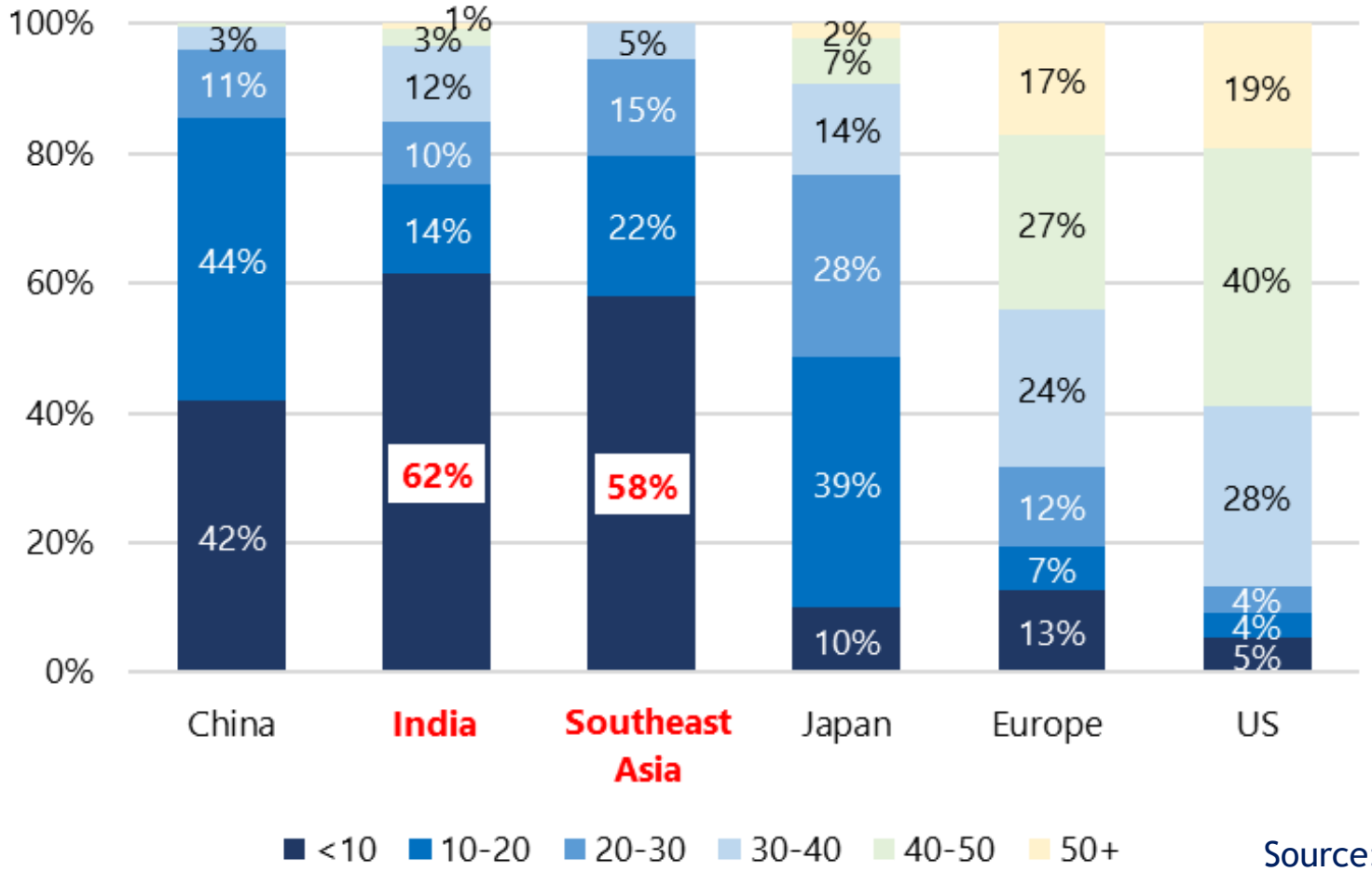
Young fleet of coal-fired power plants in Asia

- Asia's power demand will keep growing, and the average age of **its coal power fleet is still young**.

Shares of coal-fired power capacity by age (as of 2018)



Source: IEA; IEEJ

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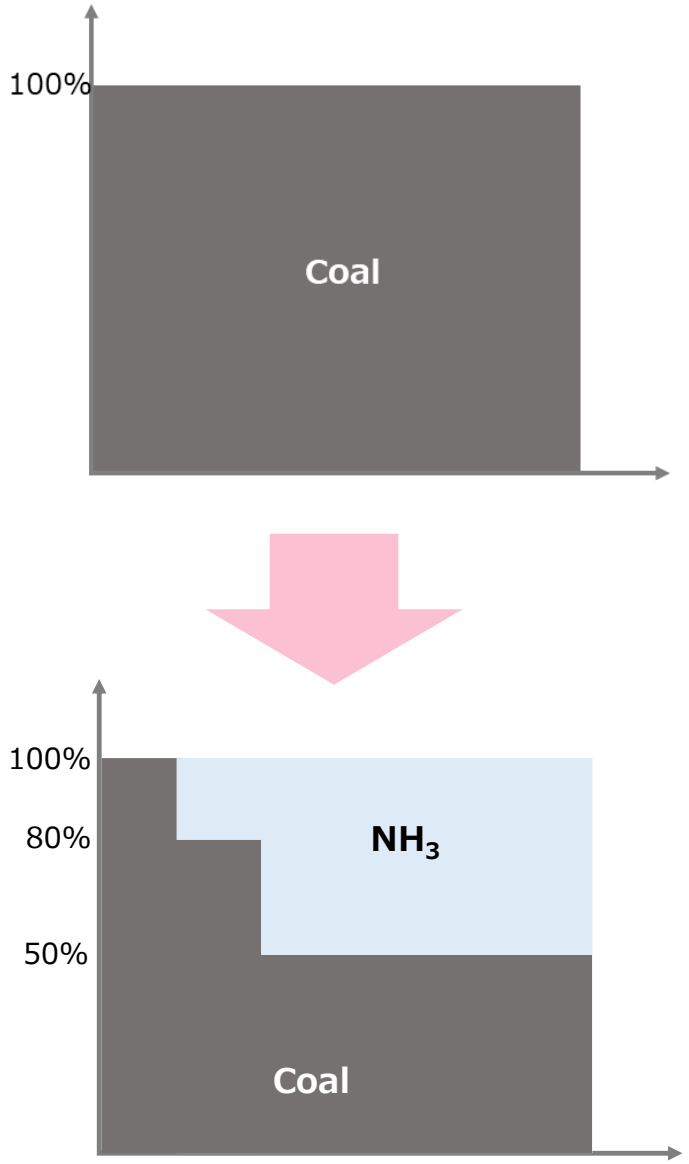
Clean ammonia as a co-firing fuel for coal

- No CO_2 emissions at burning
- Directly utilized as a fuel without cracking
- Carbon intensity can be lowered to an equivalent level to gas-fired power generation if the co-firing ratio is raised to 50%.
- Liquefied at minus 33 degree Celsius; the most cost competitive mean of hydrogen transportation
- Adopted with limited modifications to the existing coal-fired power plant facilities



- **Co-firing of ammonia can be an effective option** to decarbonize the existing coal-fired power plant.

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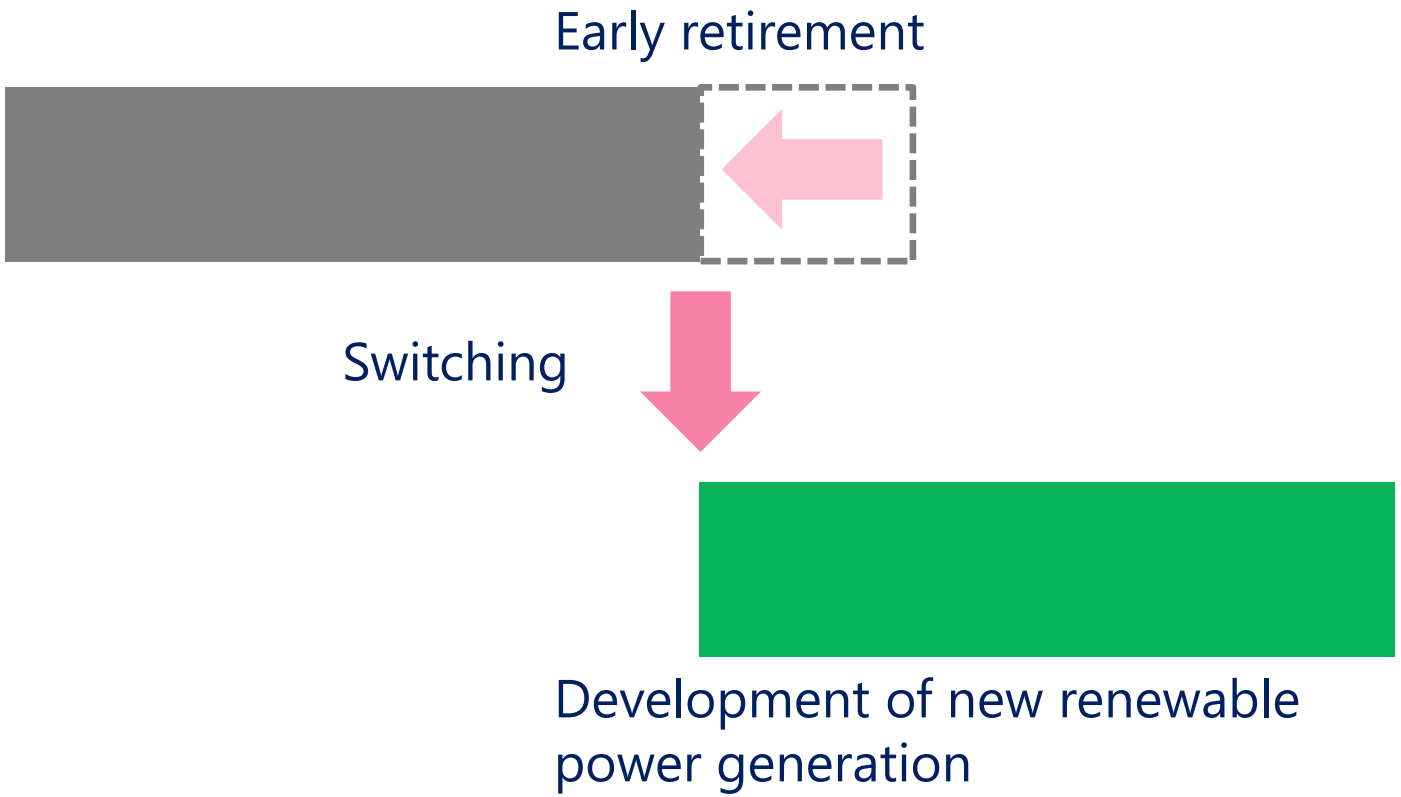
Early retirement of coal-fired power plant

- Another option to decarbonize the existing coal-fired power plant is **early retirement of the coal plant and substitution by renewable power plant**.
- The retirement of coal plant and development of renewable power generation are assisted with a packaged financial supports by Asian Development Bank (ADB).



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Scenarios for comparative analysis

1. **ETM*** (Energy Transition Mechanism): Earlier retirement of coal units and replacement with renewable energy
2. **NH_3**: Installing co-firing facilities to existing coal units (NH_3)
3. **BAU**: Business as usual (no decarbonization arrangement)

Case	Fuel mix assumptions**
ETM-Base	**Coal 100% for 25 years [5 years early retirement] + Solar & Battery**
ETM-10	Coal 100% for 20 years [**10 years** early retirement] + Solar & Battery
NH_3	**Coal 100% for 5 years + NH_3 20% for 5 years + NH_3 50% for 20 years**
BAU	**Coal 100% for 30 years**

*ETM is the name of the program supported by ADB; **The age of coal power plant is assumed as 10 years old.

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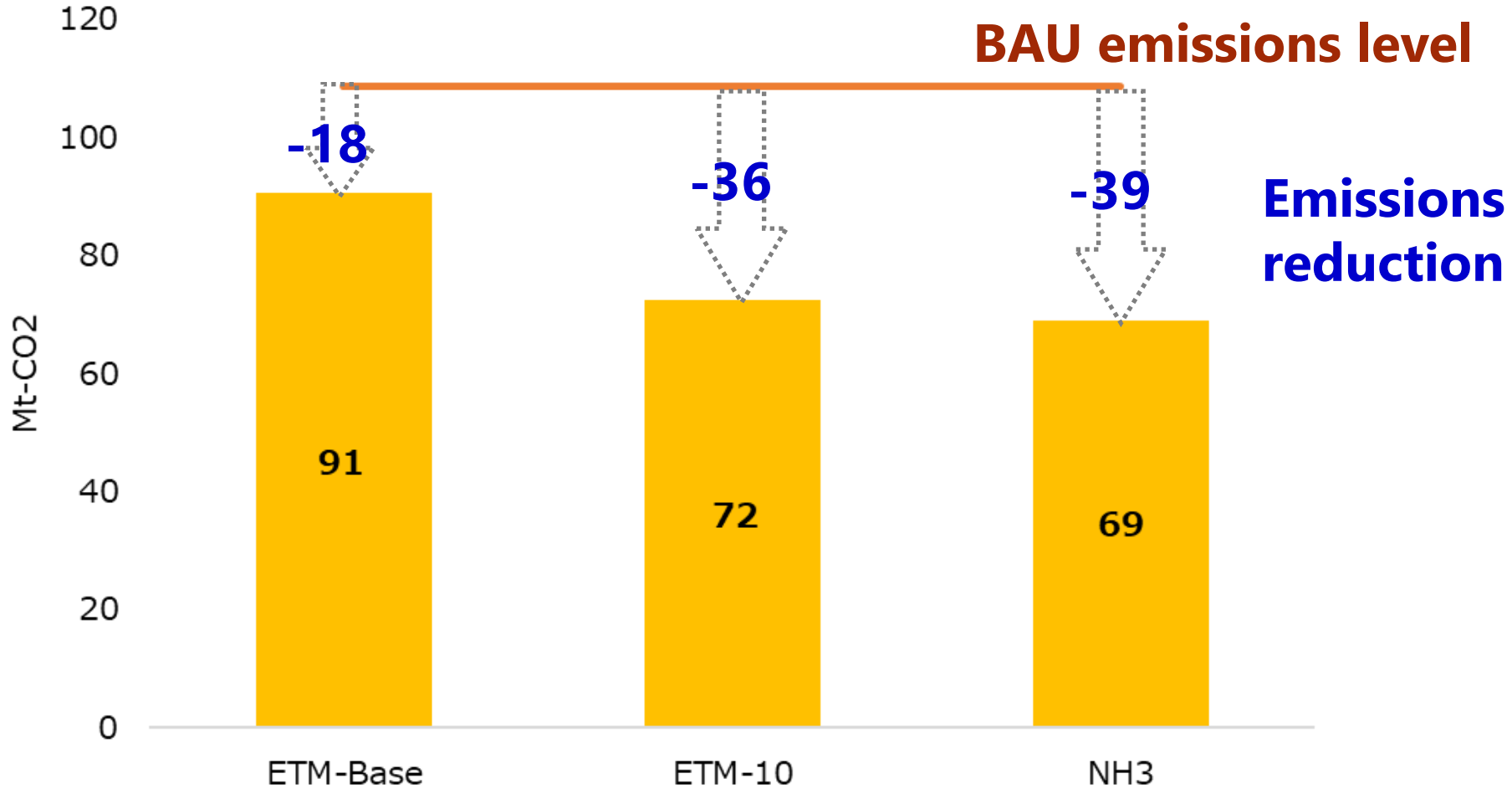
CO_2 emissions reduction

- **NH_3 case can reduce more CO2 emissions** than ETM cases.



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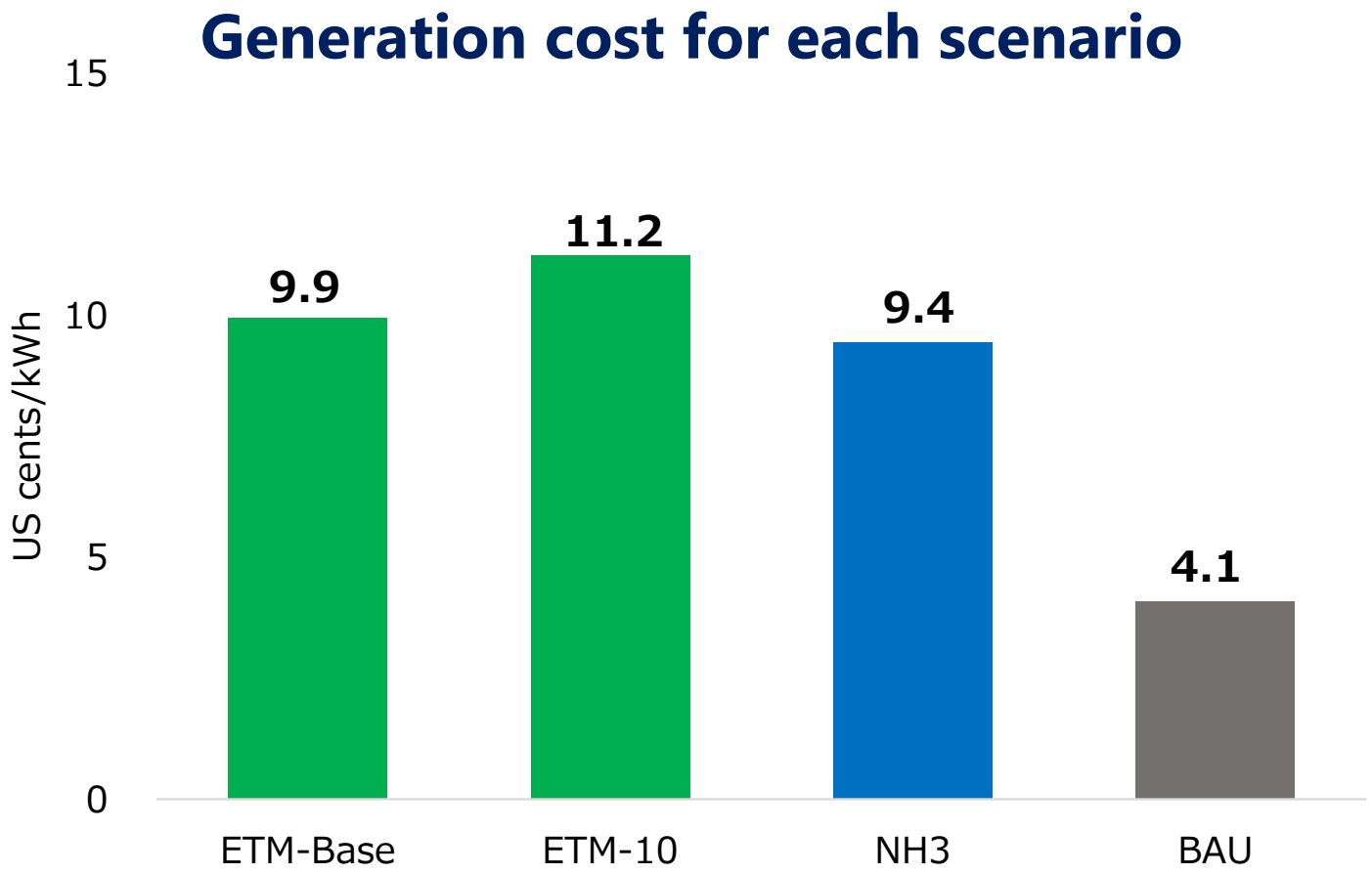
Generation cost

- Both ETM and NH_3 cases require **higher cost than BAU**.
- **Generation cost of NH_3 case is lower than those of ETM cases**.



*Initial investment cost for coal power plant is not included as the plant is assumed as 10 years old.

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Major findings of the analysis

- **Co-firing of clean ammonia (NH_3 case) should be regarded as an effective option to decarbonize the existing coal-fired power plants in Asia.**

- ✓ Both ETM and NH_3 cases will have a higher cost than BAU case.
- ✓ Generation costs of ETM cases are higher than that of NH_3 case.
- ✓ NH_3 case can reduce more CO_2 emissions for the next 30 years and at an earlier timing.
- ✓ ETM case may require additional costs for securing land for large-scale solar park development.

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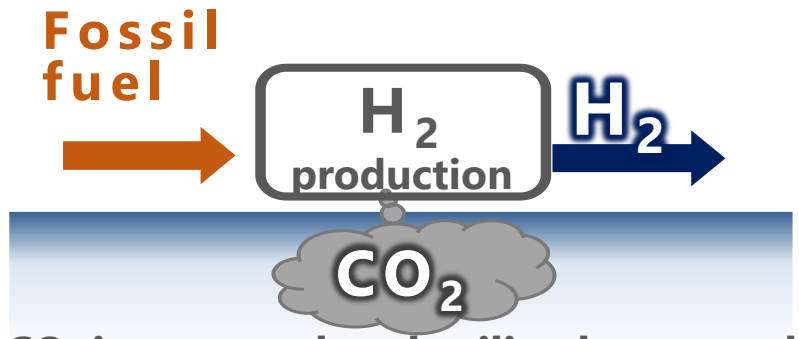
Utilization of clean hydrogen

- Various types of clean hydrogen should be utilized as a feedstock of ammonia if they contribute to emissions reduction and cost-competitive supply.

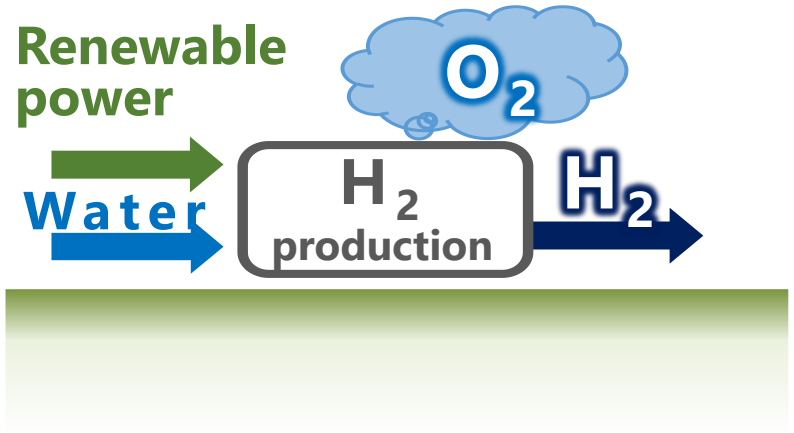
Blue hydrogen



CO_2 is captured and utilized or stored.

- ✓ **Large volume of hydrogen can be produced at single location.**
- ✓ **Minimizing CO_2 emissions and securing CO_2 storage locations are important.**

Green hydrogen



- ✓ **Cost reduction is needed as it is costlier than blue hydrogen.**
- ✓ **Production tends to be less stable because of the intermittency of renewable power generation.**

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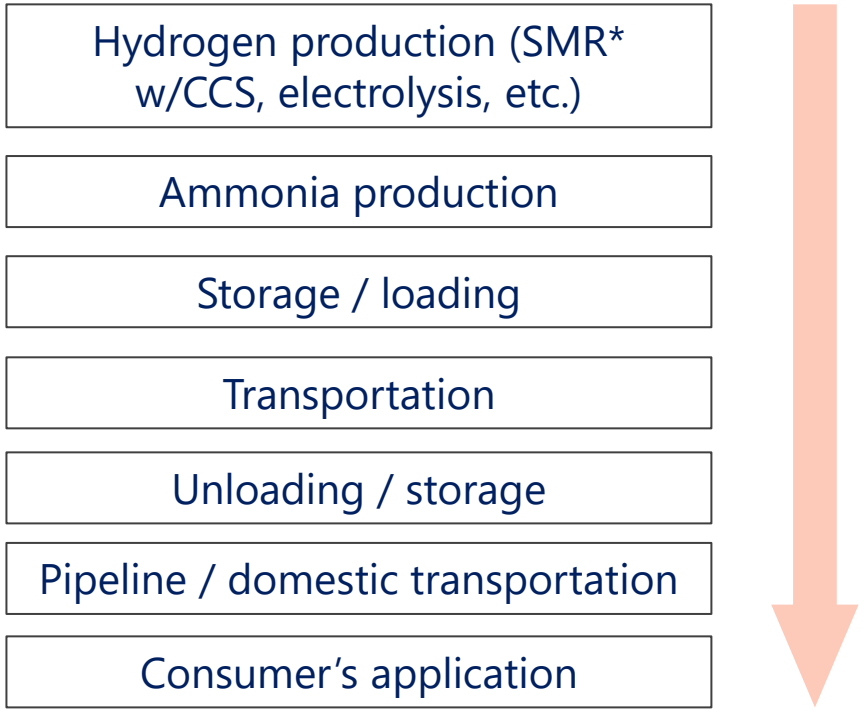
Supply chain development of clean ammonia

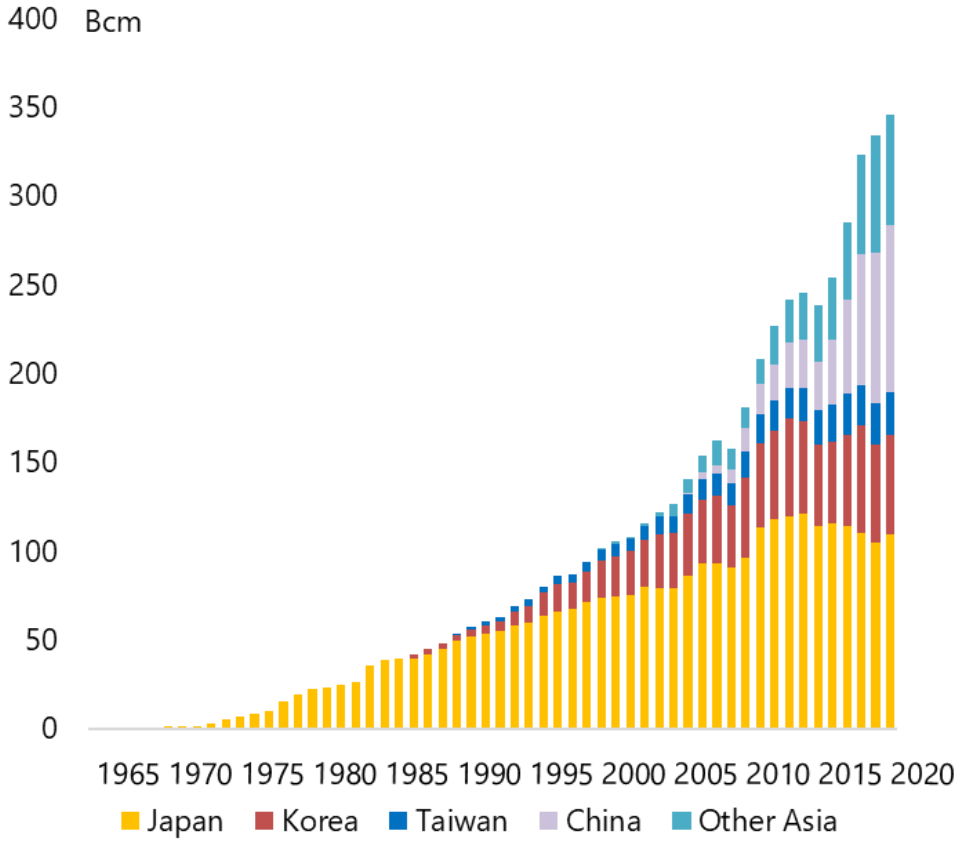
- Supply chain of clean ammonia has to be developed internationally to realize economies of scale and to develop a functioning market **at a speed much faster than in the case of the LNG supply chain**.

Ammonia supply chain



*SMR: Steam methane reforming

LNG market development in Asia



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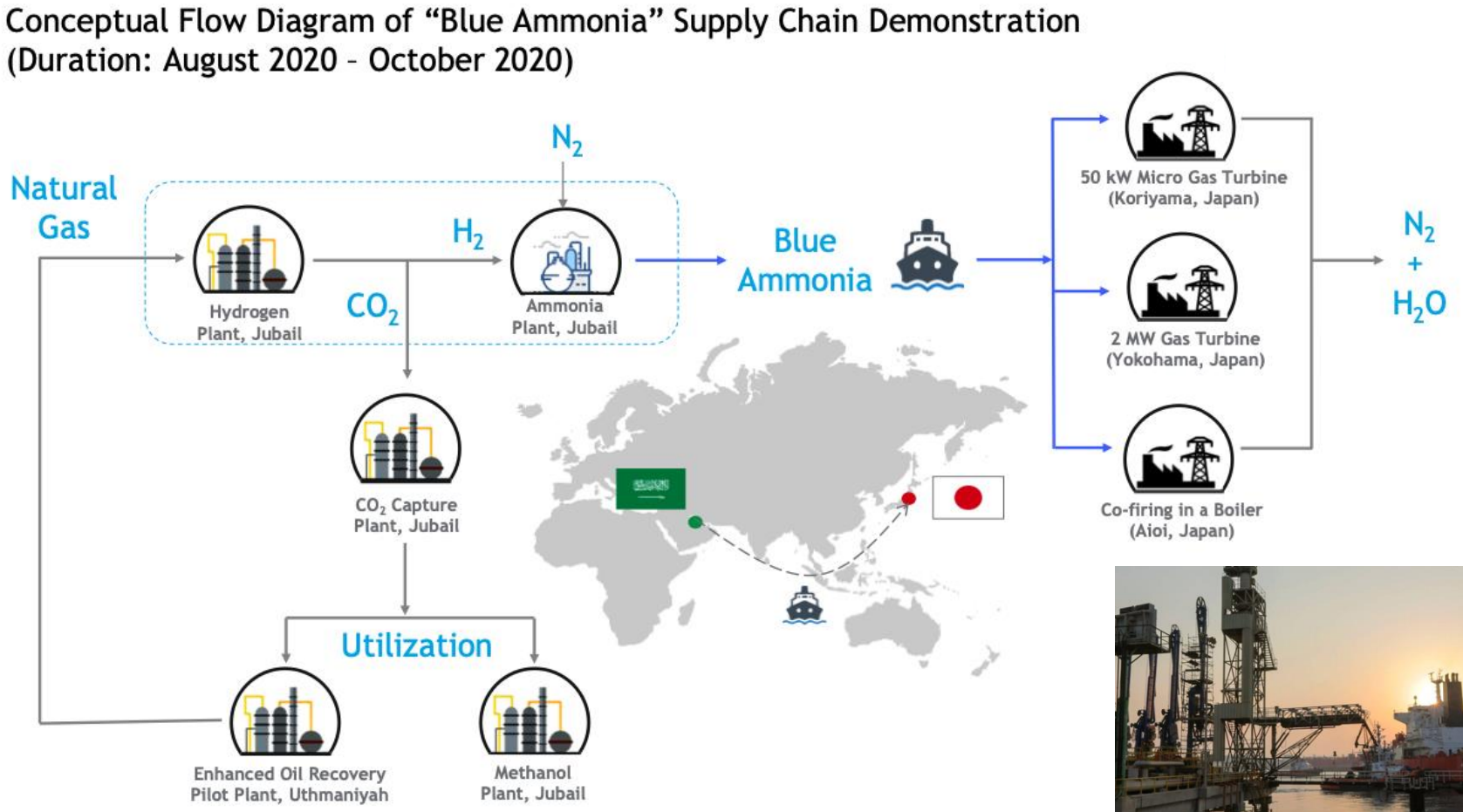
Blue ammonia pilot project by Saudi Aramco and IEEJ

- IEEJ conducted a pilot project of blue ammonia import and utilization from Saudi Arabia in 2020 in partnering with Saudi Aramco.



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Conclusions

- Co-firing of clean ammonia should be regarded as a major solution to decarbonize the existing coal-fired power plants in Asia.
- Various types of clean hydrogen should be utilized.
- Development of the global clean ammonia supply chain needs to be accelerated.
- Collaboration among governments and industries and policy support toward the supply chain development are important.

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Appendix

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Assumptions: General items

Items	Assumption
Foreign exchange rate	US$1=130 Yen (Apr-Jun 2022 Average)
Discount rate	3%
Operational lifetime	Coal: 40 years Solar & Battery: 25 years
Generation cost	Calculated as levelized cost of electricity (LCOE) (Net present value of total cost / Net present value of electricity generated) Initial investment of coal fired power plant is not included.
Assumed age of coal power plant	10 years (Initial investment of coal power plant is not included in the generation cost calculations)
Generation mix of each case	
- BAU	Coal 100% for the remaining 30 years.
- ETM-Base	Coal 100% for 25 years [5 years early retirement] + Solar & Battery for 25 years
- NH_3 Base	Coal 100% for 5 years + NH_3 20% for 5 years + NH_3 50% for 20 years
- ETM-10	Coal 100% for 20 years [10 years early retirement] + Solar & Battery for 25 years

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Assumptions: Coal and ammonia

Items	Assumption
Coal power generation	
Generation capacity	700MW
Capacity factor	70%
Heat efficiency	45.7% (LHV)
Internal use	5%
Heat vale of coal	24.8 MJ/kg (LHV)
Price of coal	44 $/t [IEA (2021) p71]
CO_2 intensity of coal	93.7 g-CO_2/MJ
Ammonia co-firing	
CAPEX for co-firing	US$ 224 million for 20% co-firing; US$ 337 million for additional 30% co-firing
Ammonia price	317.5 $/t-$NH_3$ [IEA (2021) p71]
Heat value of ammonia	14.1 MJ-Nm^3 (LHV)
CO_2 intensity of ammonia	0 g-CO_2/MJ

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Assumptions: Solar and battery

Items	Assumption
Solar power generation	
Capacity factor	17.20%
Required capacity	3.0GW (calculated based on the replaced coal fired power generation including the required power generation for battery transactions)
CAPEX (unit cost)	US$ 1,600/kW
Operational lifetime	25 years
Battery	
Compensation	12 hours
Required battery capacity	36 GWh
CAPEX (unit cost)	US$ 177/kWh (including PCS)
Efficiency	81.0% (=90% for charging x 90% for discharging)
Annual OPEX	2% of CAPEX
Operational lifetimes	25 years

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