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DME Energy System produced from Lignite derived gas and Renewable hydrogen

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Lignite utilization technology and CO_2 emission countermeasure

About half of the world's coal resources are lignite, but its utilization is limited for coal-fired power generation near mining site because of high moisture and high transportation cost per unit calorific value and high reactivity that might cause spontaneous ignition when dried.

[Improvement of transportability]

- Reformed coal (dehydration, stabilization): Briquetting, Solvent treatment,
  Reforming in oil (under development)
  Dehydration with DME (under development)
- Conversion in Liquid fuel: Direct liquefaction (Development Project) in Victoria, Australia
  DME production from lignite (FS)
  Liquid hydrogen production from lignite (FS)
  (DME, hydrogen is clean fuel.)

[CO_2 emission countermeasure]
- CCS
- Utilization of renewable hydrogen (wind power)

This study evaluates DME production, thermal efficiency, CO_2 emissions, etc. by simulation on a system that produces DME from lignite and wind power hydrogen and transports it to Japan.

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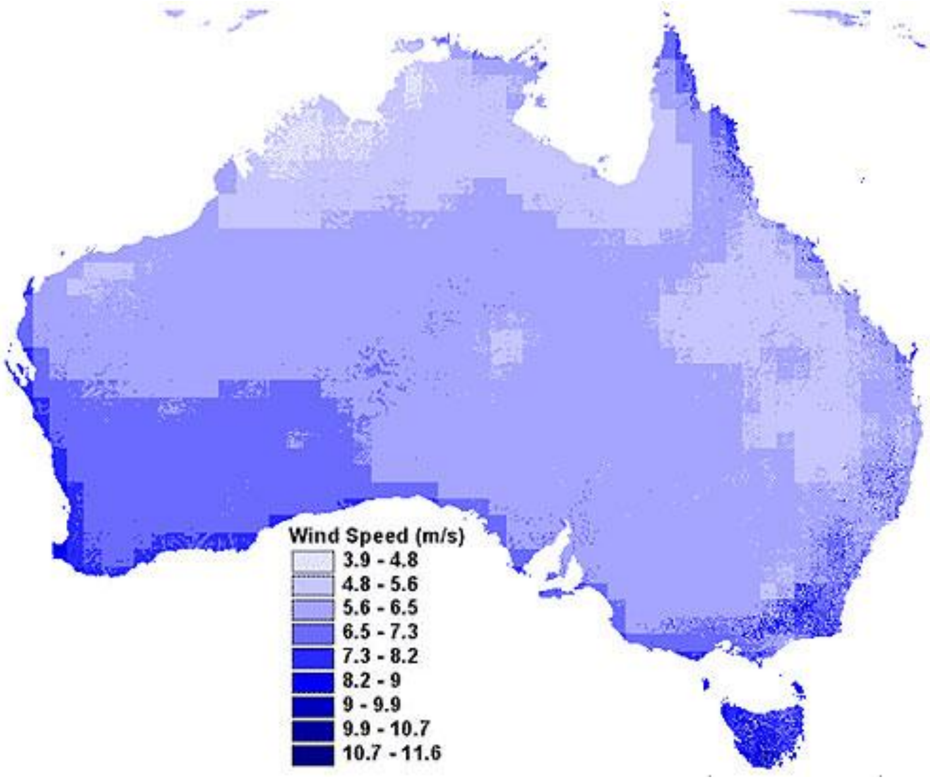
Wind power resource and development in Australia

• Australia has a large national land and high potential of wind power generation. Recently, due to policies for CO_2 emission and lowering equipment price, there are many wind power plans and the amount of generated electricity by wind power is increasing.



Wind power capacity(MW)

State	In Operation	Under Construction
SA	1475	106
Vic	1230	420
NSW	668	220
WA	491	0
Others	668	0
Total	4187	746

Ref: Clean Energy Australia Report 2015

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DME production process from Lignite

[Lignite properties]

Total water content 60%, Ash content 2%, Elemental analysis% (C: 67.8, H: 4.6, N:0.6, S: 0.3, O: 24.4), Net calorific value 25.5 MJ/kg, Ash melting point 1290ºC.

[Gasification of Lignite]

After preliminary drying and pulverization, Lignite is transported into gasifier by pneumatic transport. Carrier gas is dry CO_2, by-produced in DME synthesis process.

Gasifying agent is pure oxygen. Exit temperature of gasifier before quenching is 1340ºC. Gasification pressure is 3.5 MPa. H_2/CO ratio of product gas is about 0.43. After cooling, the gas is desulfurized.

[H_2/CO ratio adjustment]

Base case: Adjust H_2/CO= 1 by shift reaction and CO_2 removal.

Case A: Adding wind power hydrogen to synthesis gas from gasifier

Case B: Gas of high H_2/CO ratio is produced by reverse shift reaction of CO_2 by-produced in DME synthesis process with wind power hydrogen and added to synthesis gas from gasifier.

Surplus CO_2 is boosted to 14.9 MPa and processed with CCS.

[DME synthesis]

Synthesis gas of H_2/CO= 1 is pressurized to 5.5 MPa and converted into DME in a slurry phase DME synthesis reactor . $3H_2 + 3CO \rightarrow CH_3OCH_3 + CO_2$

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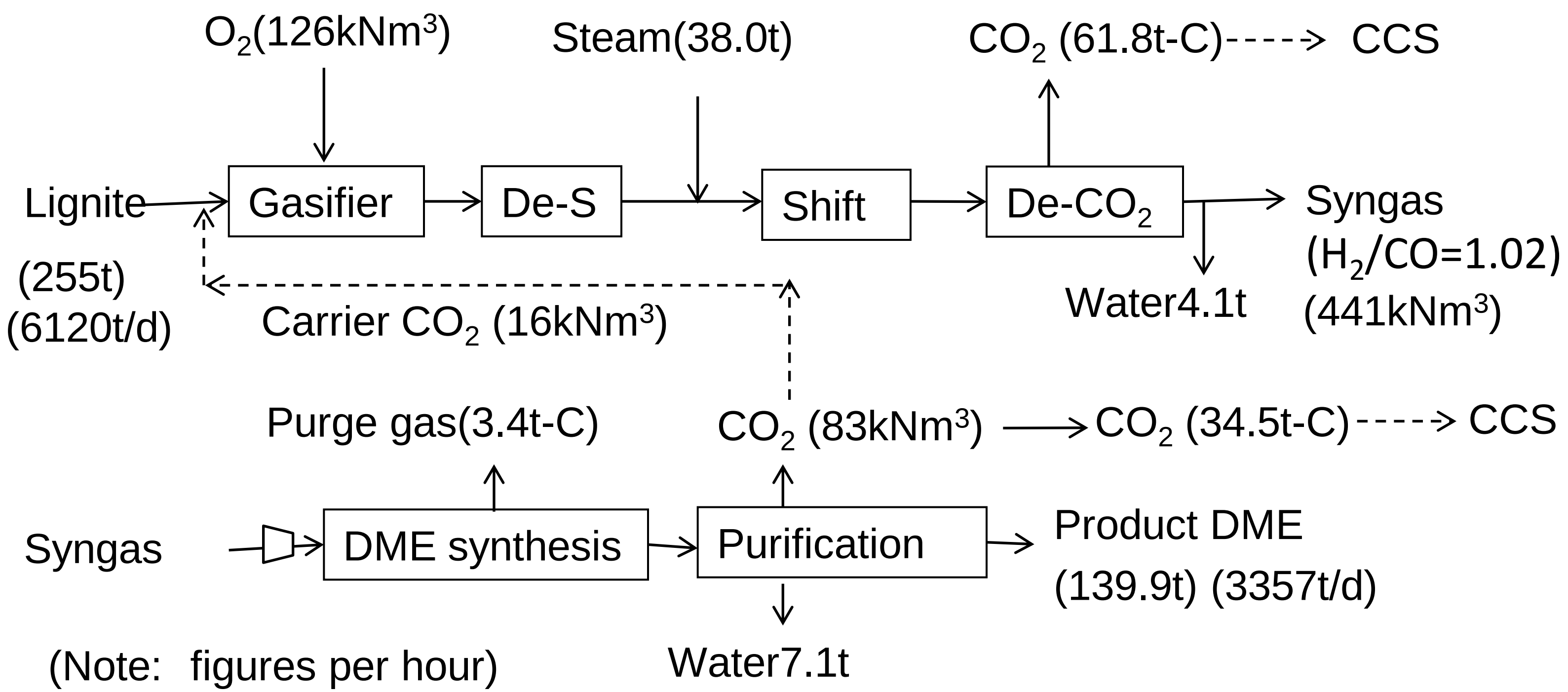
DME production process from Lignite(Base case)

- 139.9 t/h (3357 t/d) of DME is produced from lignite 255 t/h (dry base) (6120 t/d). Cold gas efficiency (calorific value of product DME / calorific value of lignite) of DME production is estimated 62.0%.
- 58% of the carbon (172.9 t-C/h) derived from raw lignite is converted to CO_2 in DME production process. Since CO_2 gas from CO_2 removal and DME purification process has high concentration, it is suitable for CCS. 96% of the CO_2 goes to underground storage.



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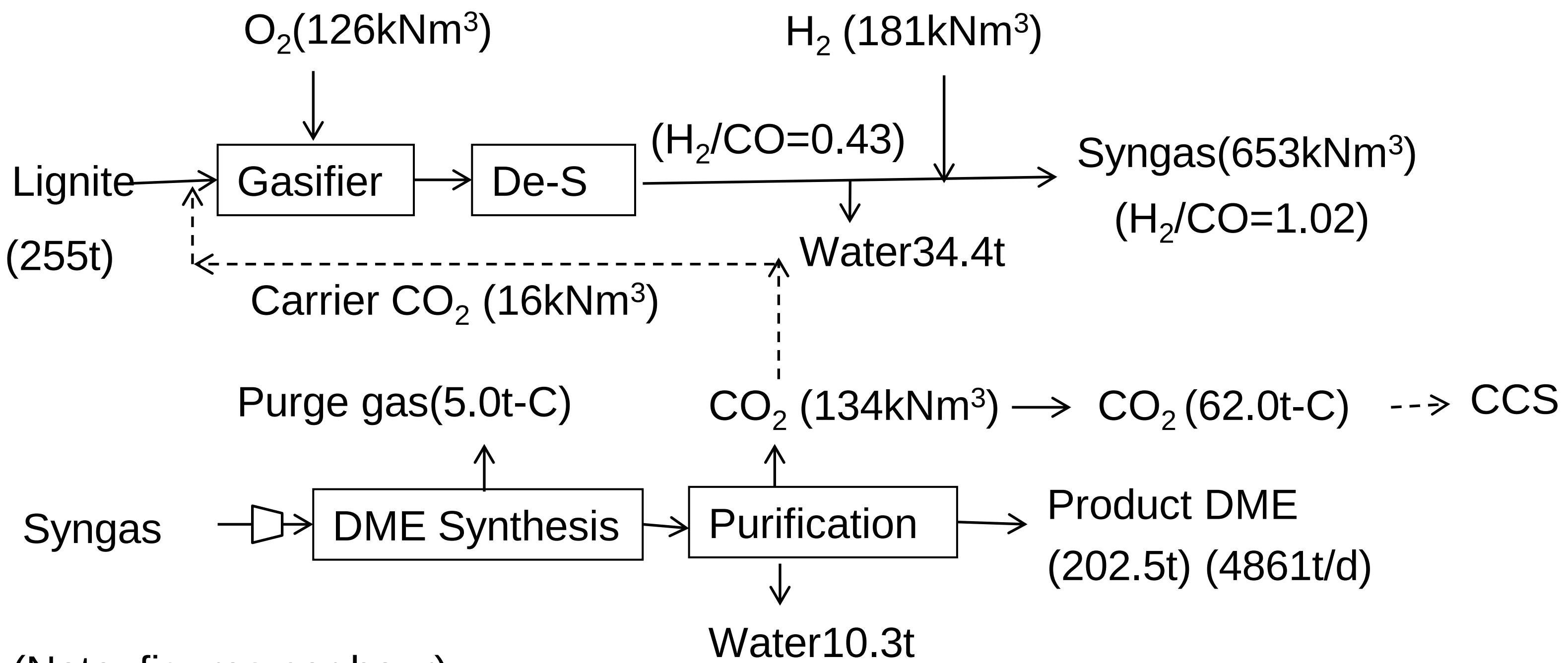
Utilization of wind power hydrogen for DME production(Case A)

- When H_2/CO is adjusted by adding H_2 from outside, it is possible to avoid CO_2 production by shift reaction. CO is used as it is as a raw material together with added hydrogen and DME production amount increases.
- By-produced oxygen in water electrolysis can be used for gasification, the oxygen plant load is reduced.



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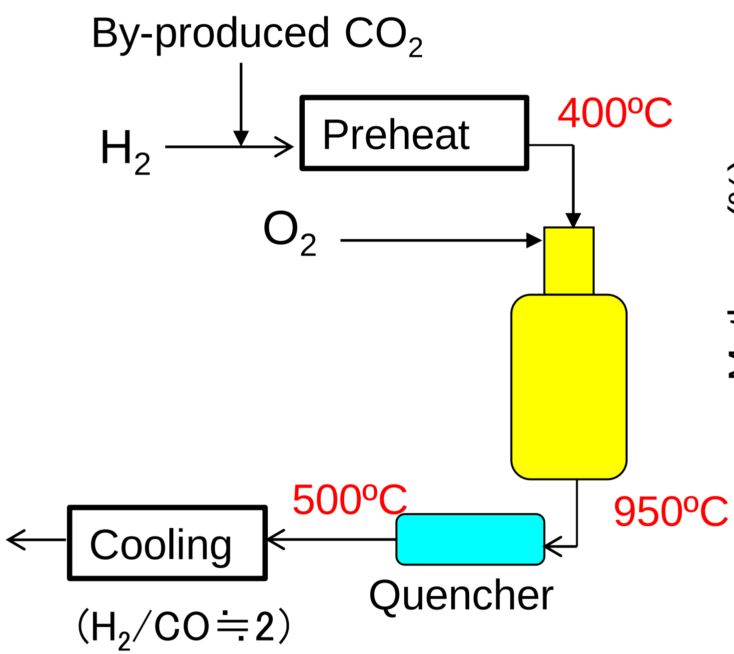
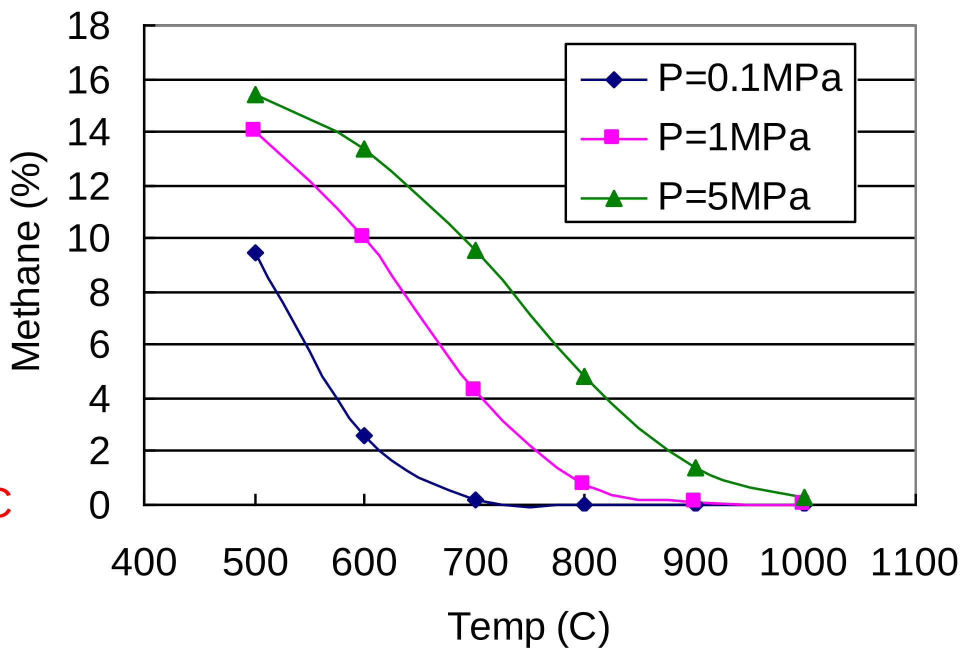
Utilization of CO_2 by-produced in DME synthesis (Reverse shift reaction)

- Reverse shift reaction of hydrogen with CO_2 by-produced in DME synthesis gives high H_2/CO gas. By mixing it with gas of low H_2/CO from gasifier, synthesis gas of H_2/CO=1 is obtained.
- To suppress methane formation in the reverse shift reactor, reaction temperature must be higher than about 950ºC, so an auto-thermal type reactor is adopted. H_2/CO_2 mixture is preheated to 400ºC. In order to avoid accumulation of trace components such as N_2 in the system, utilization rate of CO_2 is set to about 90% of the by-produced amount.





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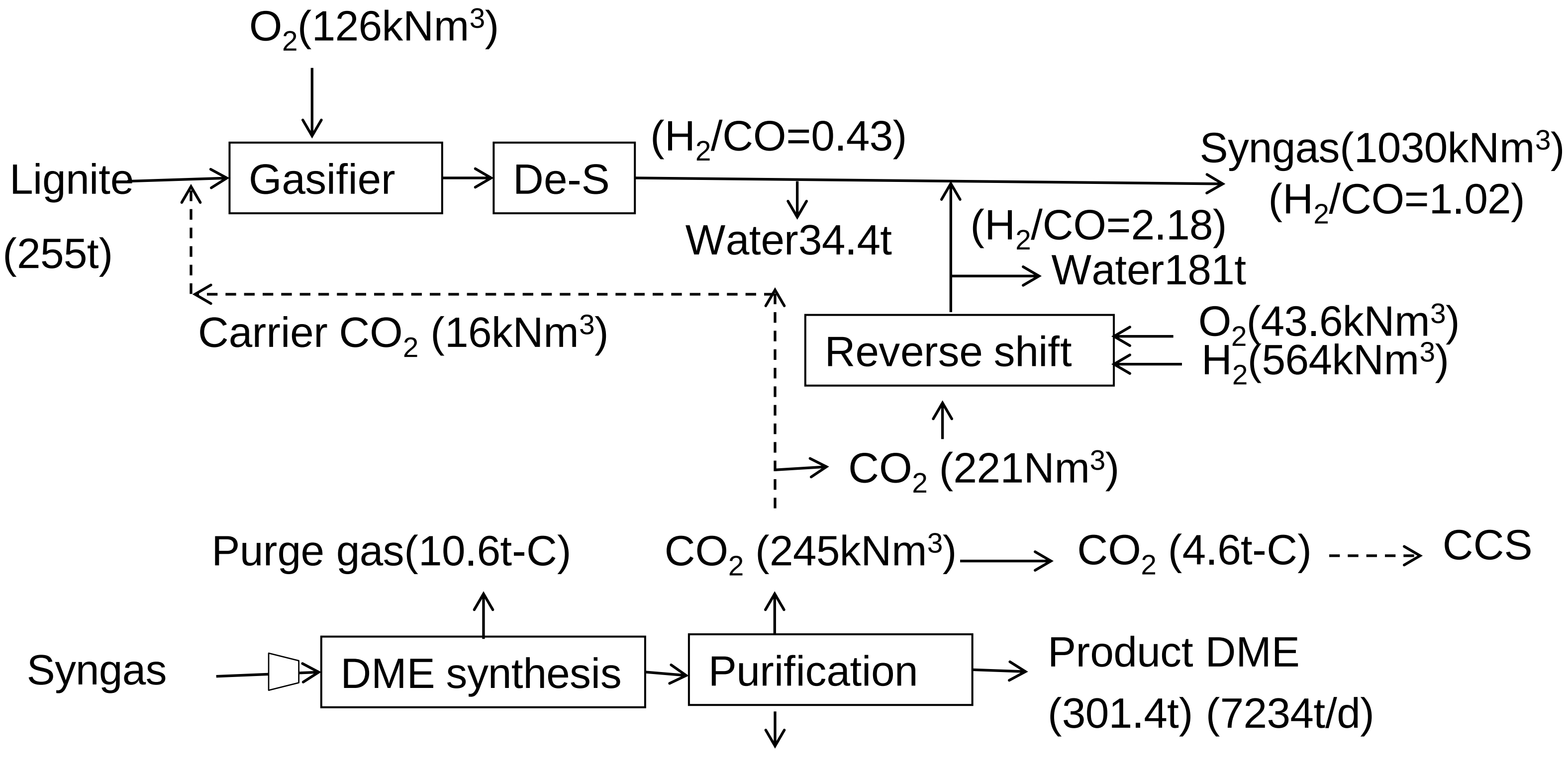
Utilization of wind power hydrogen for DME production(Case B)

- Almost of CO_2 by-produced in DME synthesis is utilized with the added hydrogen as raw material. DME production amount is increased to 7234 t/d, which is 2.15 times of the base case using only lignite as raw material. Required CCS processing amount is as small as 3% (practically unnecessary).



(Note: figures per hour)

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DME Transportation to Japan and DME utilization

- DME has boiling point of -25 ºC and vapor pressure of 0.53 MPa (20 ºC), and it is easier to transport liquid DME than liquid hydrogen

[Ocean Transportation]

IGC code for maritime transport is issued. Low-temperature LPG carrier can be used and Transportation distance is 4800 miles on one way.

[Land Transportation]

LPG tank trailer is used and transportation distance is 100 km on one way.

[Power generation fuel]

Combustion characteristics of DME gas are equivalent to those of natural gas. If the power generation efficiency by combined cycle is 55%, CO_2 emission of electricity generation is 119 g-C/kWh, which is higher than 101 g-C/kWh in case of natural gas but overwhelmingly lower than 223 g-C/kWh of supercritical coal fired power plant with power generation efficiency of 43%.

[Diesel engine fuel]

PM is not generated, and CO_2 emissions per power is lower than that of diesel. DME vehicles have undergone the verification test and the general registration can be made by the Ministry of Land, Infrastructure and Transport.

[Hydrogen carrier]

Steam reforming is carried out at around 350 ºC to produce hydrogen.

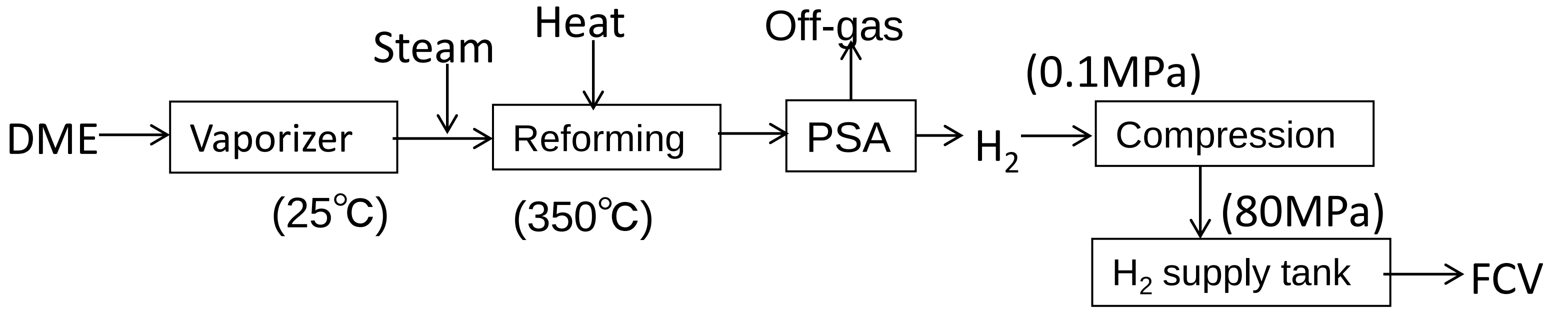
Hydrogen production from DME

• Liquid DME is evaporated and reformed into hydrogen by steam reforming reaction. Reformed gas is separated into high purity hydrogen and off-gas by PSA. Recovery rate of high purity hydrogen is about 70%.

$$CH_3OCH_3 + 3H_2O \rightarrow 6H_2 + 2CO_2$$

• Reaction heat for reforming is covered by reformer waste heat and PSA off-gas combustion. Thermal efficiency from DME to high purity hydrogen is 76.5%.

• Hydrogen is pressurized to 80 MPa for FCV hydrogen supply tank. Power consumption of the supply system including compression is as large as 32% of calorific value of the supplied hydrogen. Thermal efficiency from DME to hydrogen for FCV is 0.765 x (1 - 0.32) = 52%.



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Thermal efficiency of DME production to utilization

- Cold gas efficiency of DME production is calculated by calorific value of product DME / (calorific value of lignite and hydrogen). Cold gas efficiency has increased to 69.0% by adding hydrogen into the system.
- Thermal efficiency at DME supply stage in Japan is about 60%. Total efficiency at hydrogen station is expected as low as 30% due to large energy consumption of hydrogen pressurization in addition to DME reforming.

	Base case	**Case A**	**Case B**	**Liquid hydrogen**
Wind hydrogen (kNm^3/h)	0	181	564	0
DME production (t/h)	139.9	202.5	301.4	(H_2) 2.1
Cold gas efficiency of production (%)	62.0	68.9	69.0	59.7
Thermal efficiency of production (%)	58.3	62.2	57.9	41.7
Thermal efficiency at supply stage (%)	57.6	61.5	57.3	29.0
Power generation (MW)	615	891	1326	429
Hydrogen supply (kNm^3/h)	195	282	419	190
Total thermal efficiency (%)	29.9	31.9	29.7	21.0

Comparison of CO_2 emission

- In case B, only of 8.8% (15.2 t-C/h) of carbon (172.9 t-C/h) derived from raw lignite is discharged outside the system and 91.2% is effectively used for DME production.
- CO_2 emissions at transportation stage are relatively small compared to production and utilization stage.

		Base	**Case A**	**Case B**	**Liquid hydrogen**
CCS(t-C/h)		96.3	62.0	4.6	146.8
CO_2 emission (t-C/h)	Production	3.4	5.0	10.6	37.8
	Sea transport	1.6	2.3	3.4	7.6
	Land transport	0.7	1.0	1.5	0.7
	Utilization	73.0	105.7	157.3	0
	Total	78.7	114.0	172.8	46.1
CO_2 emission by unit power generation (g-C/kWh)		127	127	129	106

Conclusion

• As a means of securing energy supply considering CO_2 emission, we studied DME energy system composed of DME production from Australian lignite and wind power hydrogen as stranded resources, its transportation and utilization in Japan. DME production amount, thermal efficiency and CO_2 emission were evaluated.

• Utilizing wind power hydrogen reduces CCS requirement and increases DME production amount. When by-produced CO_2 in DME synthesis is used by reverse shift reaction with hydrogen, CO_2 emission at DME production stage is little and CCS is considered to be practically unnecessary.

• Thermal efficiency of DME production is about 60%. Energy consumption at the transport stage is relatively small.

• When transported DME is used for power generation in Japan, domestic CO_2 emission is of 119 g-C/ kWh, overwhelmingly lower than 223 g-C/kWh of the reformed coal fired power plant.

• For hydrogen production for FCV, the energy consumption of the hydrogen pressurization stage is large.

• Technologies from production, transportation to utilization of DME have been established and this system is considered to be one option for Japan importing the majority of energy. More detailed study on it is expected.