

LNG RE GASIFICATION

A GLOBAL OVERVIEW OF TECHNOLOGY AND COLD ENERGY UTILISATION

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World primary energy demand is expected to grow by 1.6% per annum over the period 2010 to 2030; in order to meet this requirement energy production will have to be increased by 39% over this period. Natural Gas (NG) is a natural resource which in recent years has seen a large increase in demand globally. While the share of oil in energy is forecasted to dramatically decrease by 2030, NG is predicted to reach 25.9% of the world's energy usage.

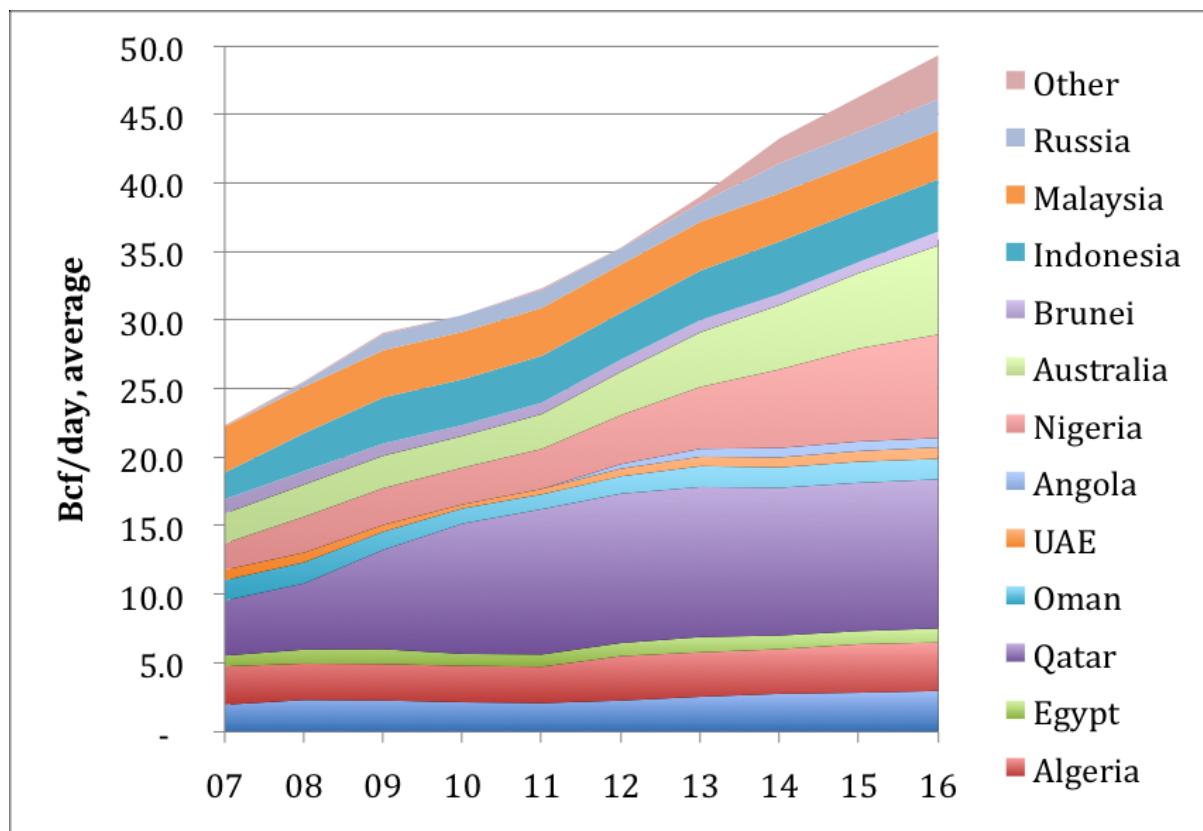


Figure 1: World LNG Production by Country (2007 - 2016)

The LNG chain can be divided into three main sections, including production region, LNG tankers and consumption region. In the production region, NG is chilled to a liquid state where its volume is reduced to 1/600th of its original volume. The LNG is transported to its destination by means of insulated cryogenic ships. In the consumption region, LNG is then changed into its normal gaseous form ("re gasified") and

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delivered to customers by gas pipelines. During LNG production, approximately **500 kWh energy/t LNG** is consumed for compression and refrigeration and a considerable portion of this invested energy is preserved in the LNG, which has a final temperature of about -163 C (110 K). Therefore, a considerable potential of energy recovery exists during the re gasification process.

Exporters \ Importers	Nigeria	Algeria	Trinidad & Tobago	Qatar	Australia	Indonesia	Malaysia	Russia	others	Total import amount
Importers										
France	0.88	3.86	0	1.29	0	0	0	0	0.26	6.29
Spain	2.2	2.32	1.66	2.63	0	0	0	0	2.19	11
England	0	0.18	0.17	6.37	0	0	0	0	0.19	6.91
Other Europe	1.85	3.37	0.06	6.93	0	0	0	0	0.77	12.98
Mexico	1.14	0	0.29	1.17	0	0.25	0	0	2.48	5.33
USA	0.06	0	1.43	0.16	0	0	0	0	0.35	2
Other America	1.29	0.06	8.6	1.42	0	0	0	0	0.76	12.13
China	0.43	0.06	0.11	7.16	3.45	2.69	2.67	0	1.99	18.56
India	0.81	0.12	0	11.07	0	0	0	0	1.06	13.06
Japan	3.8	0.42	0.27	16.41	18.16	6.26	15.21	8.6	18.6	87.73
Korea	2.71	0.12	0.64	13.54	0.68	5.79	4.23	2.03	10.36	40.1
Other Asia	1.07	0.24	0.28	7.54	0.06	3.36	3.03	0.06	2.19	17.83
Middle East	0.23	0.06	0.17	2.33	0.06	0	0	0	0.12	2.97
The total export amount	16.47	10.81	13.68	78.02	22.41	18.35	25.14	10.69	41.32	236.89

NOTE: Units are in million tons per annum (mtpa)

Table 1: Global LNG Trading 2013 (Source: Osaka LNG news publication)

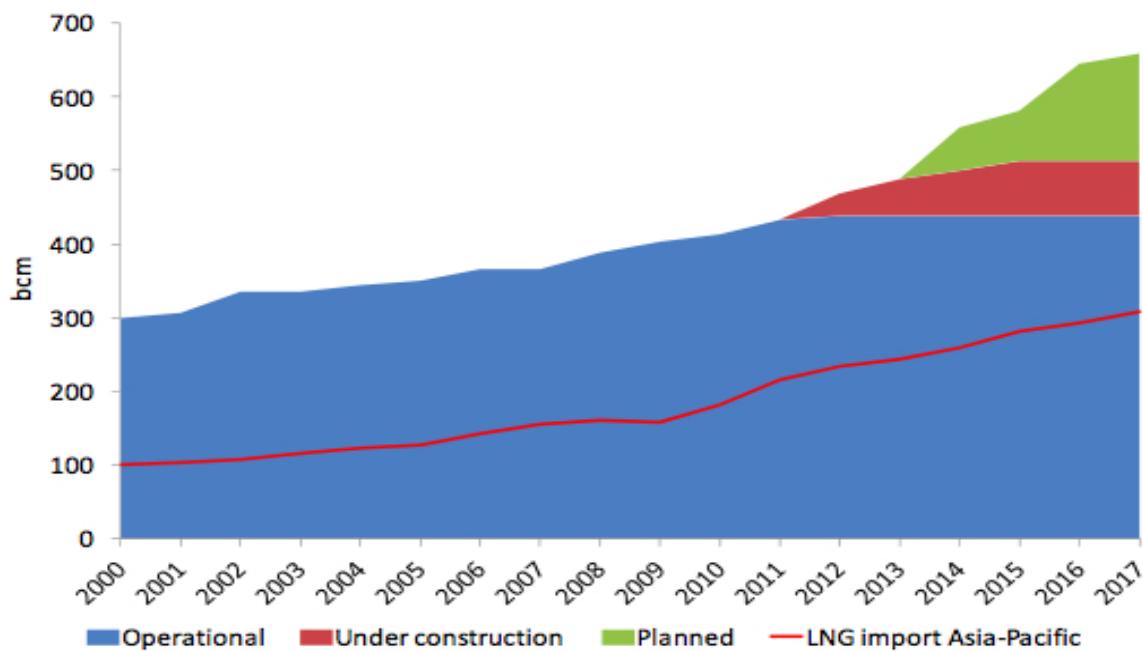


Figure 2: Re-gasification Capacities in Asia-Pacific 2000 - 2017 (Source: IEA)

Japan is the biggest LNG importer in world followed by South Korea. Japan and South Korea together import approx 50% of the world's current LNG production. Japan's total LNG imports equalling approx 87 mt during 2013.

- Total number of LNG receiving terminals 49
- Location(s), capacity & technology Refer Appendix A
- LNG imported in 2013 87 mt
- Approx estimated LNG infrastructure capital costs \$45 Billion*
- Approx % of ORV* technology 95%
- Total cold power generation capacity 40.4 MW
- Cold energy recovery efficiency 25%

*Estimated at average capital spend of US\$500m/mt re gasification capacity. The average capital calculated based on a sample cost data on ten Japanese terminals in JOGMEC handbook.

South Korea is the second biggest LNG importer. The total LNG imports equalling approx 40 mt during 2013.

- Total number of LNG receiving terminals 4
- LNG re gasification capacity 45.7 mt
- Approx total LNG infrastructure capital costs Under study
- Approx % of ORV* technology 100%
- Total cold power generation capacity NIL
- Cold energy recovery efficiency NA

Location	Capacity mtpa	Technology (Primary)
Gwangyang	1.7	ORV
Incheon	18	ORV
Pyeong Taek	18	ORV
Tongyeong	8	ORV

Table 2: Capacity of LNG Receiving Terminals in South Korea

China is the third biggest LNG importer. The total LNG imports equalling approx 18.6 mt during 2013.

- Total number of LNG receiving terminals 6
- LNG regasification capacity 25 mt
- Approx total LNG infrastructure capital costs Under study
- Approx % of ORV* technology 100%
- Total cold power generation capacity NIL
- Cold energy recovery efficiency Some (Liquid N2 etc.)

Location	Capacity mtpa	Technology (Primary)
Dalian	6	ORV
Fujian	5.2	ORV
Guangdong	4	ORV
Jiangsu Rudong	3.5	ORV
Shanghai	3	ORV
Zhejiang Ningbo	3.37	ORV

Table 3: Capacity of LNG Recieving Terminals in China

India is the second biggest LNG importer. The total LNG imports equalling approx 13 mt during 2013.

• Total number of LNG receiving terminals	4
• LNG regasification capacity	23.5 mt
• Approx total LNG infrastructure capital costs	Under study
• Approx % of ORV technology	20%
• Approx % of IFV (Glycol water) technology	65%
• Approx % of Shell & Tube technology	15%
• Total cold power generation capacity	NIL
• Cold energy recovery efficiency	NA

Location	Capacity mtpa	Technology (Primary)
Dahej I	5	IFV(Glycol water), Air
Hazira	3.5	ORV
Dahej II	5	IFV(Glycol water), Air
Dhabol	5	Shell & Tube
Kochi	5	IFV(Glycol water), Air

Table 4: Capacity of LNG Receiving Terminals in China

Year Commissioned	Terminal Location	MW	Type*	LNG flow rate t hr	Power rate kWh/LNG ton	Outlet pr. MPag
1979	Senboku II	1.5	R	60	25	3
1981	Chita Kyodo	1	R	40	25	1.4
1982	Senboku II	6	R/NG	150	40	1.7
1982	Kita Kyushu	9.4	R/NG	150	63	0.9
1984	Nihonkai	5.6	NG	175	32	0.9
1985	Negishi	4	MFR	100	40	2.4
1987	Himeji	2.8	R	120	23	4
1987	Senboku I	2.4	NG	83	29	0.7
1996	Iwasakibashi	1.2	NG	45	27	0.2
2000	Himeji	1.5	NG	85	18	0.7
2002	Yung-An, Taiwan	2.4	R	130	18	6.5
2002	Torishima	5	NG	220	23	0.7
TBA	China*	NA	NA	NA	NA	NA
	Total	42.8				

*NG: Natural gas R: Rankine cycle R/NG: Rankine cycle and NG MFR: Mixed Fluid refrigerant *Air separation unit

Table 5: Global LNG Cold Power Generation 2014 (Source: Osaka University)

Other current and potential cold energy utilisation applications include:

- Inlet air cooling (IAC) to gas turbines
- Air separation or other low temp fractionation
- Air conditioning, Cold storage & warehousing
- District cooling
- Cooling media for the adjacent refineries/ petrochemical plants, Chilled water for industry
- Cryogenic crushing
- BOG (Boil off gas) re liquefaction
- Dry ice manufacturing

It can be seen in Table 5 above that only in Japan, Taiwan & China have either implemented or planned to implement cold energy utilisation plants.

Common LNG Re-Gasification Technologies

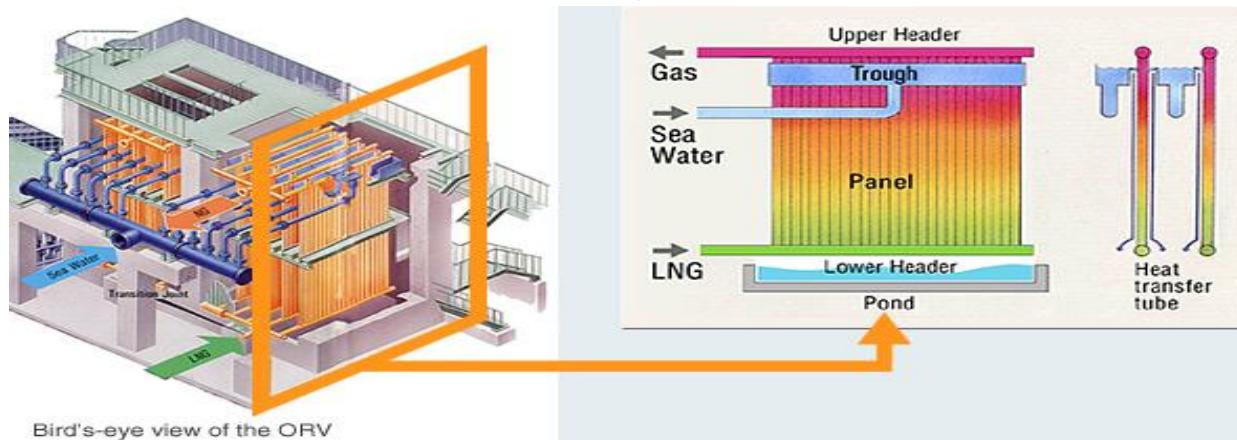


Figure 3: Open Rack Vaporiser (ORV)

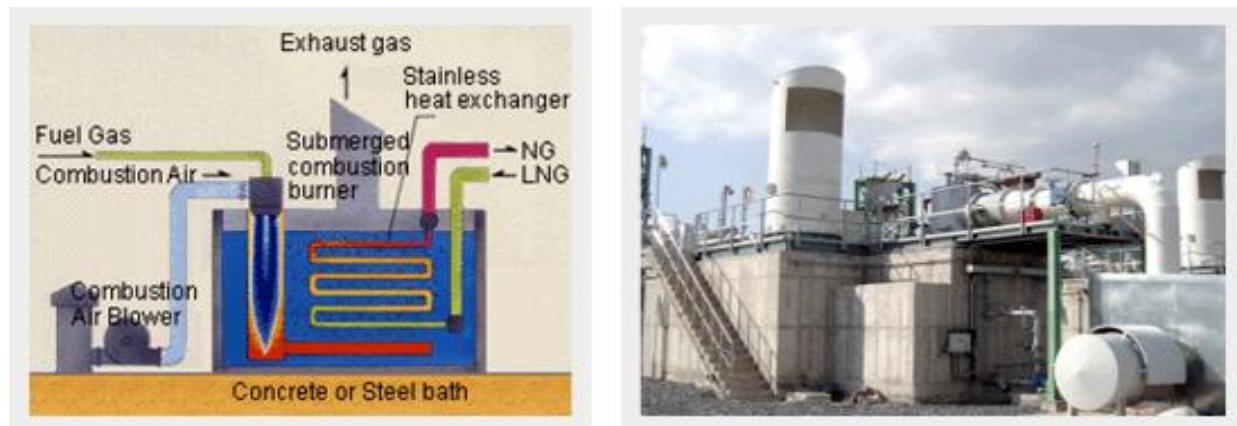


Figure 4: Submerged Combustion Vaporisers (SCV)

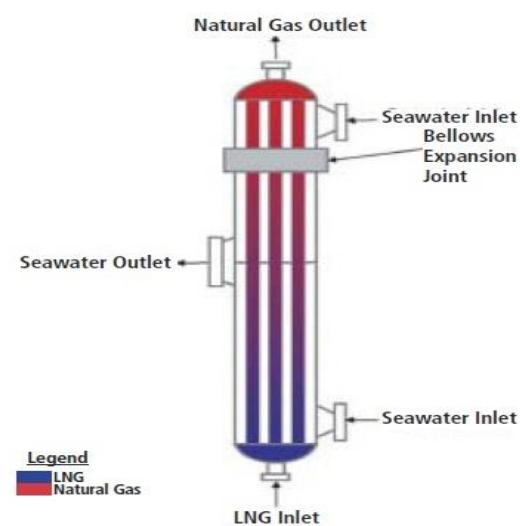


Figure 5: Shell & Tube Vaporisers (STV)

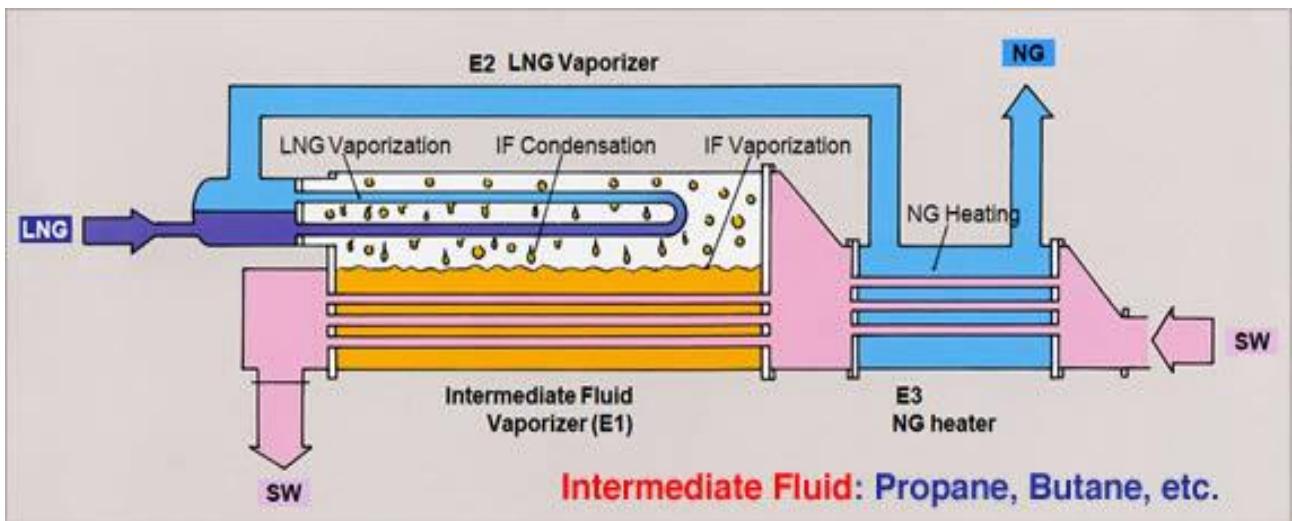


Figure 6: Intermediate Fluid Vaporisers (IFV)

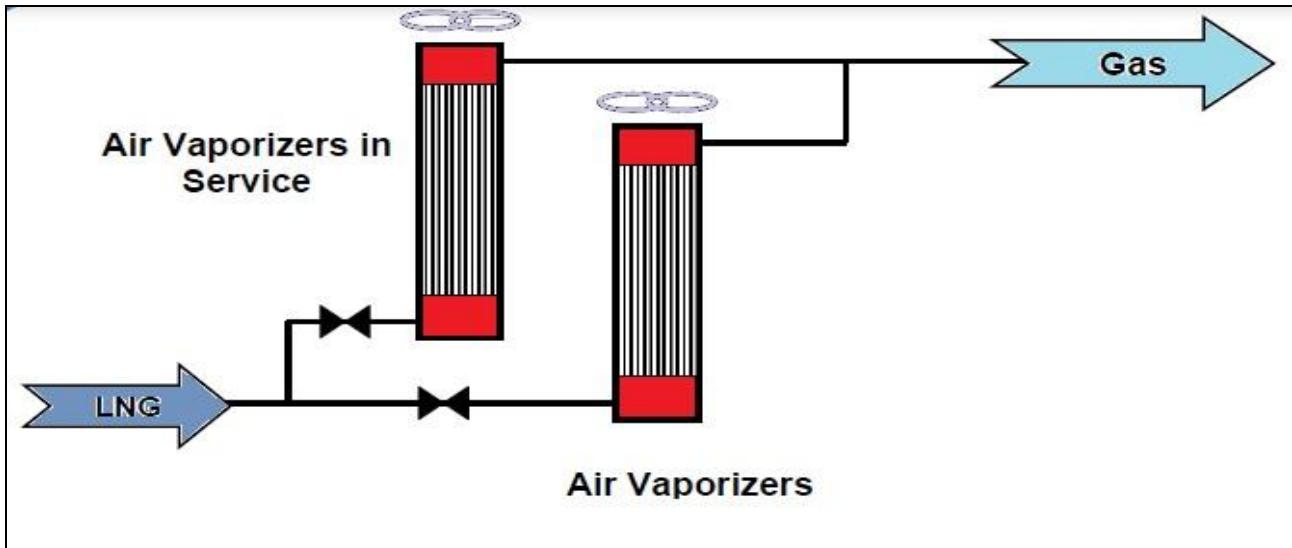


Figure 7: Ambient Air Vaporisers (AAV)

These direct and indirect heat transfer technologies illustrated in Figures 3 to 7 above are dissipative and as a result the LNG cold energy is wasted. However, there are many instances where this cold energy can be harnessed and utilised in a productive manner in existing industrial applications.

Purpose of the Study

To enhance energy efficiency of LNG re-gasification and improve utilisation of available cold energy from LNG. Consequently, to evaluate potential impact on economics of the gas supply and the gas based power generation.

Research methods

1. Establish current status i.e. Technologies, Cold utilisation and the economics.
2. Evaluation of the existing technologies without cold energy utilization. Efficiency and cost optimisation opportunities.
3. Evaluation of cold energy utilisation applications. (energy efficiency and exergy analysis, develop thermo-economics model for selected cases i.e. Integrated power generation, retrofitting cold energy to the existing terminals that are currently without etc) Analyse enhanced project economics due to Cold utilisation.
4. Develop a re-gasification technology selection process. A techno-economic model.

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Supervisors

1. Associate Professor Richard Brown, QUT, Australia.
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Appendix A: Japanese LNG Receiving Terminals 2013

Location	Company name		Capacity mtpa	Technology (Primary)	Technology Secondary(1)
Hokkaido	Hokkaido Gas	1	0.025		
Hokkaido	Hokkaido LNG	2	NA	SEV	
Hokkaido	Hokkaido Gas	2a	NA	SCV	
Hokkaido	Hokkaido Electric Power	3	NA	NA	
Hokkaido	JAPEX	4	0.06	NA	
Hokkaido	JX Nippon Oil & Energy	5	0.1 to 0.2	NA	
Aomori	JX Nippon Oil & Energy	6	0.06	NA	
Aomori	JX Nippon Oil & Energy	7	1	NA	
Akita	Tobu Gas	8	NA	NA	
Miyagi	Sendai city gas	9	0.15	ORV	SCV
Miyagi	Tohoku Electric Power	10	NA	NA	
Fukushima	JAPEX	11	NA	NA	
Niigata	Nihonkai LNG	12	5.44	ORV	SCV
Niigata	Chubu Electric	13	2	ORV	
Niigata	Tohoku Electric Power	14	NA	NA	
Niigata	Inpex	15	1.5	ORV	SCV
Toyama	Hokuriku Electric Power	16	NA	NA	
Ibaraki	Tokyo Gas & Tokyo electric power	17	NA	NA	
Kanagawa	Tokyo Electric Power	18	4.3	ORV (Double tube)	Shell and tube
Kanagawa	Tokyo Gas	19	6	ORV	SCV
Kanagawa	Tokyo Gas	20	3.3	ORV	SCV
Kanagawa	Tokyo Gas	20a	NA	ORV	
Chiba	Tokyo Gas & Tokyo electric power	21	10.7	ORV	SCV
Chiba	Tokyo Gas & Tokyo electric power	22	9	ORV	SCV
Shizuoka	Shimizu LNG	23	1.14	ORV	
Aichi	Toho gas and Chubu Electric	24	2.09	ORV	SCV
Aichi	Chita LNG	25	3.1	ORV	Shell and tube
Aichi	Toho gas	26	2.32	ORV	SCV
Aichi	Toho gas	26a	NA	ORV	SCV
Mie	Chubu Electric	27	3	ORV	Plate Fin
Mie	Toho gas	28	0.46	ORV	
Mie	Chubu Electric	29	4	ORV	Plate Fin
Mie	Chubu Electric	29a	NA	NA	
Osaka	Osaka gas	30	1.1	ORV	Shell and tube
Osaka	Osaka gas	30a	NA	ORV	Shell and tube

Osaka	Osaka gas	31	7.7	ORV	IFV
Osaka	Osaka gas	32	2.7	NA	
Osaka	Sakai LNG	32a	NA	NA	
Hyogo	Kansai Electric	33	2.6	ORV	
Hyogo	Osaka gas	34	2.6	IFV	ORV
Waka Ya ma	Kansai Electric	35	NA	NA	
Kagawa	Sakaide LNG	36	0.4	ORV	
Kagawa	Shikoku gas	37	0.43	AA	
Ehime	Shikoku gas	38	0.03 to 0.04	AA	
Hiroshima	Hiroshima gas	39	0.5	AA	IFV
Okayama	Mizushima LNG	40	1.2	IFV	ORV
Okayama	Okayama gas	41	0.057	NA	
Yamaguchi	Chugoku Electric power	42	1.3	ORV	
Fukuoka	Kitakyushu LNG	43	1.3	ORV	
Fukuoka	Seibu gas	44	0.23	ORV	
Fukuoka	Hibiki LNG	45	1	ORV	
Nagasaki	Seibu gas	46	0.11	AA	
Oita	Oita LNG	47	1.53	ORV	SCV
Kagoshima	Nihon gas	48	0.08	AA	
Okinawa	Okinawa electric power	49	0.7	ORV	
	Total		87		