DeWitt Asia Pacific Global Methanol & MTBE Conference
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New Clean Fuel DME

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Contents

- What's DME ?
- DME Utilization technologies update

  Residential, Power generation, Transportation
- DME Production technologies update

  JFE' Direct synthesis technology
- Market overview & Projects update
- Conclusion

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What's DME ?

- DME (Dimethyl ether):

  Simplest ether CH_3-O-CH_3
- Burns like Natural gas

  Wobbe index 52 (Natural gas 54)
- Handles like LPG

  Boiling point -25° C (Propane -42)

  Vapor pressure 0.53MPa (Propane 0.91)
- Outstanding diesel alternative fuel

  Cetane number 55-60 (Gas oil 40-55)
- Today,150,000t/y as aerosol propellant, plus 300,000 t/y for emerging fuel market

Methane DME Propane

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DME: Clean and Green

- **HEALTH**

- Approved as consumer product propellant
- No human hazard relative to toxicity or carcinogenicity within exposure limits

- **SAFETY**

- Flammable liquid like LPG
- Thermally stable
- No tendency to peroxide formation found
- Similar safety guidelines and codes as LPG

- **ENVIRONMENT**

- Does not deplete ozone
- Minimal impact on land/water due to volatility
- Low emission fuel like LPG and Natural gas
- Biomass-based DME (Renewable)

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DME: Multi-Use Fuel from Multi-Resources

Resources

- Natural gas
- Associate gas
- Coal bed methane
- Coke oven gas
- Coal,Lignite
- Heavy oil
- Bio-mass
- Wastes

DME Production

(1 Step process)

H_2,CO

Methanol

(2 Step process)

DME Usage

DME

Clean Fuel for

- Residential
  - LPG substitute
- Transportation
  - Diesel fuel
  - FC vehicle
- Power generation
  - Gas turbine
  - Diesel co-generation

Chemical use

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DME as LPG Substitute

- DME can be used neat or blend with LPG.
- For neat DME, minor changes required as sealing materials and burner tip.
- Same efficiency and emission as LPG from cooking stove to industrial boiler.
- DME and LPG are completely miscible.
  Below 20 % DME, existing LPG infrastructure can used without any modification.
- Coal derived DME can mitigate Indoor pollution caused by direct solid firing (Sox,Nox,PM,Formaldehyde etc.) and improve Total energy efficiency (Conversion+Heating).

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DME/LPG mixture combustion test

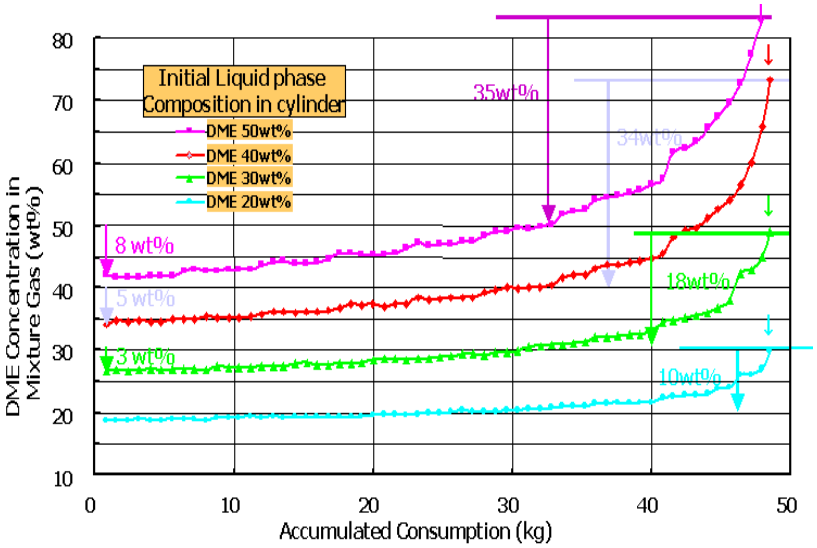
LPG Center Japan is conducting DME/LPG mixture combustion test by existing equipments specified to LPG.

- Up to 20% DME, DME/Propane gas mixture can be used as same as pure Propane for Tabletop stove, Infrared stove, Hot-water unit, 30% with minor modification
- Vaporized gas composition is almost constant from liquid LPG/DME mixture less than 20% DME.
- Durability of above appliances:

  No problem after 800hrs.

Cooking stove

Infrared stove



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Sulfur-free Odorant for DME/LPG

The High Pressure Safety Institute of Japan is conducting

Selection test for sulfur-free odorant (2005-2006)

- Primary evaluation conditions for odorant:
  strong discomfort odor, threshold level less than 1.0 ppm, boiling point lower than 120°C, stable at ambient temperature, negligible effect on human body
- Primary selection: 10 candidates
  iso-nitrile 3, hydrocarbon 4, oxygenate 2, cyclo-amine 1

Further study (2007-2008)

- Secondary evaluation conditions for odorant:
  condensation, combustibility, corrosiveness, adsorption on soil, safety
- Practicability evaluation: field test, economics

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DME for Power Generation-1

Gas turbine

- MHI verified low NOx burner for both gas-fired and liquid-fired combustion. Hitachi developed Multi-cluster Burner for low Nox emission. KHI developed liquid injection nozzle for gas turbine.
- TEPCO,Mitsubishi chemicals and JFE are conducting running test of 4 MW gas turbine with DME.

  Power output and emission as same as for natural gas firing period.
- Gas turbine suppliers guarantee power output, heat rate and performance for their gas turbines.

Chemically recuperated gas turbine system

- Toshiba and KEPCO developed 30kW system with Micro gas turbine.

  Heating value of reformed gas increases by about 10% after reforming of DME with waste heat.

  Power generation efficiency also increases by the same increment with lower NOx emission.

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DME for Power Generation-2

Diesel engine

• JFE is conducting 1,150 kW DME Diesel power generation system with Daihatsu and Iwatani.

Diesel co-generation system

• JFE is testing 8 kW system with Yanmar and Iwatani.

• AIST developed mobile 50 kW system with Isuzu.

• Kitakyushu Univ. etc. are testing 41 kW system with MHI.

DME fueled diesel engines achieve Same efficiency as with gas oil. Much low NOx emission with high EGR rate without smoke.

Fuel cell

• JGC developed Prototype of 30kW DME reforming system (On board type for vehicle and Stationary type) with short startup time and quick response.

DME is easily reformed to get hydrogen at low temperature like methanol.

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4MW Gas turbine power generation test

Joint project (TEPCO,Mitsubishi Chemicals and JFE)

Start-up and Load change conducted as smoothly as natural gas without any modification on gas turbine.

Receiving tank & Vaporizer
Tank capacity: 42ton
Vaporizer: 3.2ton/hr

Gas turbine generator
Power output: 4.2 MW
(retrofit from Natural gas firing)

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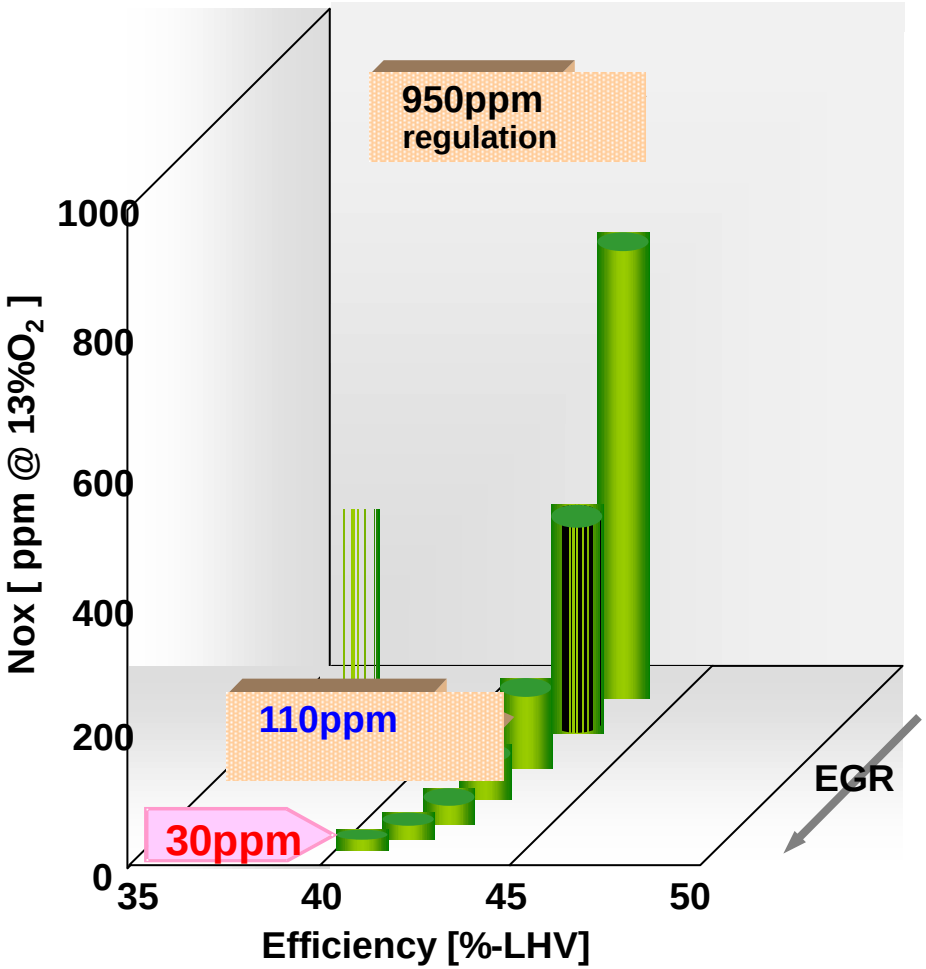
1,150kW DME Diesel power generation test

Joint project (JFE, Daihatsu Diesel and Iwatani)



Same efficiency as heavy oil. Less than 110ppm of NOx emission (which can be installed in Tokyo area) with no smoke.

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Proto-type DME vehicles in Japan

A ISUZU/COOP / JOGMEC TRUCK

D ISUZU/JOGMEC TRUCK

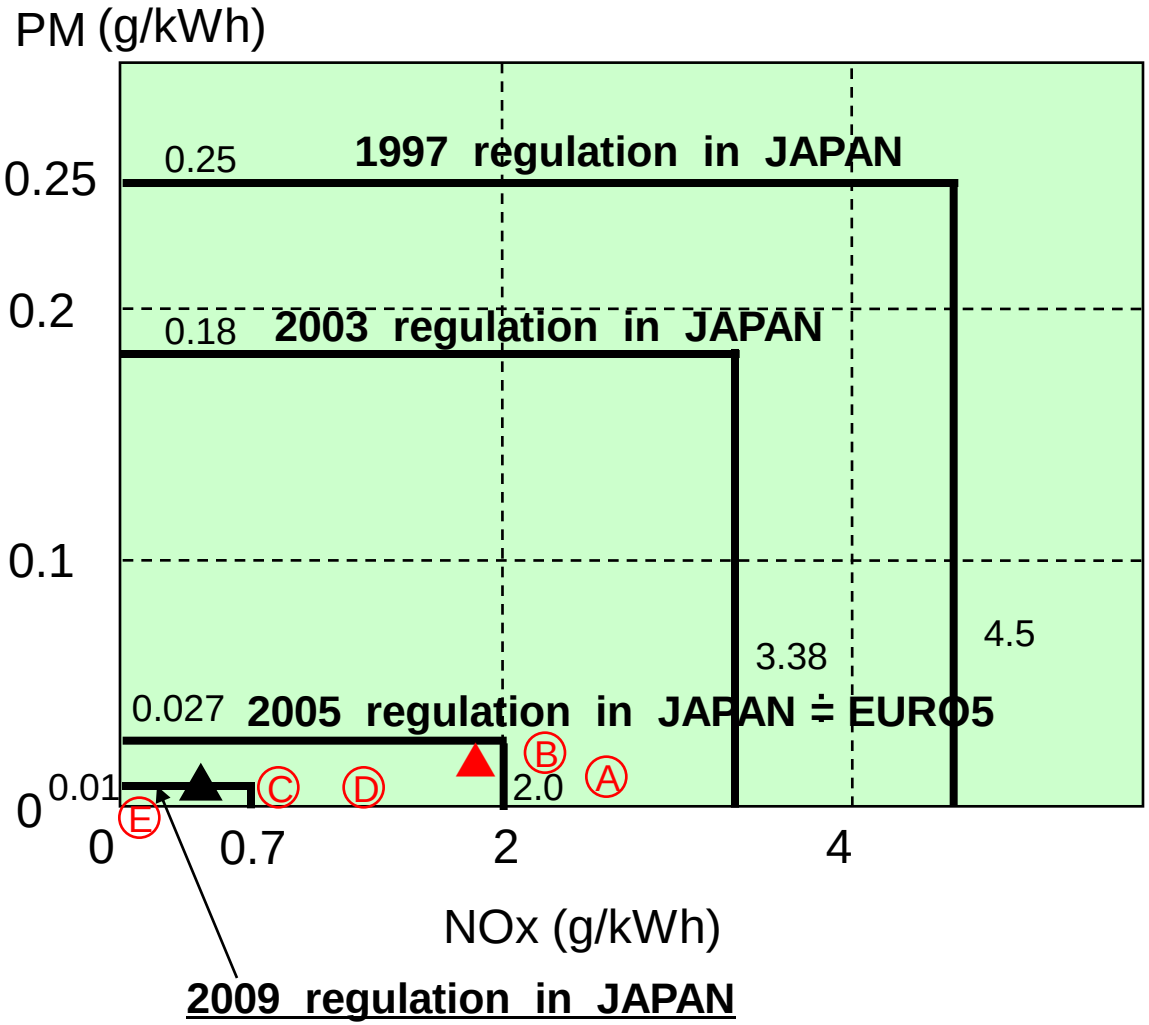
B ISUZU / MLIT BUS

C HINO / NEDO BUS

E NissanDiesel/NTSEL/MLIT TRUCK

Emissions of Proto-type DME vehicles

Efficiency same as with Gas oil, Emission much improved



Japan

A ISUZU / JOGMEC TRUCK

B ISUZU / MLIT BUS

C HINO / NEDO BUS

D ISUZU/JOGMEC TRUCK

E NissanDiesel/MLIT TRUCK
(PM = 0.001/ NOx 0.11)
(EGR+de-NOx cat.+Oxid cat)

▲VOLVO AFFORHD project

▲AVL (USA)

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Durability and Reliability of DME Vehicles

- MLIT/NTSEL: with Nissan Diesel, ISUZU & Bosch

  Long distance fleet tests by 5 -10 vehicles to evaluate practicability of DME vehicles & to get test data for technical standard & safety regulations, aiming Initial market introduction in 2010.

  Light duty truck (inline pump, jerk-type, 5.8 ton): After 13,000km, emissions are lower than 2009 regulation.

- JOGMEC: Isuzu Medium duty truck with crane (common rail type, 7.9 ton): Total cruising distance reached to 6,000km.

- Isuzu: Light duty truck (common rail type, 4.9 ton): 32,000km without serious trouble.

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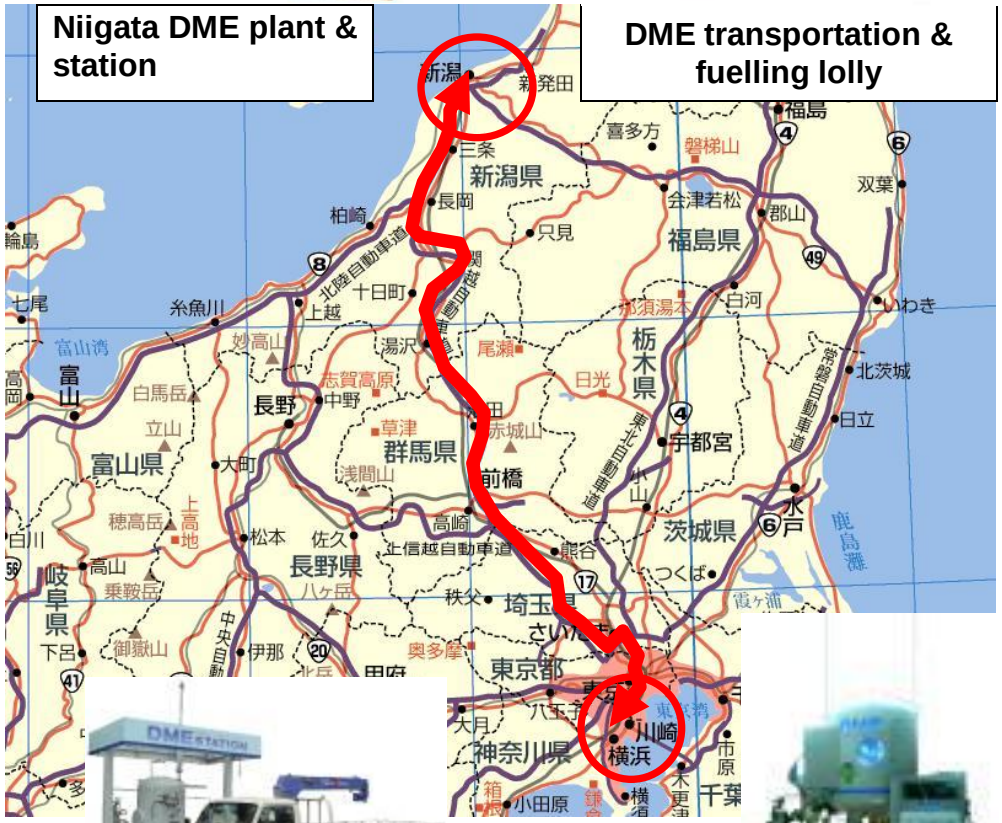
Route & Area of Road Test by NTSEL

Niigata DME plant & station

DME transportation & fuelling lolly



Kawasaki fuelling station

Yokohama fuelling station

- Route of HDT Road Test

Long distance fleet between Yokohama and Niigata where DME fuelling stations are already set up.

- Running Distance

- HDT :400km/day x 20days/month
- LDT :140km/day x 20days/month

- Payload condition

With zero, half and full payload by dummy weights

modified from Dr.Sato' presentation at 4th Asian DME Conference,Kitakyushu,November,2007

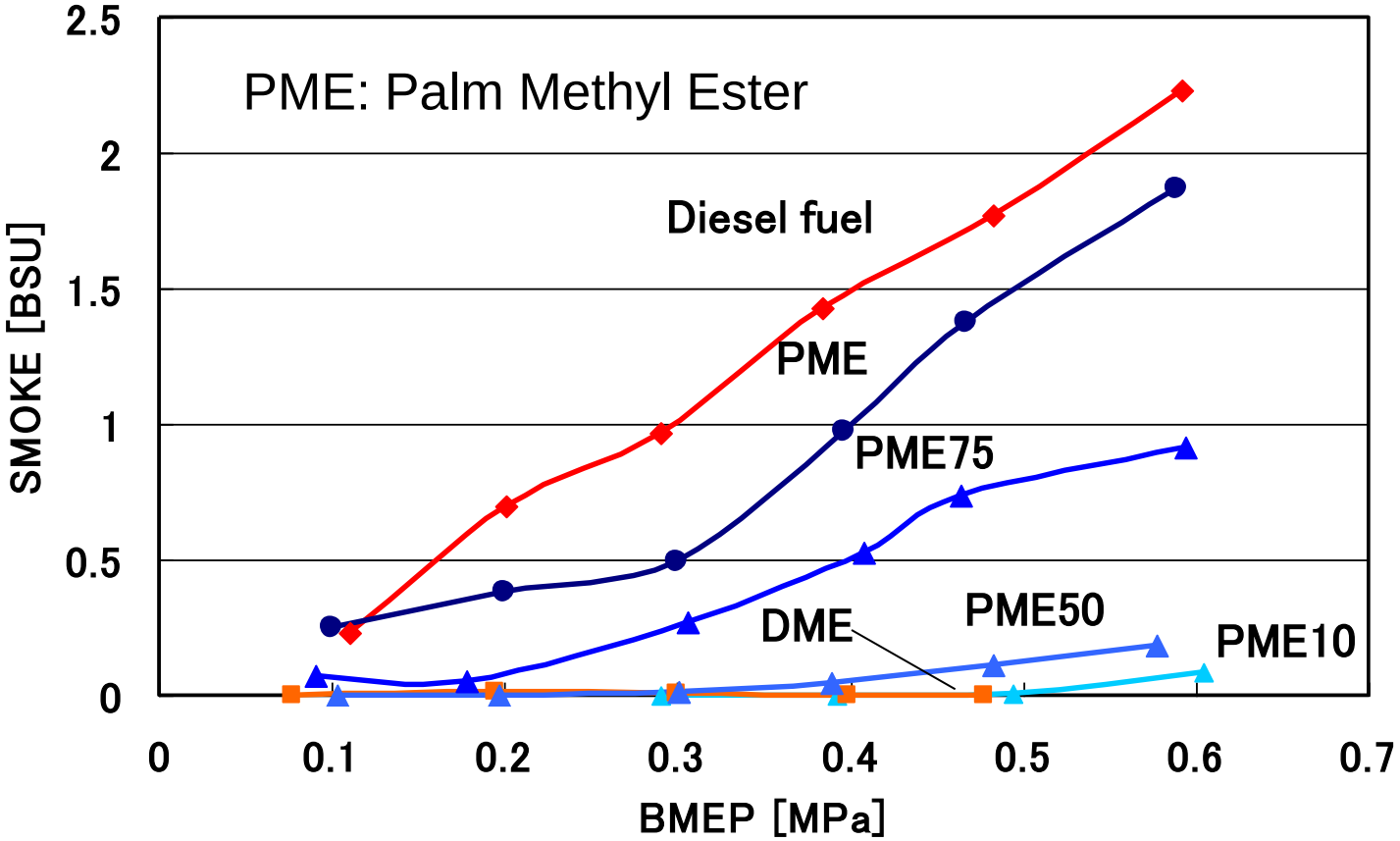
Road Map of DME Vehicle Introduction in Japan

Year	2000	2005	2010	2015	2020
Emission Regulation	▼'03 :New Short Term Reg .(NSTR) ▼'05 :New Long Term Reg. (NLTR) ▼'09 :Post NLTR				
MLIT Next Gen.EFV Project (DME vehicle)	'Dev. Promotion Project' ・DME HDT dev. ・Emissions and performances assessment ・Practicability study	'P/P Project' ・Dev. of DME vehicle ・Vehicle on road test ・Study of 'Tech. STD for DME Vehicle' ・Proposal for promotion of practical use	Introduction into market		Mass production
		'Verification Model Project' ・Dev. of practical vehicles and road test ・To arrange the 'Tech. STD for DME vehicle' ・To verify adaptability to market needs			
DME Supply	Small scale Promotion plant	50-100k t/year			
		Commercial scale plants	0.6-1.0m t/year	1.7- 2.0m t/year	

modified from Dr.Sato' presentation at 4th Asian DME Conference,Kitakyushu,November,2007

Diesel engine test with PME/DME mixture fuel

Fuel viscosity and Smoke emission decrease with DME.



Reference: Prof. M.Konno, Ibaraki Univ. Japan

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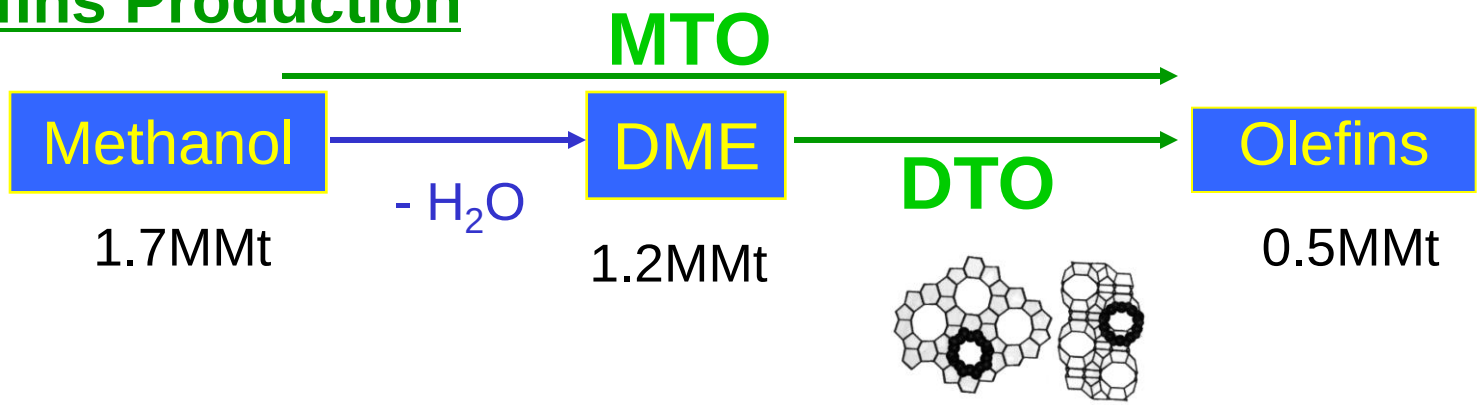
DME as Chemical Feedstock

Olefins Production



- Olefins demand have the same magnitude as LPG,LNG demand worldwide. (Ethylene: 100MMt, Propylene: 60MMt)
- Process development:
  ExxonMobil (MTO), UOP/HYDRO (MTO), Lurgi (MTP), JGC (DTO)
- Commercial Projects: 1 Project with Lurgi tech. under construction , 1 Project with domestic tech. under construction in China. 1 Project with UOP tech. under planning in Nigeria.

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DME Production Technology from Natural gas

- **Two step process (Methanol Synthesis+Dehydration)**:

Licensor: Haldor Topsoe, Lurgi, Toyo, MGC,SWI,etc.

(1)Methanol Synthesis:

$$2CH_4+O_2+H_2O \rightarrow 4H_2+2CO+H_2O\downarrow \rightarrow 2CH_3OH$$

(2)Dehydration of Methanol:

$$2CH_3OH \rightarrow CH_3OCH_3+H_2O\downarrow$$

- **One step process (Direct DME Synthesis)**:

Licensor: JFE

$$2CH_4+O_2+CO_2 \rightarrow 3H_2+3CO+H_2O\downarrow \rightarrow CH_3OCH_3+CO_2$$

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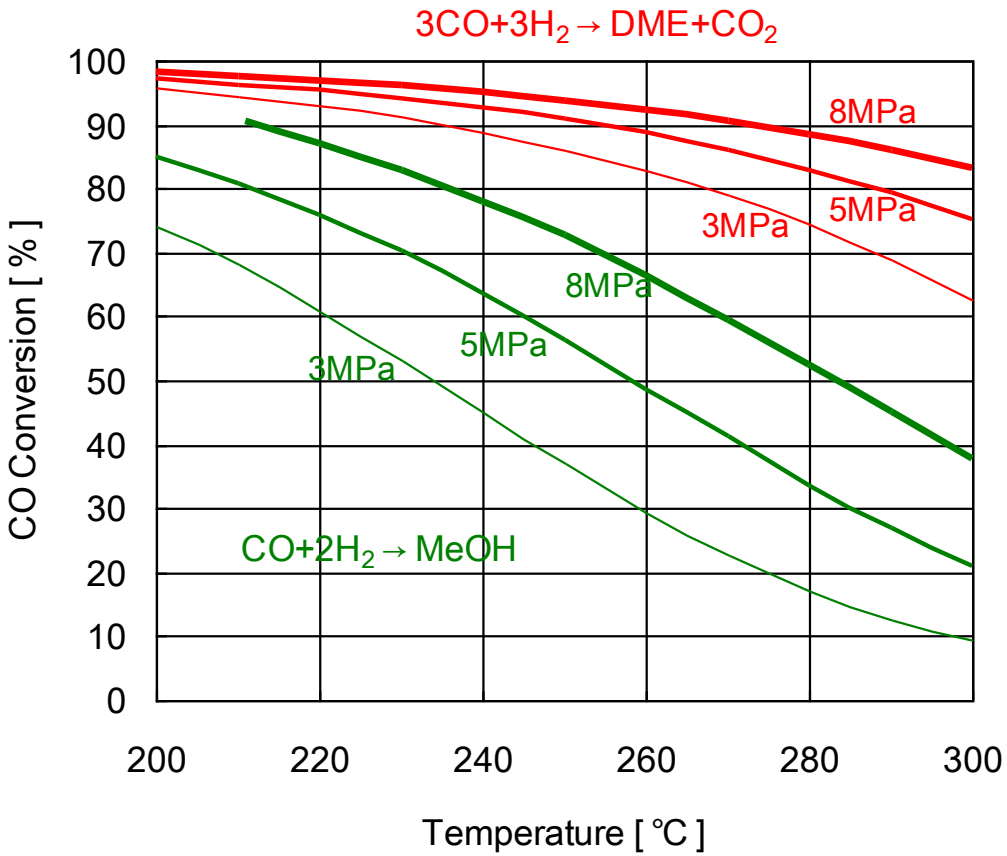
Equilibrium conversion for Methanol synthesis and DME synthesis



Comparison of Direct synthesis process with Indirect process (two step)

Process	Direct (JFE)	Indirect (Two Step)	
		Methanol	Dehydration
Reaction pressure(MPa)	5	8-10	1-2
Reaction temperature(^{o}C)	240-280	180-270	300-340
One through conversion(%)	50	38	70
Reaction by-product	CO_2	-	Water
(Water+MeOH)/DME (molar ratio)	0.1	-	1.9
Reactor	Slurry Phase	Fixed Bed	Fixed Bed
Cold gas efficiency from Natural gas (%)	71(83)	57(83)	
( ) – Theoretical value		66(84)	87(98)
Cold gas efficiency from Coal (%)	66.3	53.7	
		61.7	87

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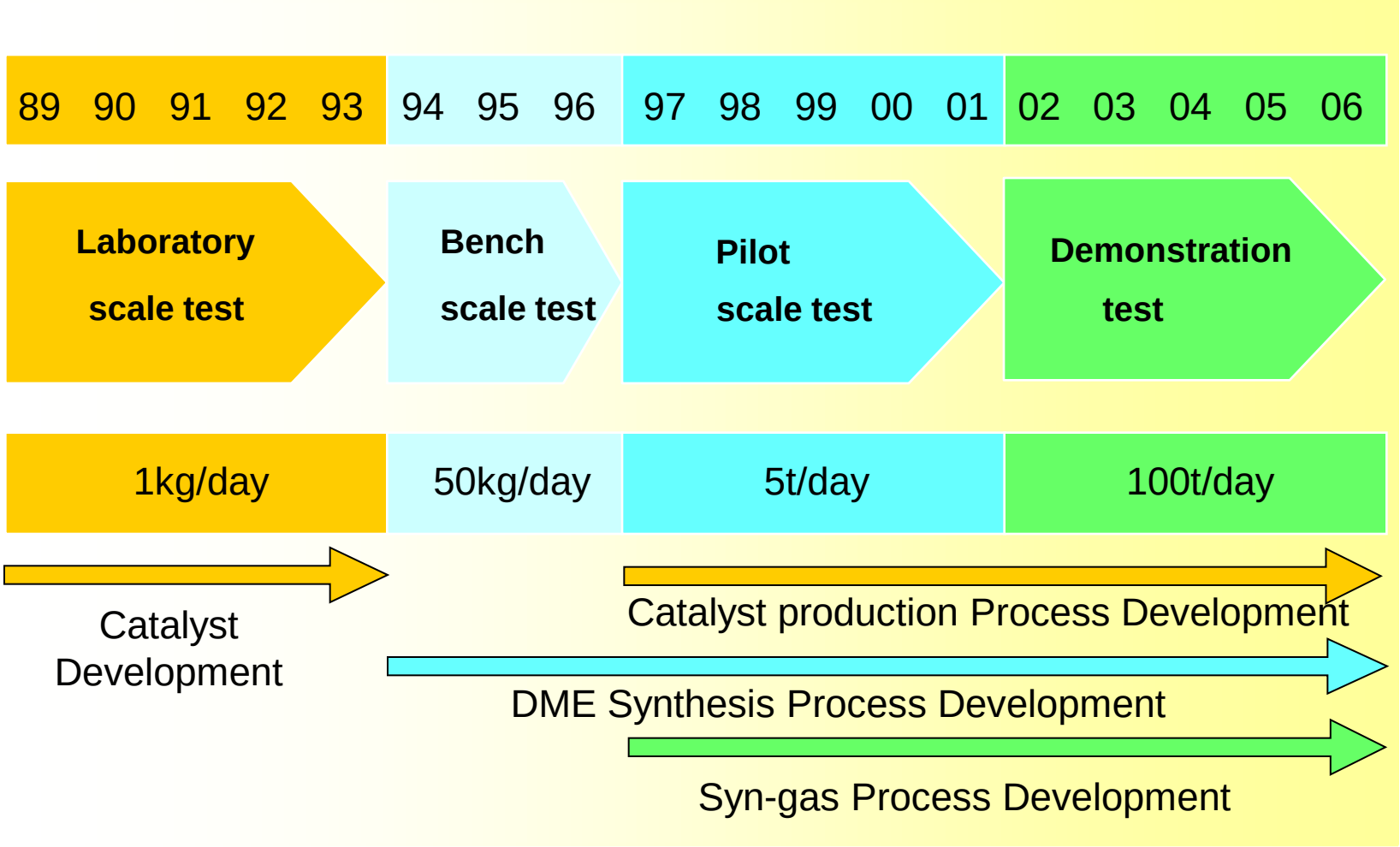
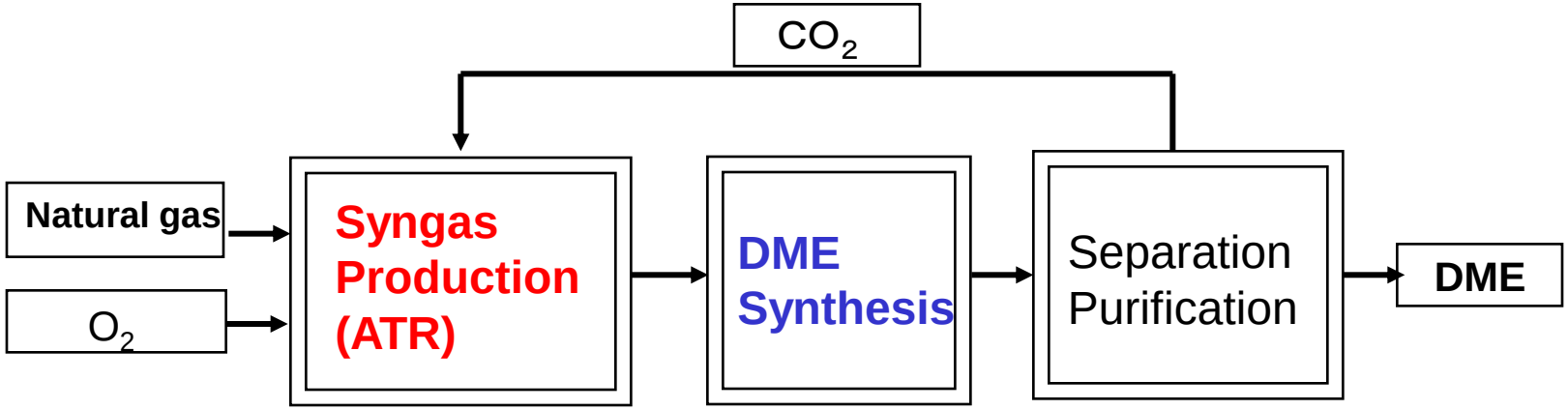
Development History of JFE Direct DME Synthesis



DME Production from Natural gas by JFE Process



- **Syngas Production (Auto-Thermal Reformer)**

$$2CH_4+O_2+CO_2 \rightarrow 3CO+3H_2+H_2O\downarrow$$

- **DME Synthesis (Slurry phase reactor, Catalyst)**

$$3CO+3H_2 \rightarrow CH_3OCH_3+CO_2$$

- **Overall reaction** $2CH_4+O_2 \rightarrow CH_3OCH_3+H_2O$

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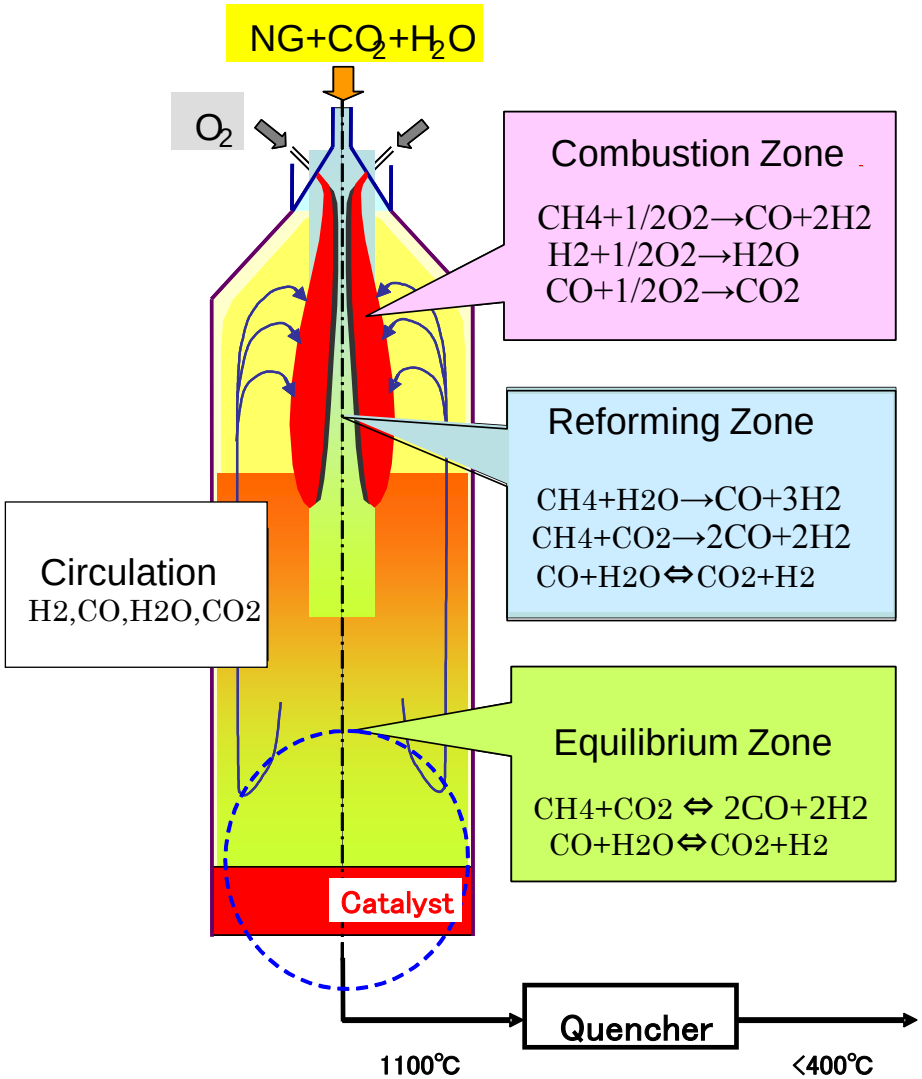
Characteristics of JFE Autothermal Reformer



1. Burner design and furnace profile

- Enhanced mixing of feed
- Water cooled burner
- Well designed refractory works

2. Catalyst bed

- Complete methane reforming

3. Rapid quench

- Prevent Boudouard reaction

$$2CO \rightarrow CO_2 + C$$

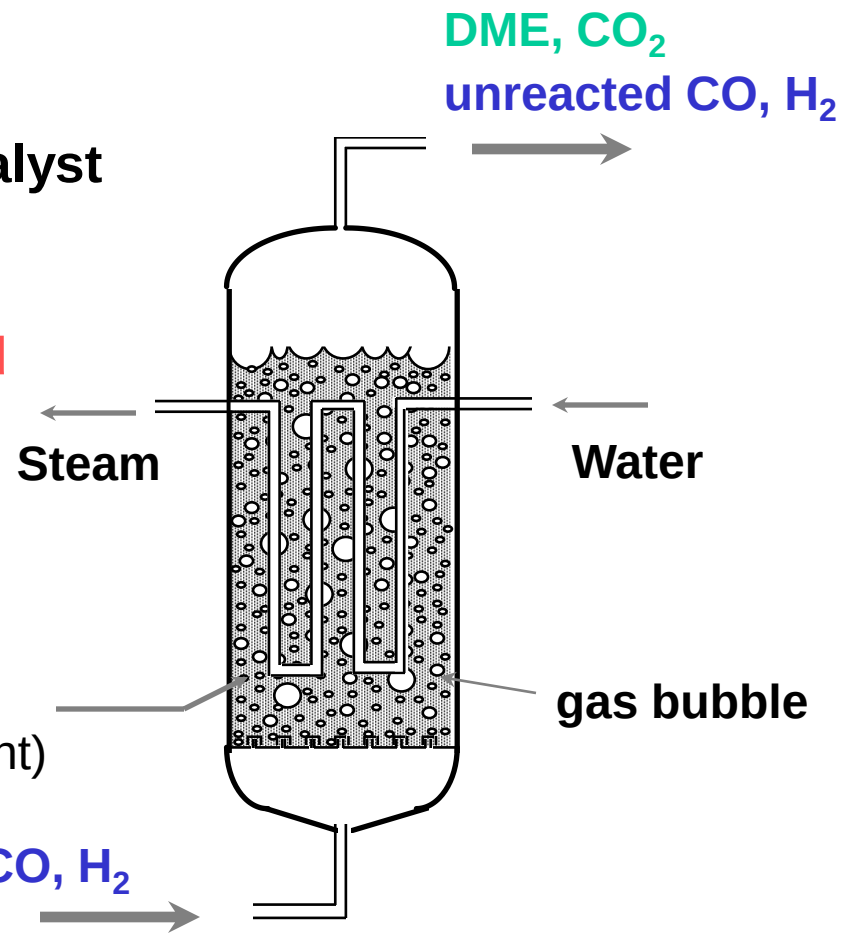
Slurry Phase Reactor for DME Synthesis

1. **Homogeneous temperature distribution**

2. **Possibility of changing catalyst during operation**

3. **NO need for Catalyst/Liquid separation**

4. **JFE Proprietary catalyst**



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DME 100 tons/day Demonstration Plant

Results of Test Operation

- Operation time and production

RUN NO.	Period	Duration (day)	DME production(t)
RUN100	2003/12/12-2004/1/26	43	1,240
RUN200	2004/6/20-7/31	39	2,500
RUN300	2004/10/6-12/16	72	4,230
RUN400/500	2005/6/15-11/13	152	9,070
RUN600	2006/4/3-5/12	40	2,480
(Total)		346	19,520

- Cold gas efficiency from natural gas:

  69.4% (ATR: 84.9%, DME synthesis: 81.7%)

  (71% expected for commercial scale plant)

- Stable DME synthesis catalyst activity:

  152days (1 year expected for commercial scale plant)

- Purity of produced DME: 99.8%

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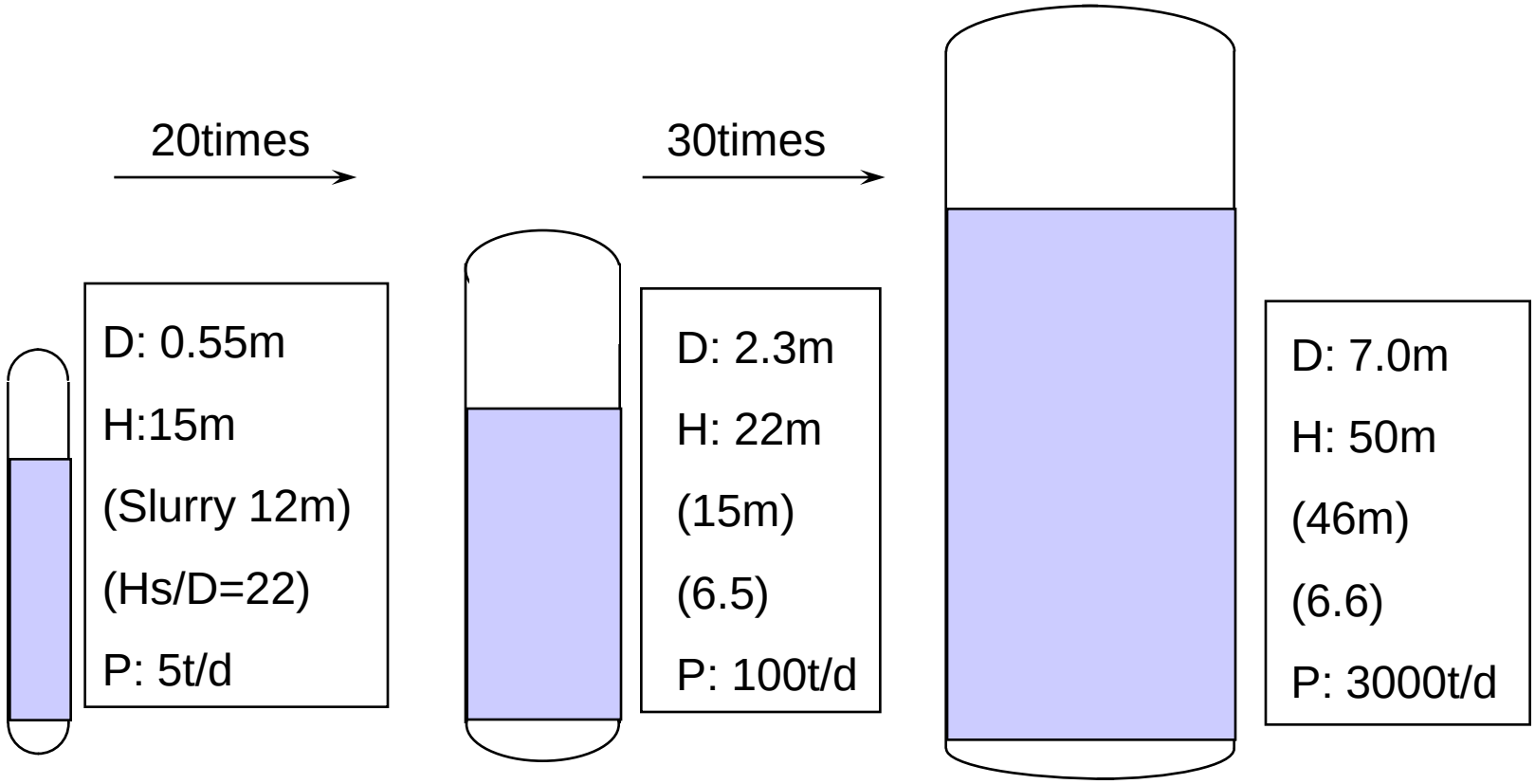
Scaling–up of Slurry Phase Reactor



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Summary of JFE Process Development

- JFE has completed the development of Direct DME synthesis process and CO_2 recycle type ATR.
- JFE has developed own efficient catalyst system and its mass production technology.
- Scale-up technology has been established. FEED and VE have been completed for a commercial scale plant.
- JFE process configuration is more compact and less expensive and more efficient than two step technology.
- **JFE is ready for process licensing and catalyst supply.**

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DME Production from Multi-resources

• JFE process is suitable to produce DME from such feedstock as

- CO_2 rich natural gas
- Coal (Bituminous to Lignite)
- Biomass (Wood chip,Corn Stover,other crop residues)

Bio-DME is a Second generation Biomass fuel which has no conflict with food supply.

-Locally stranded or recycled resources as Coke oven gas, Coal bed methane, Heavy residue, Agriculture/forestry waste,Municipal waste,etc.

• CO_2 sequestration should be integrated to DME production in future.

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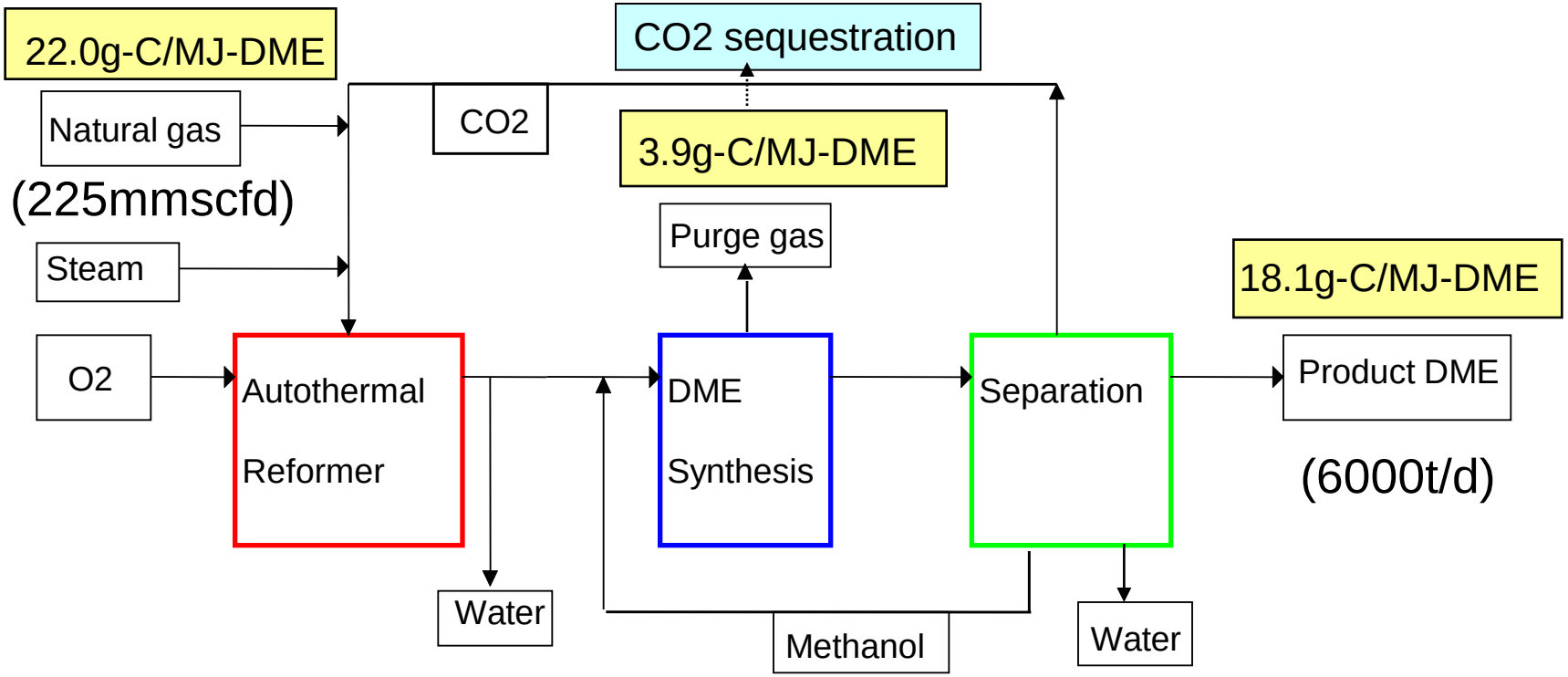
DME production from Natural gas



Cold gas efficiency (including fuel) :70.2%

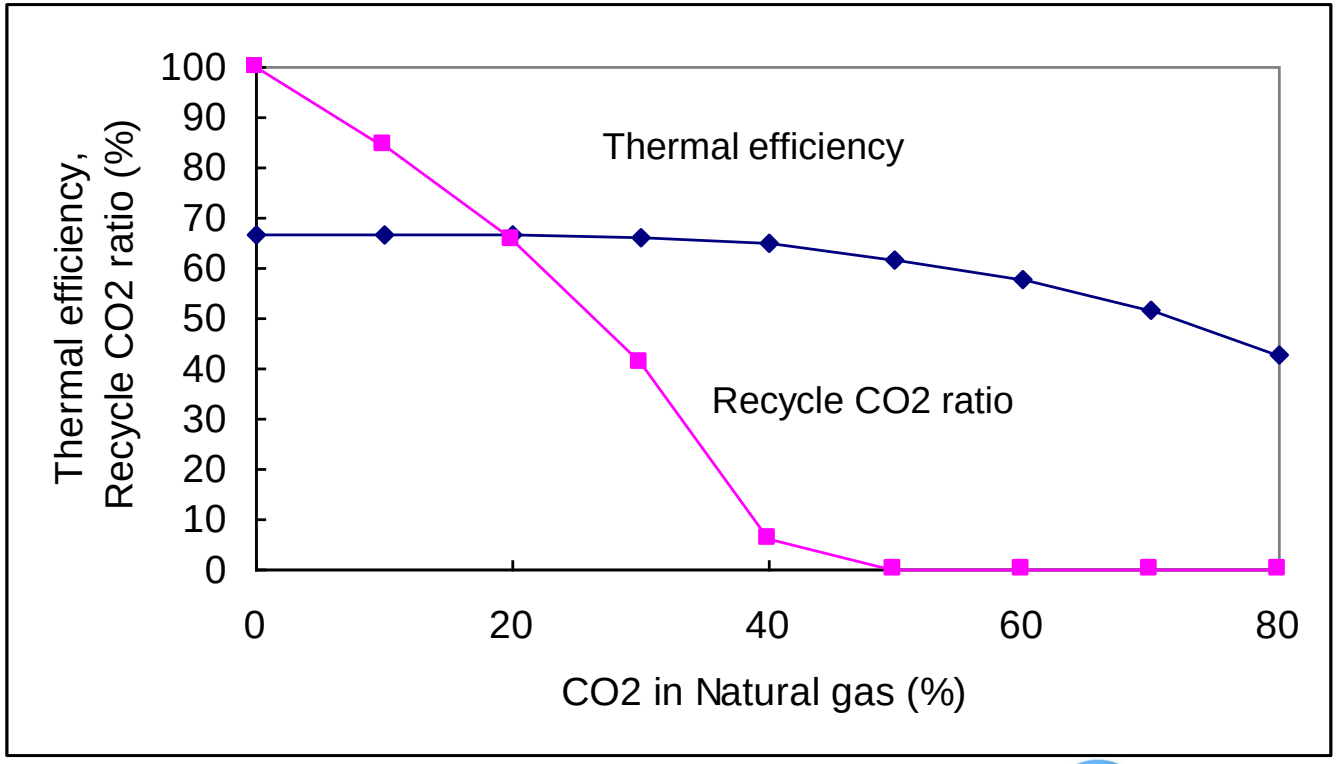
Natural gas consumption : 1032Nm^3/t-DME, Oxygen consumption : 1.02t/t-DME

Natural gas composition : C1 87.9%, C2 8.6%, C3 2.7%, C4 0.4%, N2 0.4%

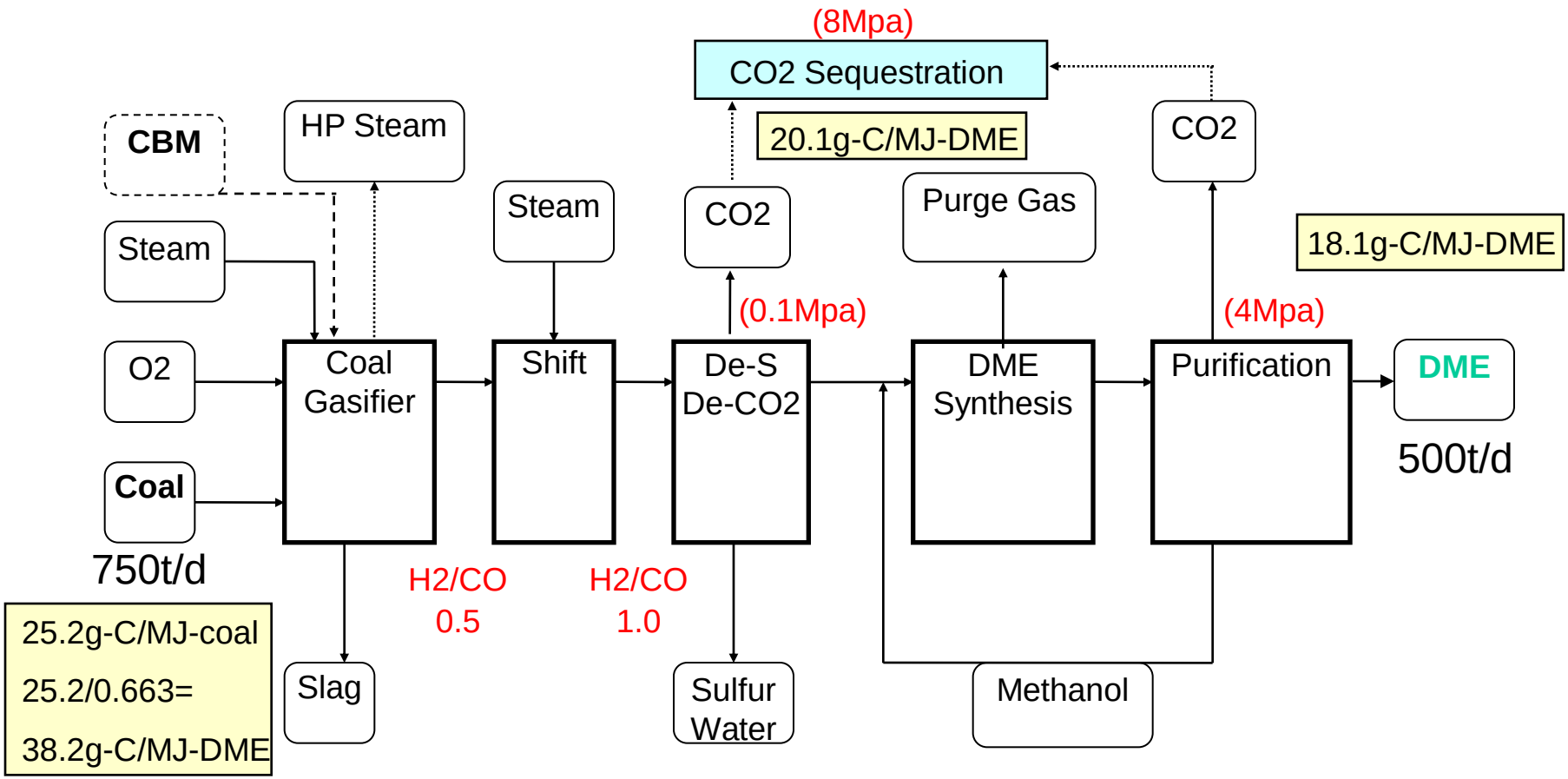
: CO_2 emission

DME production from CO_2 rich natural gas

- With increasing CO_2 up to 40% in natural gas, recycle CO_2 decreases to keep H_2/CO=1 of synthesis gas. Excess CO_2 is separated and compressed up to 8Mpa for storage.
- Thermal efficiency of DME production almost constant up to 40% CO_2.



DME production from Coal



: CO2 Emission , Conversion efficiency from Coal to DME : 66.3%

Coal consumption: 1.5 dry-t/t-DME, Oxygen consumption: 1.2 t/t-DME

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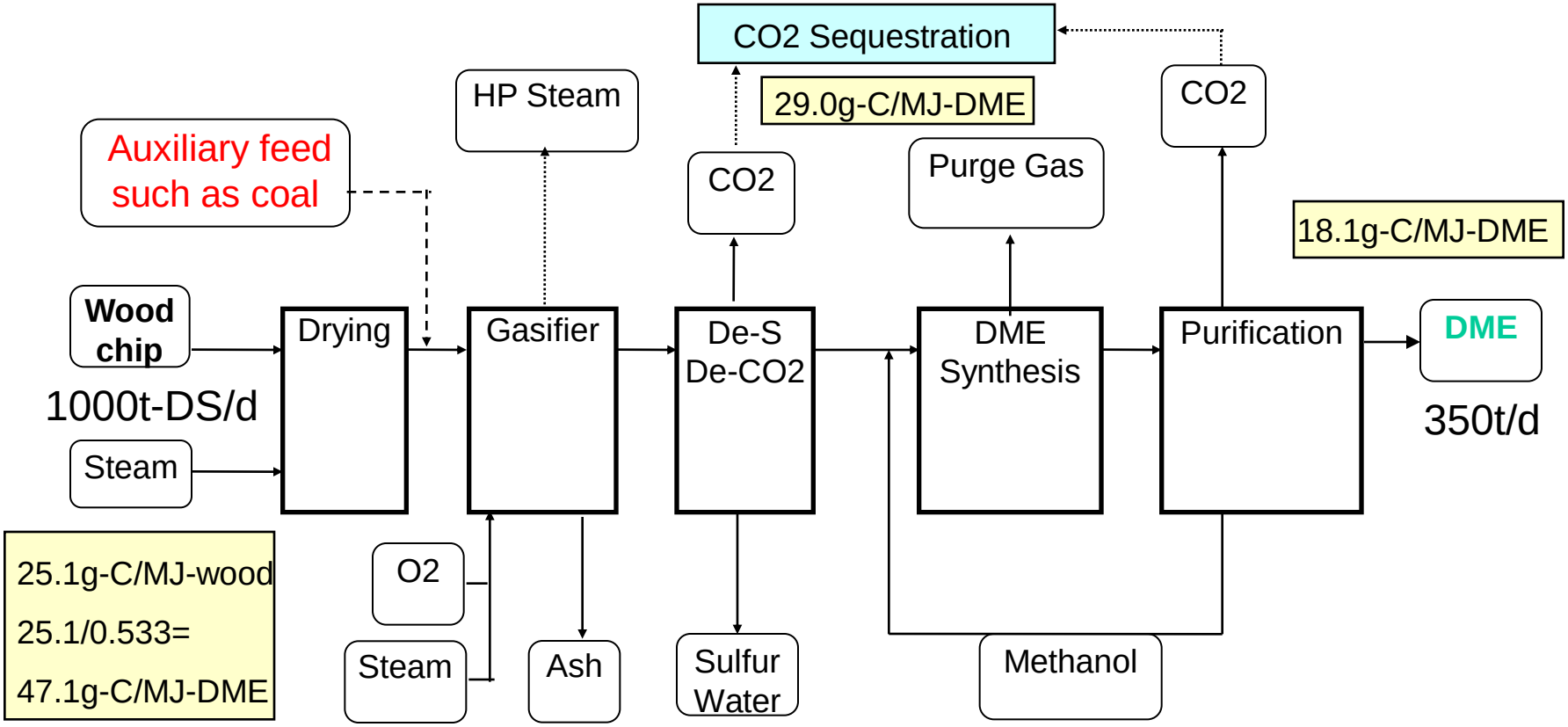
DME production from Biomass(wood chip)

DME from Biomass is carbon neutral. If CO_2 emitted at production is stored, it create negative emission.



: CO2 Emission , Conversion efficiency from Wood chip to DME : 53.3%

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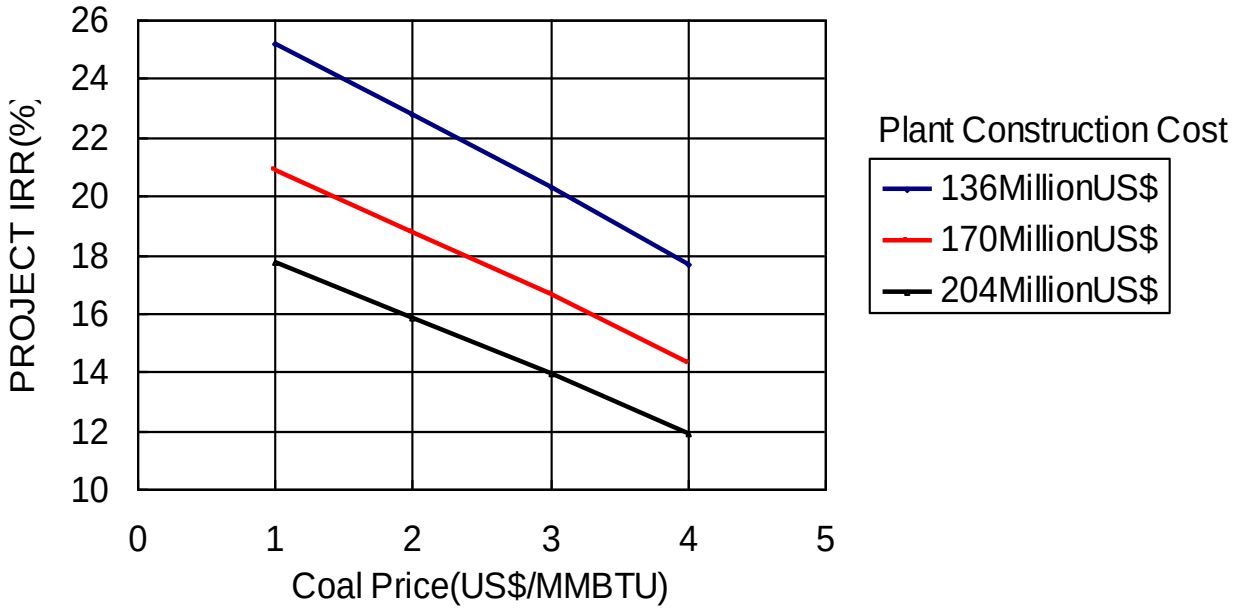
Feasibility for DME production from Coal



Plant Site	: China
Plant Capacity	: 500t/d
Plant Construction	: 170MMUS＄ ±20% – Including Coal Gasifier
DME Price	: 4,000Yuan/T (US$500/T)
Coal Price	: 1～4US$/MMBTU
	1.0US$／MMBTU = 200Yuan/T

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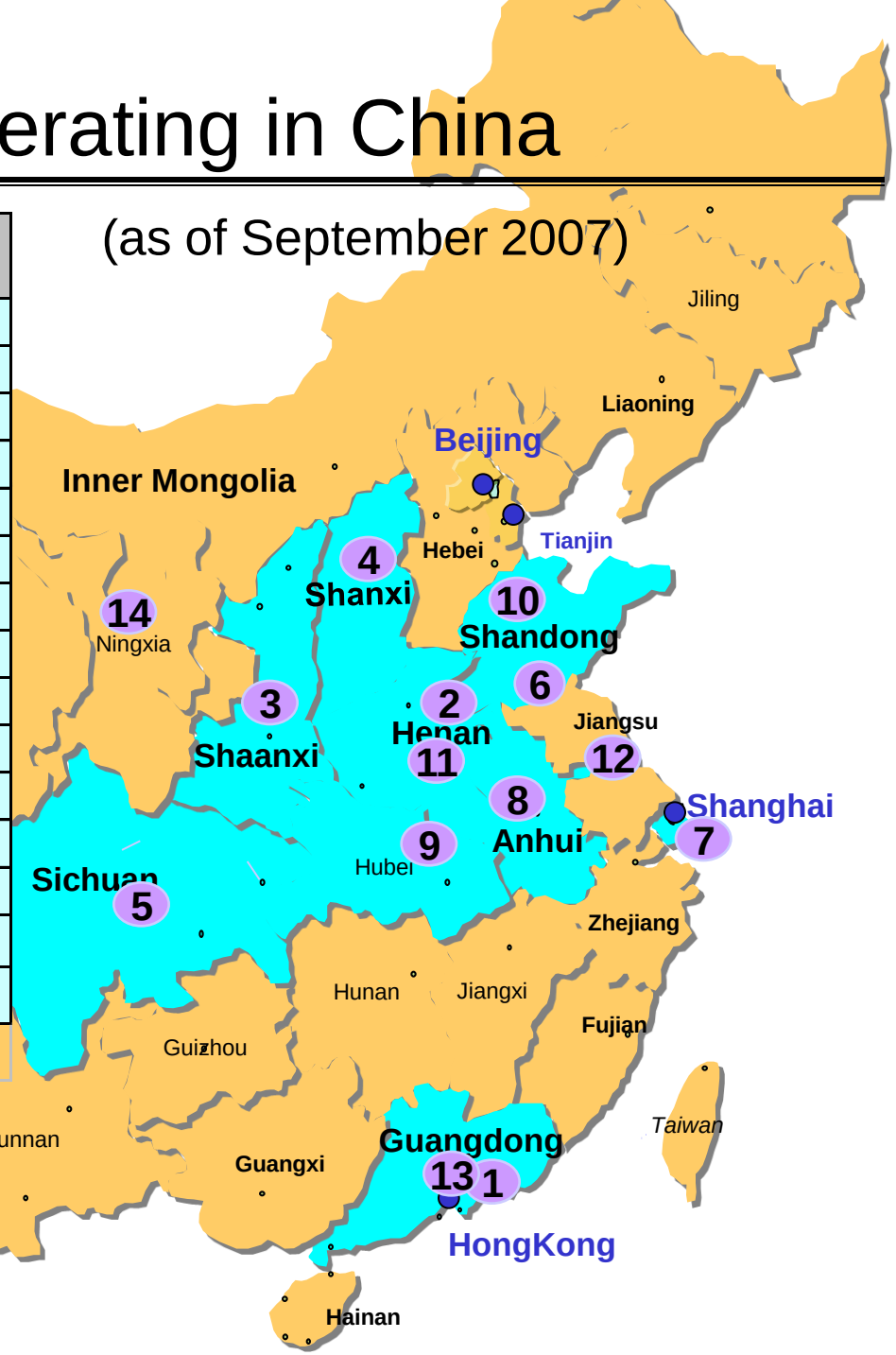
DME Commercialization Activities in China

- Annual production of DME increases sharply, 20kt in 2002 to 320kt in 2006 as LPG /DME mixture, produced from methanol.
- NDRC announced in June 2006
  - Importance of DME. A production capacity should be more than 1million t/y and from coal. NDRC target: 20 Mt/y in 2020.
- A 3million t/y DME plant in Inner Mongolia has been approved by the government. There are a lot of DME production projects, total production capacity is expected to reach 15 million t/y in 2010.
- DME pipeline is under planning from Inner Mongolia to Beijing region.
- Development of Diesel alternative through Shanghai bus project.
  - Environmental need for clean transportation fuels.

DME Plants operating in China

(as of September 2007)

	Province	Feed-stock	Capa. ktpa	Start-up
1	Guangdong	Methanol	8	1994
2	Henan	Coal	10	1994
3	Shaanxi	Nat. Gas	10	1998
4	Shanxi	Methanol	10	2000
5	Sichuan	Nat. Gas	10	Aug/03
			100	Apr/06
6	Shandong	Coal	150	May/05
7	Shanghai	Coal	5	Dec/05
8	Anhui	Methanol	20	Dec/05
9	Hubei	Methanol	100	May/07
10	Shandong	Methanol	10	May/07
11	Henan	Methanol	100	July/07
12	Jiangsu	Methanol	50	Aug/07
13	Guangdong	Methanol	300	Sept/07
14	Niingxia	Coal	210	May/07
			1093	

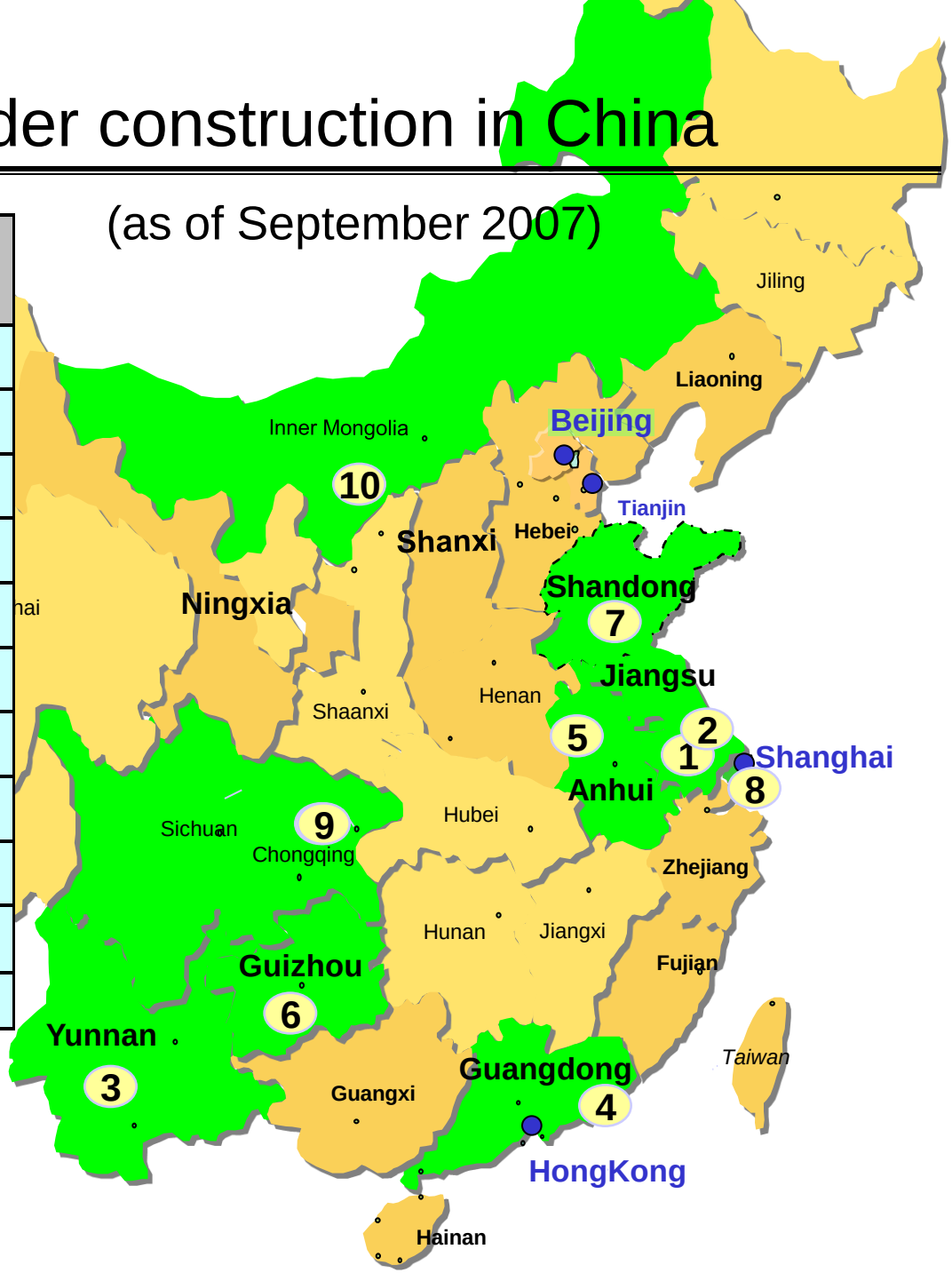


By courtesy of Mr.Taupy of International DME Association

DME Plants under construction in China

(as of September 2007)

	Province	Feed-stock	Capa. ktpa
1	Jiangsu	Methanol	200
2	Jiangsu	Methanol	300
3	Yunnan	Coal	150
4	Guangdong	Methanol	200
5	Anhui	Methanol	100
6	Guizhou	Coal	180
7	Shandong	Methanol	250
8	Shanghai	Coal	50
9	Chongqing	Coal	80
10	I. Mongolia	Coal	3000
			4510



By courtesy of Mr.Taupy of International DME Association

DME Commercialization Activities in Japan

- Japan DME: FS for 700 -1,200 Kt/y from Natural gas in Papua New Guinea
- Fuel DME Production Co.Ltd established to start 80 Kt/y production in June 2008 (by dehydration of imported methanol) (Japan DME,etc)
- DME International: FS for 2,000 Kt/y from Natural gas in Middle East
- JFE etc.: FS for 200 - 1,000 Kt/y from Coal or COG in China
- DME Demand forecast for introductory period in Japan
  (DME promotion center(2006))

	2007	2008	2009	2010-2012
Demand (Kt)	20	50	100	1,200
LPG substitute	19.7	40	50	800
Model project*	0.3	10	50	400

*Distributed Power generation, Vehicle, Boiler, Chemical feedstock

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DME Commercialization Activities in other countries -1

Iran

- Zagros Petrochemical Co. , 800kt/y DME plant next to Methanol Plant at Assaluyeh, expected production in 2009.
- 50% DME will be blended in LPG for local market as household fuel and surplus LPG (300kt/y) for export.
- Production Technology : Methanol dehydration, fixed-bed reactor,

  Engineering and License: NPC-RT and Haldor Topsoe AS

Egypt

- 1.3 million ton per year methanol plant under construction
- MOU signed with Egyptian government on DME plant
- 200 kt/y DME for blending into LPG
- Expected to be located adjacent to the methanol plant (Mubarak Gas and Petrochemicals Complex, Damietta)

DME Commercialization Activities in other countries-2

South Korea

- KOGAS 10 t/d DME Demo Plant under construction to complete in May 2008, DME demonstration project (2009)
- Target : 3,000t/d from small-medium size gas field in 2009-2012 to supply DME into Korea.

Sweden

- AFFORHD: Alternative Fuel for Heavy Duty Engines
- Bio-DME project: from Wood chip(Växjö), Black liquor(Chemrec)

Russia

- Moscow program: "Alternative fuels use in city's motor transport for 2002-2004". Dual fuel (DME,Gas oil) vehicle confirmed reliable.
- VNIIGAZ (GAZPROM Research Institute) developing technology to manufacture DME

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Potential markets of DME in Asia (MMt/y)

	Electricity		Transport		Residential		Total	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Japan	2.7	8.0	0.2	3.6	0.6	5.4	3.5	17.0
China	6.7	10.0	3.0	7.1	4.8	7.5	14.5	24.6
India	4.0	6.0	1.6	3.2	4.3	6.4	9.9	15.6
South Korea	2.0	3.0	1.0	2.0	1.0	1.5	4.0	6.5
Other Asia	4.1	8.1	-	2.3	2.6	4.2	6.7	14.6
Total	**19.5**	**35.1**	**5.8**	**18.2**	**13.3**	**25.0**	**38.6**	**78.3**

Source: Japan DME Forum,“DME Handbook“(2006)

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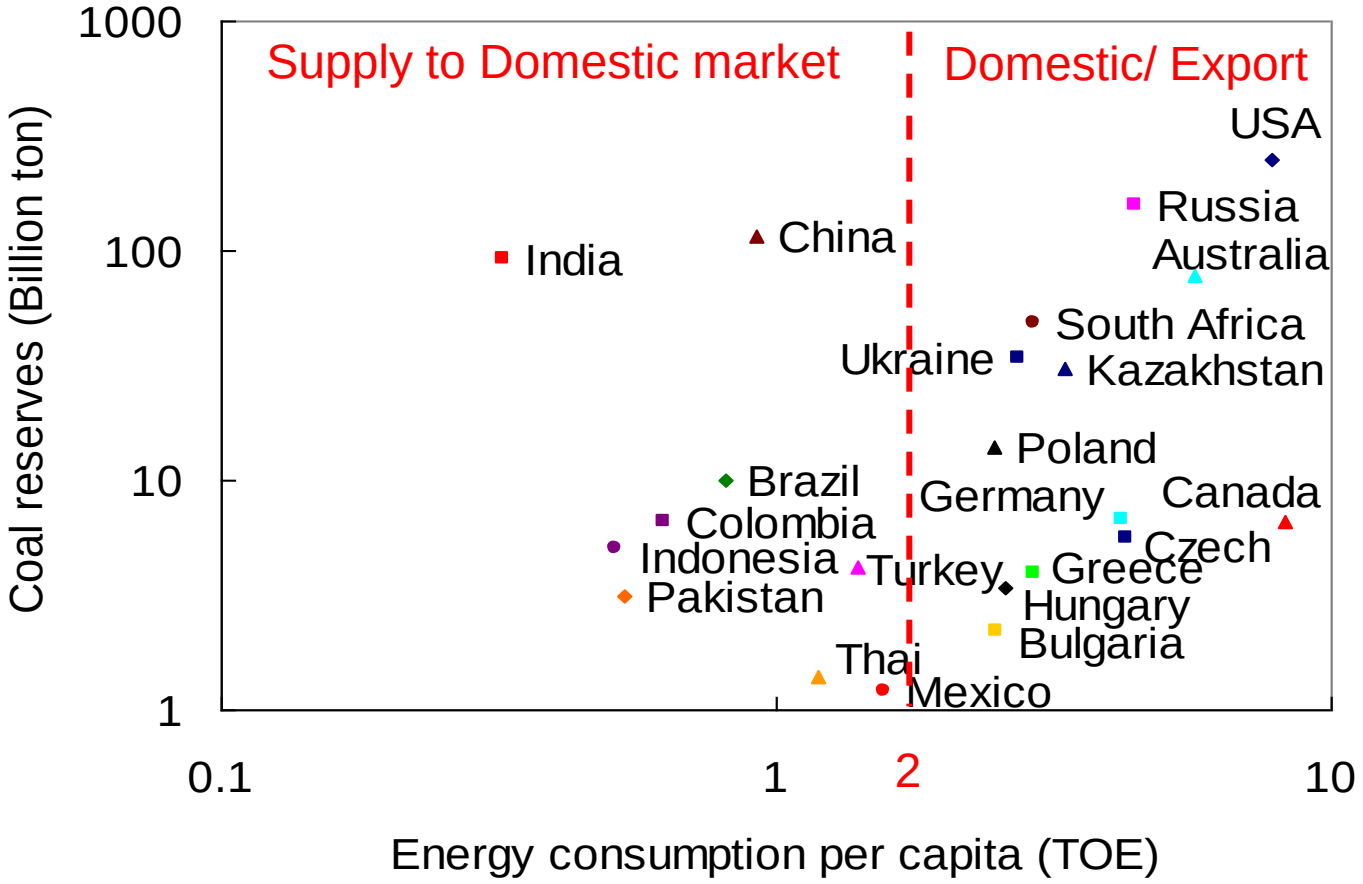
Coal reserves and DME production potential

Countries with more than 1 Billion coal reserves are plotted.
(1 Billion coal =10 Million t/year-DME for 50years.)

Energy consumption per capita 2 TOE necessary for sufficient UN HDI.



Standard and IGC code of Fuel DME

• Domestic Standard

• In Japan, TS(Technical Specification) for DME standard for industrial and power generation fuel was published in Nov. 2005.

• Standards for home use and vehicle are under study.

As for vehicle use, effects of impurities and additives on durability and performance of engine are investigated by AIST.

• In China,Ministry of Construction published DME standard for home use in Aug.2007 (effective Jan. 2008).

• International Standard

• International work for DME standard has started in 2007 in subcommittee SC4 and SC5 of ISO/TC28.

(Countries involved: China,France,Germany,Japan,Poland,South Korea,Sweden,Turkey,USA)

• IGC code amended for maritime transportation of DME

• Liquid DME can be transported by Bulk carrier from July 2008.

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DME – International cooperation

International DME Association

Dimethylether: A Fuel for the 21st Century

Please visit IDA website:
www.aboutdme.org

Korea DME Association

DME

Japan DME Forum

China DME Association

- **4th Asian DME Conference, 12th-14th November 2007,Kitakyushu,Japan**
  51 presentations, Proceedings available
  Please visit JDF Website: www.dmeforum.jp
- **Sino-Japan Symposium on DME Vehicle**
  3rd December 2007, Shanghai,China
- 5th Asian DME Conference & 3rd International DME Conference[DME3]
  21st-24th September 2008, Shanghai,China

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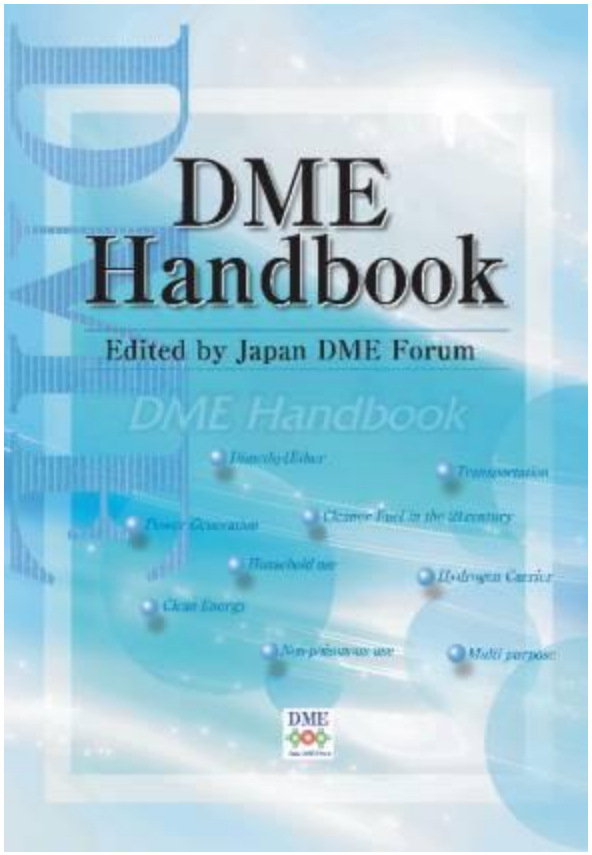
DME Handbook edited by JDF

English edition was published in October,2007



Please visit JDF Website:
www.dmeforum.jp

Introduction

Fundamental properties

Combustion of DME

Reforming of DME

Production technologies

Utilization technologies

Distribution network

Economics and Market

Safety,Environment

Standard,etc.

600 pages, 40,000JPY

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Conclusion

- DME production and utilization technologies have been developed and are now ready for commercialization.
- DME is economically competitive against conventional fuels.
- Study for International standard has been started and will be finalized in a few years.
- Coal to DME and Biomass to DME will be promoted in view of resource potential and environmental conservation.
- For vehicle use,a certain amount of DME penetration is necessary for preparation of DME fueling station and to persuade vehicle manufacturers of mass production.
- DME will be an essential feedstock for chemicals as olefins.

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