Estimation of WtT Emissions of Zero- or Low-Carbon Fuels

Fuel Pathway Case Studies for Further Consideration of the Draft LCA Guidelines

---

JTTRI
Japan Transport and Tourism Research Institute

Thursday, 24th February 2022

Supported by 日本財団 THE NIPPON FOUNDATION

Contents

1. Background

2. Objectives

3. LCA Methodology

4. LCA of the target fuels
   - 4.1 LH_2 converted from brown coal
   - 4.2 LH_2 from electrolysis
   - 4.3 LNH_3 from electrolysis
   - 4.4 Synthetic methane
   - 4.5 Comparison of WtT emissions
   - 4.6 Comparison of WtW emissions

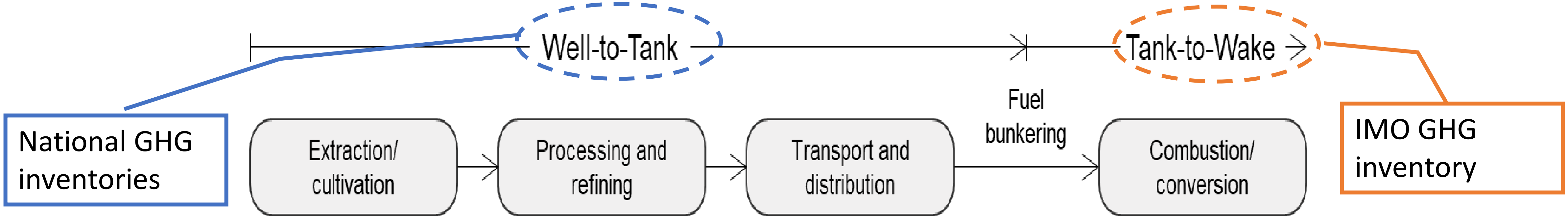
5. Variation of LNG WtT emissions

6. Conclusion

Supplemental information

Contents

1. Background 1.1 Why WtT Emissions matter



Well-to-Tank

Tank-to-Wake

National GHG inventories

Extraction/ cultivation

Processing and refining

Transport and distribution

Fuel bunkering

Combustion/ conversion

IMO GHG inventory

We do NOT want

WtT emissions increase in return for the achievement of zero TtW emissions.

We want this world to be….

- Fuel producers/suppliers make efforts to reduce WtT emissions of their fuel products the improvements of the production pathway, the use of renewable energy, and the use of CCS/CCU
- Such efforts, as well as their outcome (i.e., estimated WtT emissions) are made visible to the fuel users and other stakeholders.
- Fuel users (shipping industries) can select the fuels with smaller WtT emissions so that they can minimize WtW emissions.

LCA Guidelines are the first step to achieve the above goal!

1. Background 1.2 Key Issues in the draft LCA Guidelines

The draft LCA Guidelines under development: Annex 1 of MEPC77/WP.6, proposed revision in ISWG-GHG 11/2/3

1. FLL (Fuel Lifecycle Label) categorizes the fuel per feedstock, production pathway and other aspects.
2. It is proposed that the default WtT emission values are provided for relevant priority fuels.
3. It is considered that default emission values in the draft Guidelines should reflect, for each fuel, the higher end of the possible emission range to cater for uncertainty thus encouraging the use of verified actual values. Performers (e.g., fuel producers/suppliers) who believe to do better than default values should be given the opportunity to demonstrate their real performance through the application of a certification scheme.

Example of FLL and default emission values (Table 1 from ISWG-GHG 11/2/3)

Part I: Carbon content	**Part II: Feedstock Nature**	**Part III: Production Pathway**	**Part IV: Fuel type**	**Region of the world(*)**	**GHG_{CO2eq} [gCO_{2eq}/MJ]**
Carbon	Fossil	Default	LFO	Global	13.2
Carbon	Fossil	Default	HFO	Global	[9.6]/[14.1]
Carbon	Fossil	Default	LNG/methane	Global	18.5
Carbon	Captured carbon	Captured carbon/ Electrolysis/ electricity mix	Diesel		-47.6
Carbon	Captured carbon	Captured carbon	LNG/methane		97
Zero-carbon	Fossil	Natural gas	Hydrogen		132
Zero-carbon	Fossil	Natural gas	Ammonia		121
Zero-carbon	Fossil/renewable	Electrolysis/ electricity mix	Hydrogen		3.6
Zero-carbon	Fossil/renewable	Electrolysis/ electricity mix	Ammonia		0

(*) The geographical scope can be applicable to each fuel.

1. Background 1.3 Relevant Questions regarding the draft Guidelines

The draft LCA Guidelines contain an initial set of priority fuels and their default values.

- ✓ Shouldn't we **need to add other fuels with high sustainability and production potential**, as well as **specialization of some pathways depending on geographic regions**?

The draft LCA Guidelines Para. 6.4:

"The following sustainability criteria apply to a marine fuel: .1 [the WtW GHG emissions should be [at least XX%] lower than for fossil low sulphur fuel oil (LSFO)]

- ✓ If such criteria is to be introduced, quantitative, fair and verifiable evaluation method for WtT emissions would be indispensable. **Can we develop such robust scheme?**
- ✓ Further, **how to set XX%?** Looks a bit onerous!

Length	116m	Speed	13knot
Width	19m	Cargo	1,250m3
Crew	25person	Propulsion	Diesel Electric

There may be a bunch of questions.
We could start by carrying out the trial calculation of WtT emissions for specific fuels and their production pathways.
Then we may see a better picture.

Contents

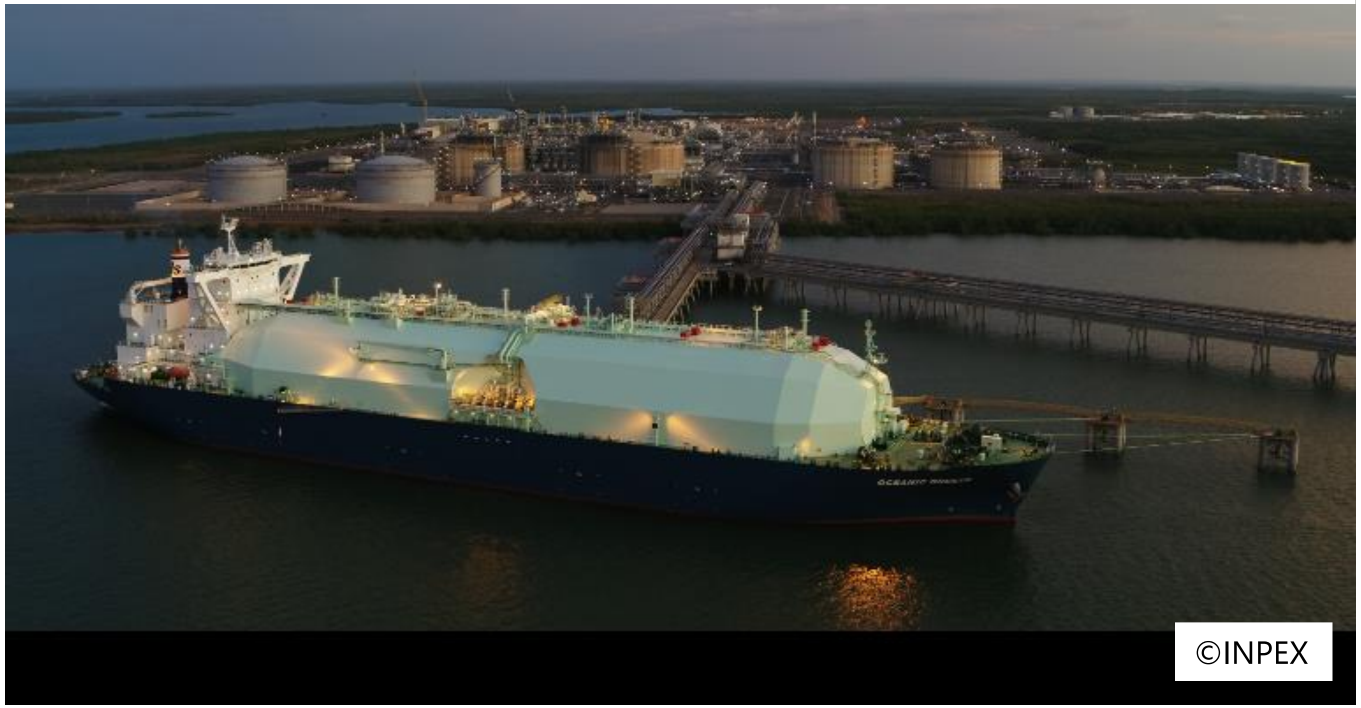
2. Objectives

Japan and JTTRI consider:

- WtT GHG emissions would significantly vary depending on production states, regions, and projects, with various parameters such as CO_2 Intensity of Power Produced, production process, and transportation (e.g., geographical distance between production/consumption locations). This is applicable not only to Zero- or Low-Carbon Fuels, but also to fossil fuels such as LNG.

- It is important to develop a calculation method that can reflect the above parameters as well as the future development of the key technologies to reduce WtT emissions.

- Such methods should be utilized in setting default values possibly with regional subcategories, as well as verified actual values of the emissions.



©INPEX

2. Objectives

Based on the observations above, JTTRI conducted the literature review and the **trial calculation of WtT emissions of several zero/low carbon fuels**, for the purpose of contributing to further development of the draft LCA Guidelines.

Through this exercise, JTTRI intended to get the insights on:

- Whether all zero/low-carbon fuels with high production potential have already been considered;
- How regional and geographical parameters could make difference in the WtT emissions;
- Whether the proposed default values are based on conservative assumptions; and
- How the application of CCS and other technological developments could reduce the WtT emissions.

Contents

3. LCA Methodology-3.1 Scope of LCA

Based on the production pathway of the target fuel, the annual GHG emissions (g-CO_2eq/year) are calculated for each three scopes shown below. The total emissions are then divided by Low Calorific Value (MJ/year) of the fuel on distribution basis (MJ/year), to make comparisons between regions, between projects and between fuels.

1. Emissions as material streams, e.g., from reforming and refining ISO 14040-Scope1
2. Indirect emissions from electricity consumption and heat supply ISO 14040-Scope2
3. Indirect emissions from fuel uses for Product Storage, Transportation, and Distribution ISO 14040-Scope2*

* JTTRI assumed that the same corporate group for fuel production will operate the whole supply chain, thus the process would be classified as Scope 2.

Assumptions	Fuel production	CCS (optional)	Storage and Loading at Export Terminal	International transportation	Storage and Loading at Import Terminal and Distribution	Use
For each fuel, JTTRI selected a project in progress or under consideration, that can be operational by 2030. The production scale for each fuel is based on the available researches on the project. Assumed Production area: Australia Assumed Distribution ports : Japan	1. Exploitation, transportation and production of raw materials 2. Gasification, Conversion incl. WGS (water-gas-shift), Synthesis and Gas refining 3. Liquefaction or conversion to NH_3	1. CO_2 capture, treatment and compression to put into pipeline 2. Transportation (if needed) 3. Geological Sequestration	1. Storage (Re-liquefaction of BOG during storage) 2. Loading fuel as cargo for shipping	Boil-off gas (BOG) will be primarily used as fuel. Fossil Fuel will be used only when sufficient amount of BOG is not expected.	1. Offloading and storage of the fuel (Re-liquefaction of BOG during storage) 2. Loading the fuel as cargo for distribution 3. Short transportation and bunkering	TtW emissions are not estimated in the study. When needed for reference purpose, the Default Values of TtW, as contained in the draft Guidelines, are used.
	Sum up	Deduct the amount of CO_2 captured and sequestered.	Sum up	Sum up	Sum up	

WtT GHG emissions per unit calorific value of the target fuel

3. LCA Methodology-3.2 Fuels subject to LCA evaluation

Fuel and pathway	Slides	Outline of the production process	Product transported
Hydrogen converted from brown coal	Slide 14-23 (4.1)	The schematic chemical reaction for Hydrogen conversion from Carbon: **$2C + O_2 \rightarrow 2CO$** (Gasification Process) **$CO + H_2O \rightarrow H_2 + CO_2$** (water-gas-shift(WGS) Process) The exact equivalent of Freshwater for WGS is produced from seawater by Desalination Process, and mol equivalent CO_2 will be by-produced. The CO_2 is captured and stored under the seabed.	as Liquified Hydrogen (LH_2) BOG will be used as fuel.
Hydrogen produced from water and electricity	Slide 24-27 (4.2)	The schematic chemical reaction for Electrolysis of Freshwater (using alkaline and PEM process) **$2H_2O$ + electrical energy $\rightarrow 2H_2 + O_2$** Freshwater is generated from seawater as same as 4.1.	as Liquified Hydrogen (LH_2) BOG will be used as fuel.
Ammonia produced from water and electricity	Slide 28-30 (4.3)	The schematic chemical reaction for Ammonia production: (Using Haber-Bosch Process) **$N_2 + 3H_2 \rightarrow 2NH_3$** Hydrogen is produced as same as 4.2, and Nitrogen is separated from the atmospheric air.	as Liquified Ammonia (LNH_3) BOG will be used as fuel.
Methane synthesized with Hydrogen and CO_2 captured	Slide 31-33 (4.4)	The schematic chemical reaction for synthesis of Methane: **$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$** CO_2 is collected from exhaust gas emitted from the Industrial sources, reacted with Hydrogen produced as 4.2 to generate Methane.	as Liquified methane (Synthesized methane) BOG will be used as fuel

3. LCA Methodology-3.3 Notes on the calculation

Several Issues to be noted for WtT emissions calculation;

1. CO_2 Intensity of Electricity Power

In each process, electricity power consumed (kWh) was identified with its origins (wind power, On-site power generation, from the Power Grid in Australia or Japan).
For each process, respective CO_2 Intensity was applied, taking into account the improvement of the Intensity by 2030.

2. The Target year for the project

We presumed that all the projects will start their full operation by 2030. The best efficiency expected by 2030 was applied.

	Current	By 2030
The efficiency or rate of		
Hydrogen fueled GTCC	Not available	40% (HCV basis)[*1]
Hydrogen Liquefaction	13.6 kWh/kg	6.17 kWh/kg
Alkaline Electrolysis	4.5 kWh/Nm^3	4.3 kWh/Nm^3
PEM electrolysis	4.9 kWh/Nm^3	4.5 kWh/Nm^3
CO_2 Intensity of Power Grid		
Victoria, AU	0.98 kg-CO_2eq/kWh	0.51 kg-CO_2eq/kWh
Western AU WEM	0.68 kg-CO_2eq/kWh	0.45 kg-CO_2eq/kWh
Japan	0.441 kg-CO_2eq/kWh	0.370 kg-CO_2eq/kWh

*1 The target efficiency of Hydrogen fueled GTCC of an actual project in Japan is set at approx. 40% (HCV basis) with capturing 90% of CO_2.

3. Boundary for evaluation in this research

Construction and decommissioning of the relevant plants for the project is out of the boundary for this LCA.

4. Biofuels

LCA evaluation was not conducted for Biofuels.

Contents

4.LCA of the target fuels-4.1 LH_2 converted from brown coal- Pilot project

Status of the Pilot Demonstration Project: Hydrogen Production

Hydrogen Production (Australia)

J-Power and J-Power Latrobe Valley achieved High purity, 99.999%, hydrogen made from Victorian Coal.
Ceremony was held at Latrobe Valley on 12th, March, 2021 for this monumental world’s first success.

Courtesy：HySTRA,J-Power and J-Power Latrobe Valley

© J-Power Latrobe Valley

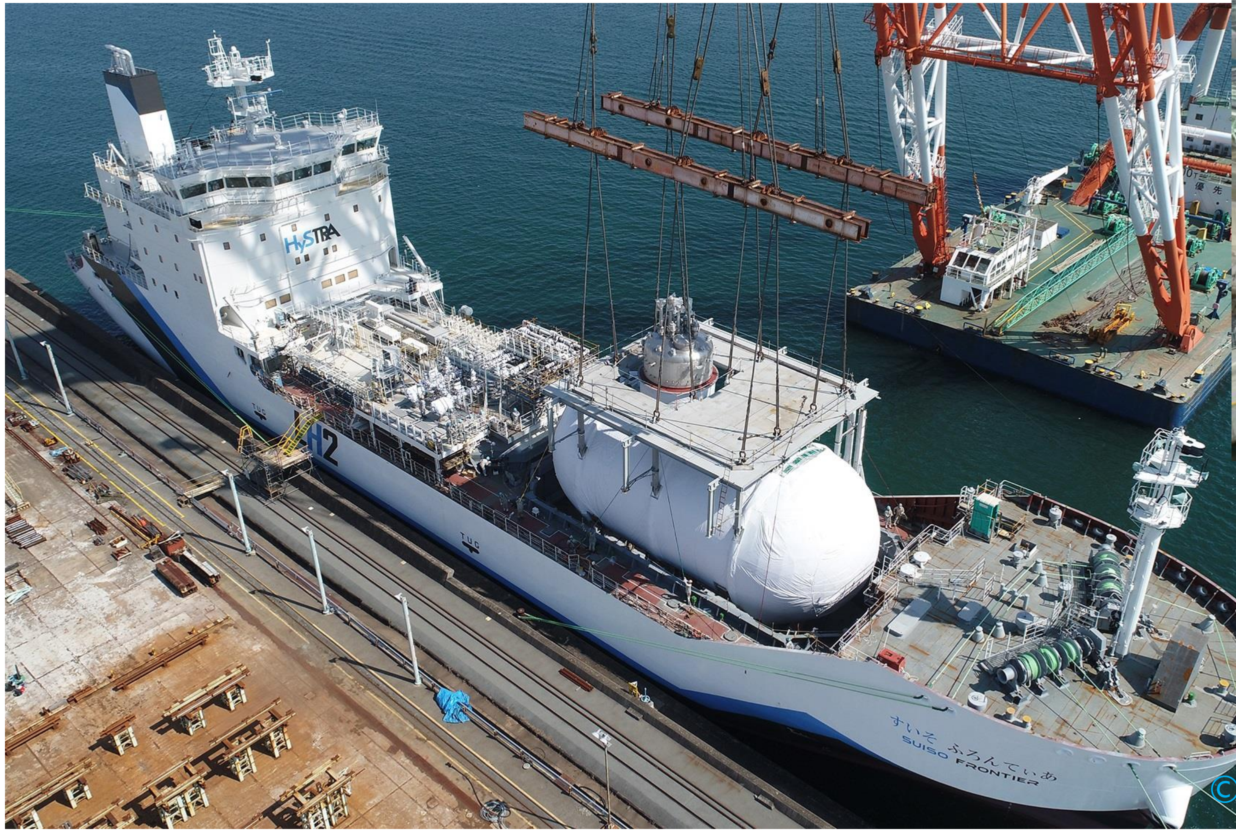
4.LCA of the target fuels-4.1 LH_2 converted from brown coal- Pilot project

Specification

Length	116m	Speed	13knot
Width	19m	Cargo	1,250m3
Crew	25person	Propulsion	Diesel Electric

© HySTRA

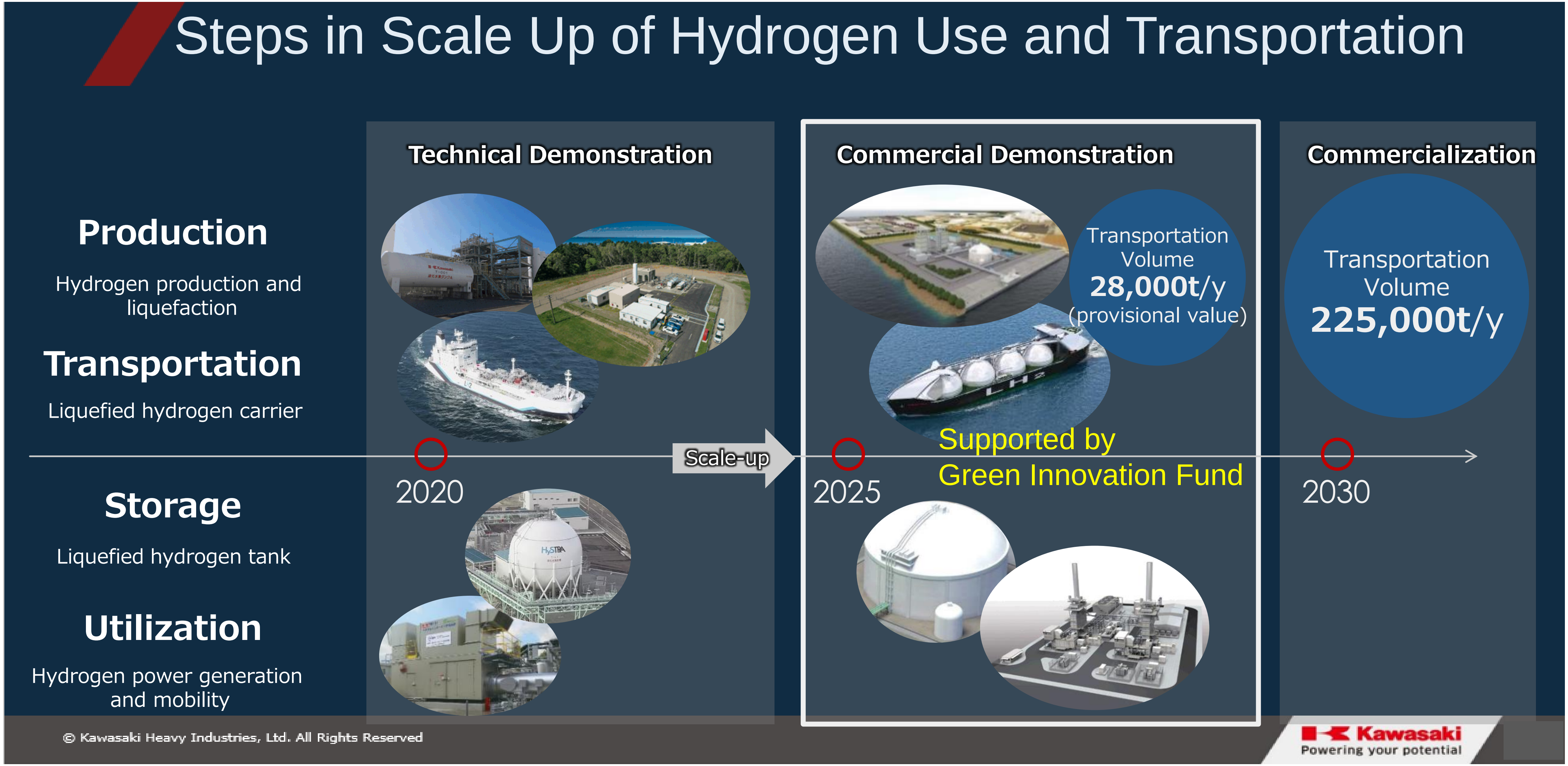
LH_2 Carrier, Loading and Storage Facilities



©HySTRA

LH_2 tank being installed on LH_2 carrier

4.LCA of the target fuels-4.1 LH_2 converted from brown coal- Pilot project



Steps in Scale Up of Hydrogen Use and Transportation

Technical Demonstration

Commercial Demonstration

Commercialization

Production

Hydrogen production and liquefaction

Transportation

Liquefied hydrogen carrier

Storage

Liquefied hydrogen tank

Utilization

Hydrogen power generation and mobility

Transportation Volume **28,000t/y** (provisional value)

Transportation Volume **225,000t/y**

Supported by Green Innovation Fund

Scale-up

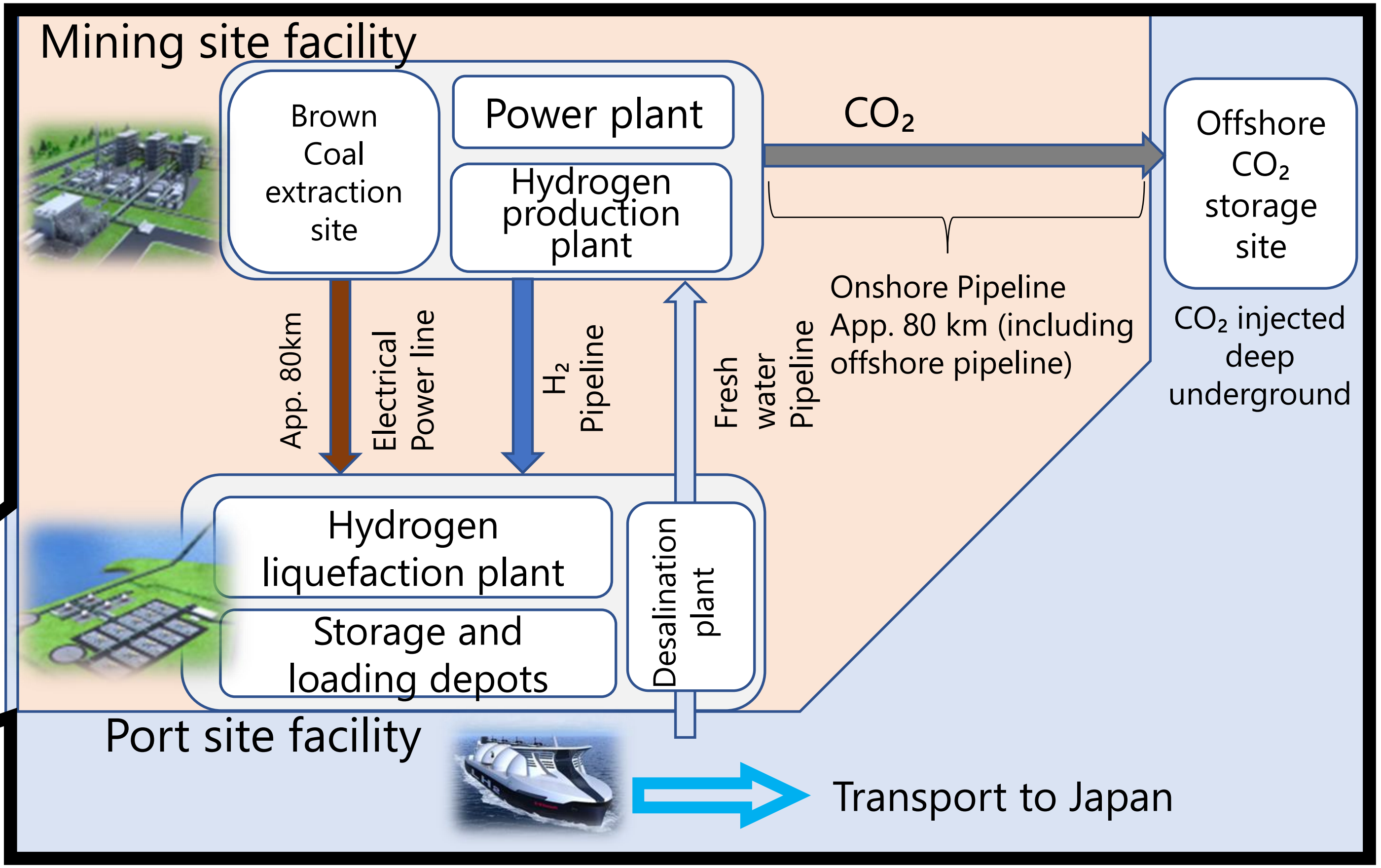
2020

2025

2030

Kawasaki Powering your potential

4.LCA of the target fuels-4.1 LH_2 converted from brown coal-Supply chain diagram



Mining site facility

Brown Coal extraction site

Power plant

Hydrogen production plant

CO_2

Offshore CO_2 storage site

CO_2 injected deep underground

Onshore Pipeline App. 80 km (including offshore pipeline)

App. 80km

Electrical Power line

H_2 Pipeline

Fresh water Pipeline

Hydrogen liquefaction plant

Storage and loading depots

Desalination plant

Port site facility

Transport to Japan

1. It is presumed that there will be 2 facility sites in Australia, i.e., the mining site facility for Hydrogen production and the port site facility for liquefaction and loading. The mining and port sites are connected by hydrogen gas pipelines, fresh water pipelines and dedicated power lines.
2. CO_2 pipelines between mining site and offshore CO_2 storage site and geological sequestration is to be provided and operated by CarbonNet*.

---

*The CarbonNet project aims to establish a commercial-scale carbon capture and storage (CCS) network in Victoria, Australia. The network will deliver carbon dioxide (CO_2) captured from a range of industries based in Victoria's Latrobe Valley, via an underground pipeline, to offshore storage sites in Bass Strait. Project is to be operational by 2030.

4.LCA of the target fuels-4.1 LH_2 converted from brown coal- Assumptions and CO2 intensity of Power grid

Assumptions

	Case1	Case2	Case3（For Reference）
LH_2 Production scale	238,500 ton/year（Before international shipment） Production volume is presumed considering actual projects (refer to page 16).		
Electricity Source for LH_2 production process	On-site power generation using brown coal, combined cycle: Efficiency of 40% (HCV basis)		Electricity from the grid
CCS capture rate	90%	95%	N/A

	Case1	Case2	Case3
CO_2 intensity of on-site power generation [kg-CO_2eq/kWh]	0.134	0.068	N/A

Calculation of CO_2 Intensity of Power Grid (Australia)

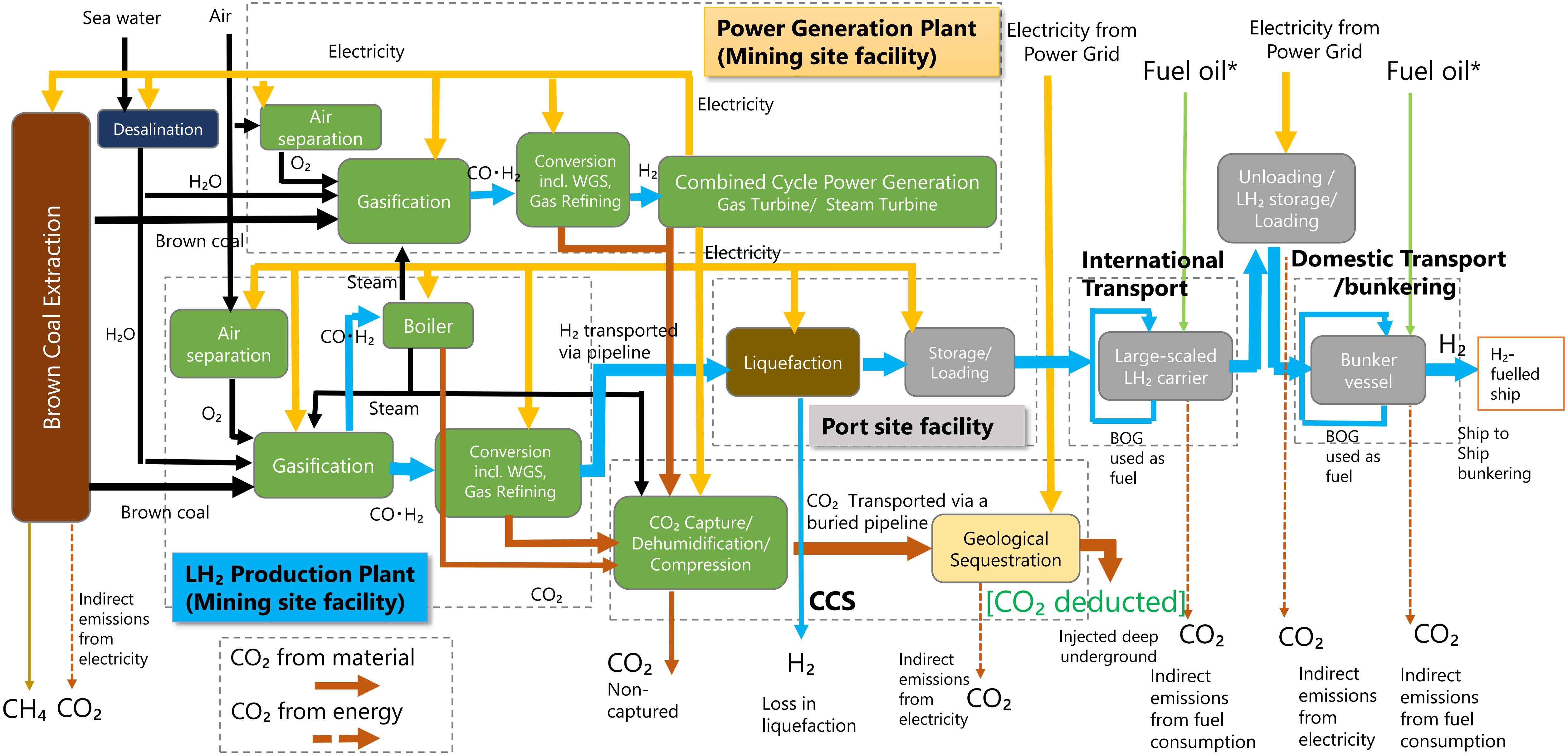
	Share of Renewable energy in the total power generation[*1]			CO_2 Intensity of Power Grid [kg-CO_2eq/kWh]		
	2019 (b)	2025 (c)	2030 (d)	2019 (a)	2025 $\frac{a \times (1-c)}{1-b}$	2030 $\frac{a \times (1-d)}{1-b}$
Victoria Australia	22%	50%	61%	1.02	0.65	0.51
WAWEM [*2] Australia	15%	37%	45%	0.69	0.51	0.45

CO_2 Intensity of Power Grid (Japan)

	CO_2 Intensity of Power Grid [kg-CO_2eq/kWh]		
	2020	2025	2030
Japan	0.44	0.41	0.37 [*3]

*1 Source: Australia's emissions projections 2021
*2 WAWEM: West Australia Wholesale Electricity Market
*3 Data from Agency for Natural Resources and Energy

4.LCA of the target fuels-4.1 LH_2 converted from brown coal - (Case 1 & 2)Process Diagram Expected in 2030



Power Generation Plant (Mining site facility)

Sea water

Air

Electricity

Brown Coal Extraction

Desalination

Air separation

O_2

H_2O

Brown coal

Gasification

$CO \cdot H_2$

Conversion incl. WGS, Gas Refining

H_2

Combined Cycle Power Generation Gas Turbine/ Steam Turbine

Electricity

Electricity

Steam

Boiler

H_2O

Air separation

$CO \cdot H_2$

O_2

Steam

Gasification

Conversion incl. WGS, Gas Refining

Brown coal

$CO \cdot H_2$

H_2 transported via pipeline

LH_2 Production Plant (Mining site facility)

CO_2

CO_2 Capture/ Dehumidification/ Compression

Liquefaction

Storage/ Loading

Port site facility

CO_2 Transported via a buried pipeline

Geological Sequestration

CCS

[CO_2 deducted]

Electricity from Power Grid

Fuel oil*

International Transport

Large-scaled LH_2 carrier

BOG used as fuel

Electricity from Power Grid

Fuel oil*

Unloading / LH_2 storage/ Loading

Domestic Transport /bunkering

Bunker vessel

BOG used as fuel

H_2

H_2-fuelled ship

Ship to Ship bunkering

CH_4 CO_2

Indirect emissions from electricity

CO_2 from material

CO_2 from energy

CO_2 Non-captured

H_2 Loss in liquefaction

Indirect emissions from electricity CO_2

Injected deep underground

CO_2 Indirect emissions from fuel consumption

CO_2 Indirect emissions from electricity

CO_2 Indirect emissions from fuel consumption

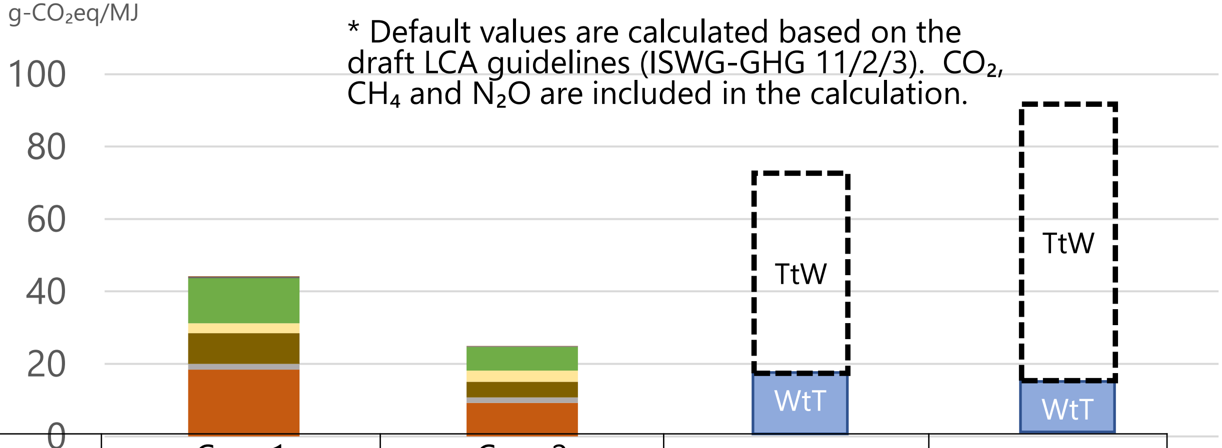
* Amount of Hydrogen BOG is not sufficient for international voyage, therefore additional fuel oil is needed.

4.LCA of the target fuels-4.1 LH_2 converted from brown coal

-Comparison among the results of LH_2 from brown coal and the default values of the Fossil Fuels

The results of WtT of LH_2 from Brown Coal are compared with the default WtW of the LSFO and LNG/natural gas as contained in the draft Guidelines. Since the TtW emission of Hydrogen is zero, it is clear that the WtW emissions of LH_2 are significantly lower than those of fossil fuel.

As the project will start its full-scale operation by 2030, the project intends to use the best available technologies by 2030. Appling the future technologies, the WtT emission will be significantly reduced to 44.2 g-CO_2eq/MJ from 294 g-CO_2eq/MJ of Case 3 (reference) where Electricity from the local Power Grid was used and no CCS was applied.



* Default values are calculated based on the draft LCA guidelines (ISWG-GHG 11/2/3). CO_2, CH_4 and N_2O are included in the calculation.

		Case 1 2030 On-site power generation CCS90％	Case 2 2030 On-site power generation CCS95％	LNG (Default*)	LSFO (Default*)
🟫	1. Brown coal extraction	0.2	0.1		
🟦	2.Desalination of seawater, 3.Water transfer	0.3	0.2		
🟩	4. Brown coal pre-treatment, 5. Air separation, 6. Gasification, 7. Conversion incl. WGS, Gas refining, 8. CO_2 capture, 9. CO_2 transportation and compression, 10. Others	12.5	6.5		
🟨	11. CO_2 injection	2.8	3.1		
🟫	12.Liquefaction	8.5	4.3		
⬛	13. Storage and loading, 14. International transport, 15. Unloading and storage, 16. Domestic transport, 17. Bunkering	1.6	1.5		
🟧	Emissions from material flows	18.4	9.2		
🟦	WtT Total	44.2	25.0	18.5	13.2
	TtW Total	0.0	0.0	57.9	76.8

Case 3 (reference) 100% Power Grid electricity, no CCS: WtT emissions is 294.1 g-CO_2eq/MJ

4.LCA of the target fuels-4.1 LH_2 converted from brown coal
-GHG emissions of LH_2 converted from brown coal by process (Case 1)

($g\text{-}CO_2eq/MJ$)

【 **Energy flows** 】	Emissions from On-site power plant (supplying the electricity to Processes 2-13 of the hydrogen production plant and the electricity to be consumed by Processes 2-10 of the power plant itself)		Energy emissions that cannot be supplied by on-site power generation*	Total	*Note
	Methane leakage	Brown coal-derived CO_2 (not captured in Process 8)			
1. Brown coal extraction	0.05	0.14		0.20	
2. Desalination of seawater		0.28		0.28	
3. Water transfer		0.04		0.04	
4. Brown coal pre-treatment		1.32		1.32	
5. Air separation		2.87		2.87	
6. Gasification		0.11		0.11	
7. Conversion incl. WGS, Gas refining		2.30		2.30	
8. CO_2 capture (mining site)		0.85		0.85	
9. CO_2 transportation and compression (mining site)		2.70		2.70	
10. Others		0.27	2.04	2.31	Fuel for On-site boilers (gas refined from brown coal)
11. CO_2 Injection			2.78	2.78	Grid electricity (Australia)
12.Liquefaction		8.47		8.47	
13. Storage and loading		0.23		0.23	
14. International transport			0.78	0.78	Fuel Oil for H_2 BOG shortage backup
15. Unloading and storage			0.54	0.54	Emissions from grid electricity (Japan)
16. Domestic transport, 17. Bunkering			0.07	0.07	Fuel Oil for H_2 BOG shortage backup
Total	0.05	19.6	6.21	**25.8**	

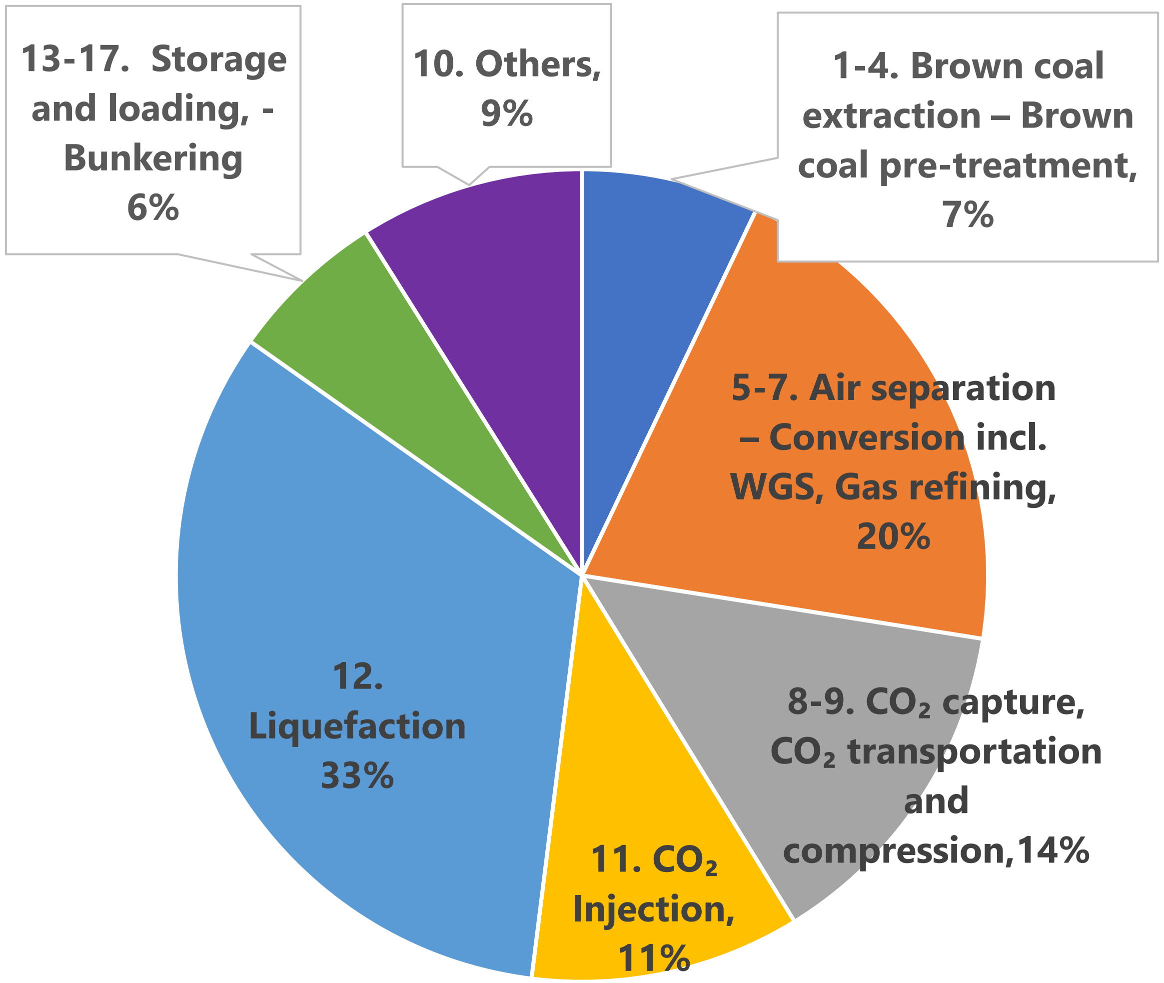
【Material Flow】 Emissions from brown coal in hydrogen production plant	Emissions from hydrogen production plant			Total	
	Methane leakage	Brown coal-derived CO_2 (Items not recoverable in 8)			
	0.06	18.3		**18.4**	

Total	0.11	37.9	6.21	**44.2**	

4.LCA of the target fuels-4.1 LH_2 converted from brown coal - Shares of WtT emissions from energy uses by Process

The emissions from energy uses are summarized by process. As on-site generated Electricity was used for all the processes in Australia, except ‘11 CO_2 injections’, the share of the emissions is largely determined by the electricity power requirement of each process.

1. Even applying the efficient liquefication technology under development, the H_2 liquefaction consumes the largest Electricity among all processes.
2. Process of capturing, transport by pipeline, and injection of CO_2 will emit around a quarter of total emission from energy uses.
3. Further reduction of those emissions mentioned above would necessitate Electricity from renewable energy.
4. Shown in the previous slide, the total emissions from Electricity consumption at the mining and port site (19.6 g-CO_2eq/MJ) are almost the same as those of the material flow to produce Hydrogen (18.3 g-CO_2eq/MJ).



Case 1: 2030, On-site power generation, 90% CCS
Percentage of GHG emissions from energy flows

4.LCA of the target fuels-4.1 LH_2 converted from brown coal- Comparison with existing studies

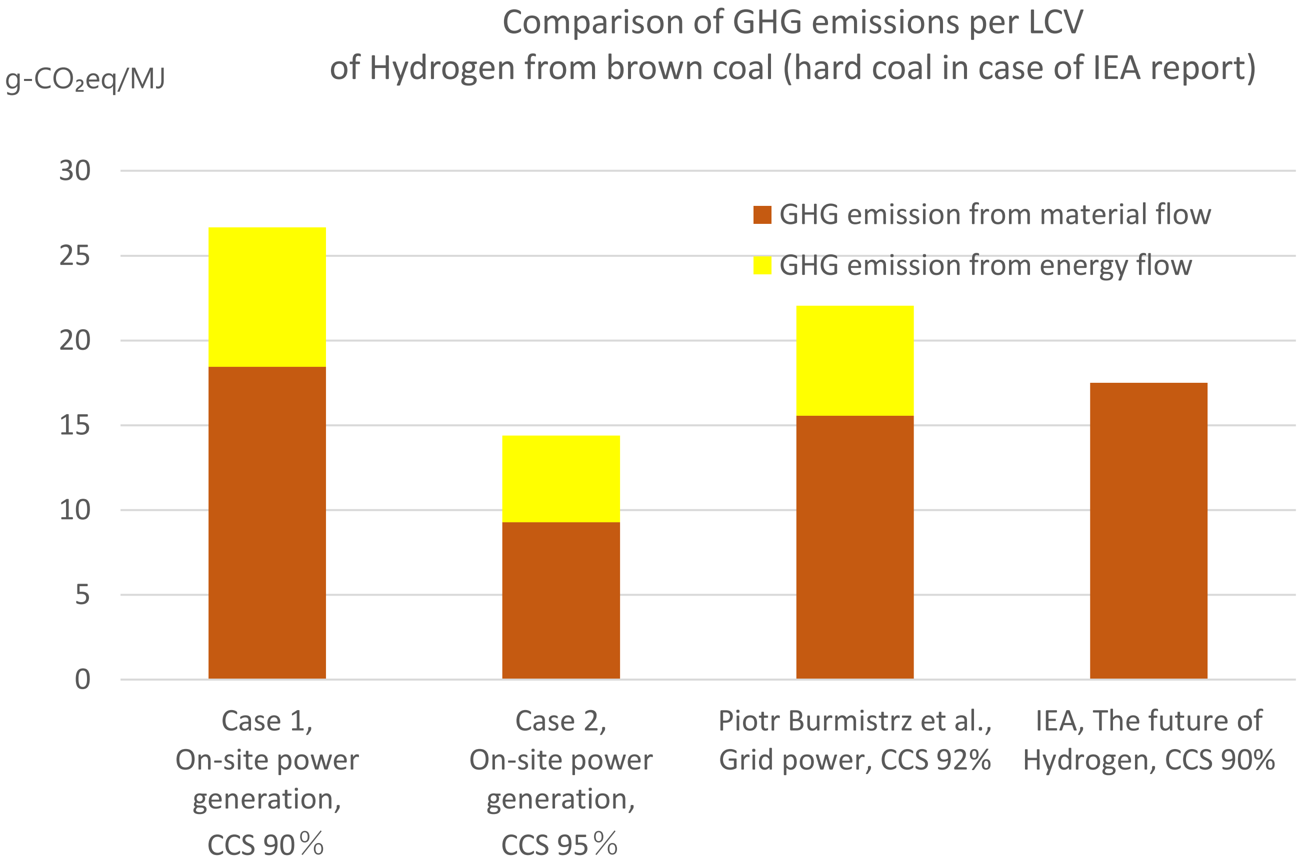
As Default WtT value of the Hydrogen from brown coal is not provided in the draft LCA Guideline, JTTRI compared the results with the emission values provided in other studies.

The boundaries for WtT, CO_2 Intensity of the Power Grid, and the rate of Carbon Capture rate differ in each study from the conditions set for our calculation. Therefore, JTTRI applied the unified values for those parameters for comparison purpose.

The WtT emission of Hydrogen produced of Hard Coal estimated in "The IEA G20 Hydrogen report: Assumptions*[1] ", with applying 90% capture of CO_2, led to 17.5 g-CO_2eq/MJ. Note that the IEA report excludes the emissions from electricity consumption because they may vary among geographical locations (which means that only material flow is considered).

*Burmistrz et al.**[2] estimated the WtT emission from Brown Coal in Poland, both from material flow and Electricity consumption. While 92% CO_2 capture was assumed in this study, the authors applied the Polish CO_2 Intensity of the Power Grid. For comparison, JTTRI applied the same Intensity, as it assumed for Australia in 2030. Re-calculation with such adjustment led to 22.1 g-CO_2eq/MJ.

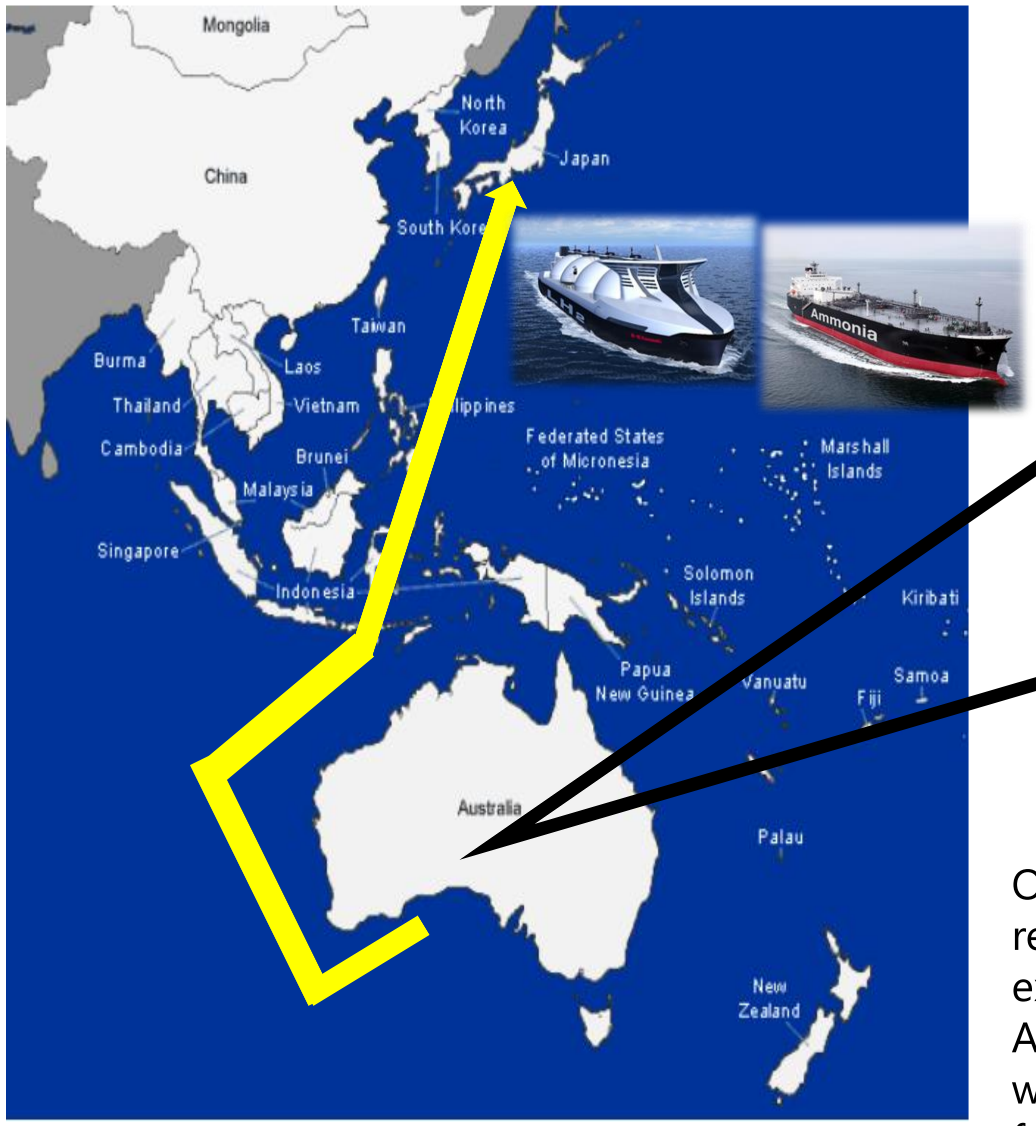
The WtT emissions from the material flow are similar among all the three results, and WtT emissions from the Electricity consumption are similar between JTTRI's and Polish studies. JTTRI considers that our calculated WtT emission would be in an appropriate range for the default value.

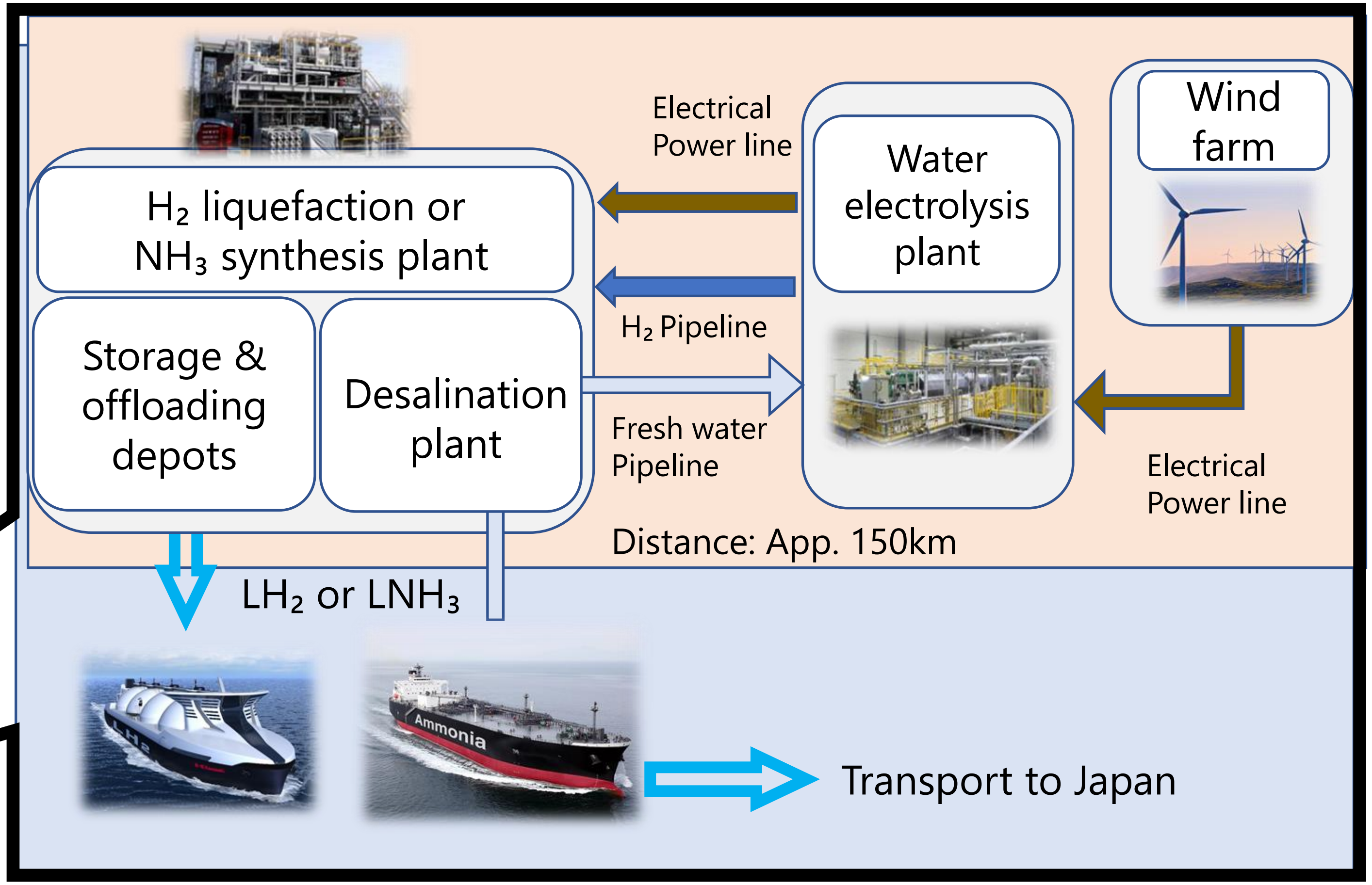


[1] IEA G20 Hydrogen report; Assumptions, https://www.iea.org/reports/the-future-of-hydrogen/data-and-assumptions

[2] Piotr Burmistrz et al. "Carbon footprint of the hydrogen production process utilizing subbituminous coal and lignite gasification", Journal of Cleaner Production 139 (2016) 858-865

4.LCA of the target fuels-4.2/4.3 LH_2/LNH_3 from electrolysis- Supply chain diagram





Electrical Power line

H_2 liquefaction or NH_3 synthesis plant

Water electrolysis plant

Wind farm

H_2 Pipeline

Storage & offloading depots

Desalination plant

Fresh water Pipeline

Electrical Power line

Distance: App. 150km

LH_2 or LNH_3

Transport to Japan

Our calculations on LH_2 or LNH_3 from electrolysis are not based on realized projects or concrete project plans; plant concept is based on the existing feasibility studies. JTTRI assumed that there would be two sites in Australia, i.e., a port site for H_2 liquefaction or NH_3 synthesis and a site for water electrolysis and wind farm. They are connected by H_2 gas pipelines, freshwater pipelines and dedicated power lines.

4.LCA of the target fuels-4.2 LH_2 from electrolysis- Assumptions and Results

Assumptions

	Case1	Case2	Case3
H_2 Production[t]	158,800 [*1]		
Power source (AU)	Wind power100%		Wind 62%+Grid 38%
Electricity buffering	No	Yes	NA
Electrolysis technology	PEM	Alkaline	Alkaline
Electrolysis efficiency	5.18kWh/Nm^3 [*2]	4.3kWh/Nm^3	4.3 kWh/Nm^3
CO_2 Intensity of Power Grid (kg-CO_2eq/kWh) [*3]	Japan：0.37	Japan：0.37	Australia：0.45 Japan：0.37

Results

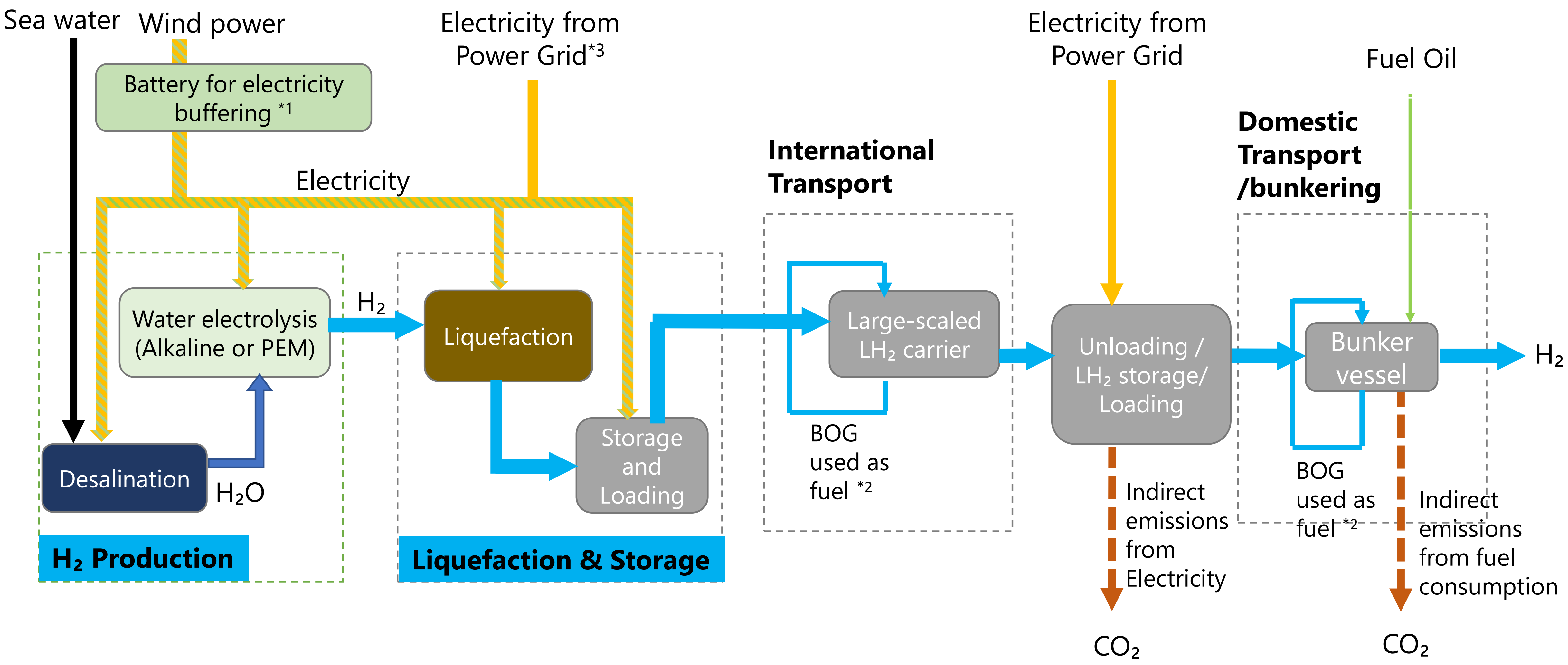
	Case1	Case2	Case3
Fuel for International Transportation	100% H_2（BOG）		
Total electricity consumption [billion kWh/year]	11.6	9.9	9.9
CO_2Total emissions [g-CO_2eq/MJ-NH_3]	0.62		95.4
Required number of wind turbines with 15MW (rated)	253	216	134

[*1] Production volume is presumed, taking into account actual project under consideration. Reference: “Renewable Hydrogen and Ammonia Feasibility Study by GHD for BP Australia” https://arena.gov.au/assets/2021/08/bp-ghd-renewable-hydrogen-and-ammonia-feasibility-study.pdf

[*2] Case1 assumes that the electrolysis efficiency of PEM batteries deteriorates by about 15% from the expected PEM efficiency in 2030 due to lack of electricity buffering.

[*3] Refer to slide 18

4.LCA of the target fuels-4.2 LH_2 from electrolysis - Process Diagram (Cases 1,2,3)



*1 Only in Case 2

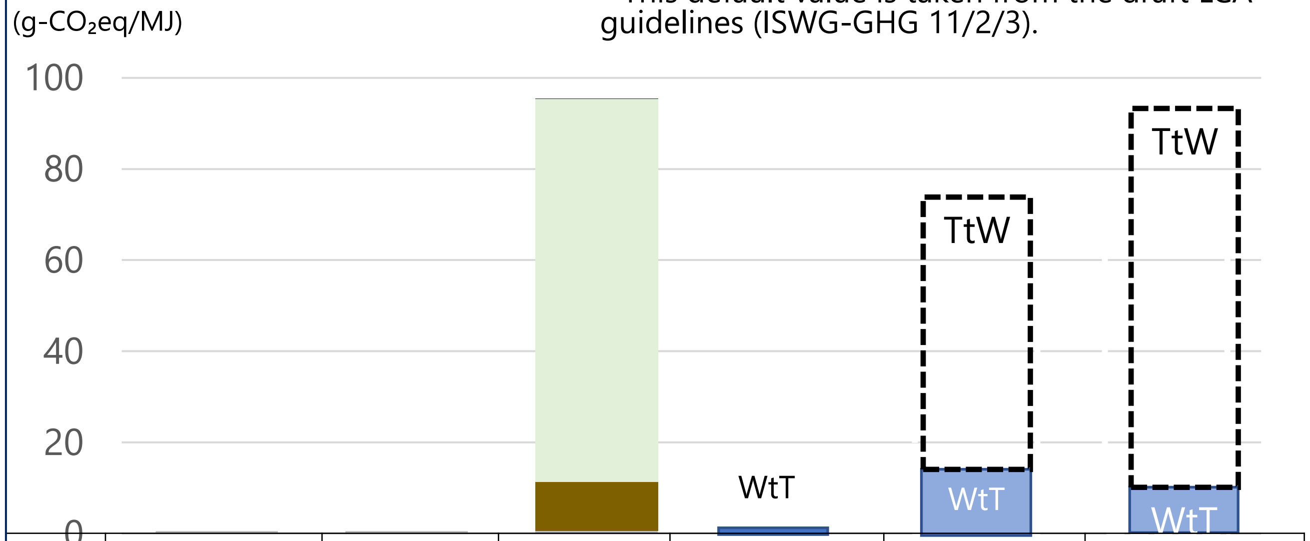
*2 Sufficient Hydrogen BOG is expected for international voyage, therefore no additional fuel oil is needed.

*3 Only in Case 3

4.LCA of the target fuels-4.2 LH_2 from electrolysis
-Comparison among the results of LH_2 from electrolysis and the default values of the Fossil Fuels

If all the processes used Electricity by 100% renewable energy, the WtT emission would be 0.6 g-CO_2eq/MJ (Cases1-2), smaller than the default value (3.6 g-CO_2eq/MJ). If a small portion of the electricity is supported by the Power Grid to secure the stability of plant operation, the emission would be significantly higher (Case3). JTTRI considers that the default values should be separately established for the use of 100% renewable energy and for the use of Electricity mix.

Case1 assumed the use of Additional renewable Electricity without any buffers (i.e., batteries or capacitors). In order to secure the minimum Power for steady operation, additional wind farms would have to be connected. Furthermore, when the Power supply exceeds the capacity of water electrolysis, such excess Power would be wasted. Such project design and operation to keep the Additionality would increase both CAPEX/OPEX. These commercial implications, which would affect the investment decisions, are not covered in this study.



* This default value is taken from the draft LCA guidelines (ISWG-GHG 11/2/3).

		Case1	Case2	Case3	Hydrogen Electrolysis/ electricity mix * (Default)	LNG (Default)	LSFO (Default)
🟦	1. Desalination	0.0	0.0	0.0			
🟩	2. Water electrolysis	0.0	0.0	84.0			
🟫	3. Liquefaction	0.0	0.0	11.1			
⬛	4. Storage and loading, 5. International transport, 6. Unloading / LH_2 storage / Loading, 7. Domestic transport / Bunkering	0.6	0.6	0.6			
🟦	WtT	0.6	0.6	95.8	3.6	18.5	13.2
⬜	TtW	0.0	0.0	0.0	0.0	57.9	76.8

4.LCA of the target fuels-4.3 LNH_3 from electrolysis- Assumptions and Results

Assumptions

	Case1	Case2	Case3
NH_3 Production[t]	900,000 [*1]		
Power source (AU)	Wind 100%		Wind62%+Grid38%
Electricity buffering	NO	Yes	NA
Production technology	PEM	Alkaline	Alkaline
Electrolysis efficiency	5.18 kWh/Nm^3 [*2]	4.3kWh/Nm^3	4.3kWh/Nm^3
CO_2 Intensity of Power Grid [kg-CO_2eq/kWh][*3]	Japan：0.37	Japan：0.37	Australia：0.45 Japan：0.37

Results

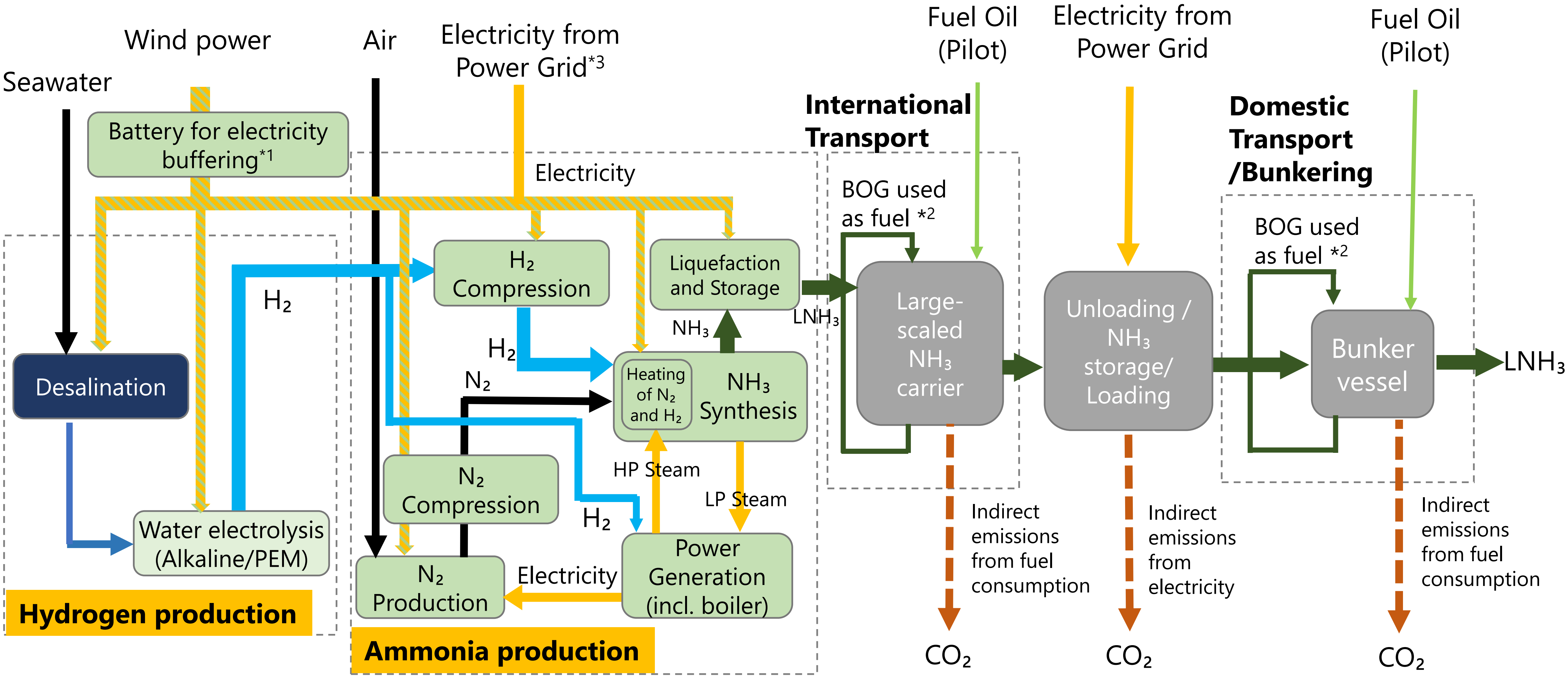
	Case1	Case2	Case3
Fuel for International Transportation	NH_3 and Fuel Oil only for pilot injection		
Total electricity consumption [billion kWh/year]	12.6	10.6	10.6
CO_2Total emissions [g-CO_2eq/MJ-NH_3]	0.81		130.4
Required number of wind turbines with 15MW(rated)	275	233	144

[*1] Production volume is presumed, taking into account actual project under consideration. Reference: "Renewable Hydrogen and Ammonia Feasibility Study by GHD for BP Australia" https://arena.gov.au/assets/2021/08/bp-ghd-renewable-hydrogen-and-ammonia-feasibility-study.pdf

[*2] Case1 assumes that the electrolysis efficiency of PEM batteries deteriorates by about 15% from the expected PEM efficiency in 2030 due to lack of electricity buffering.

[*3] Refer to slide 18

4.LCA of the target fuels-4.3 LNH_3 from electrolysis- Process Diagram (Cases 1,2,3)



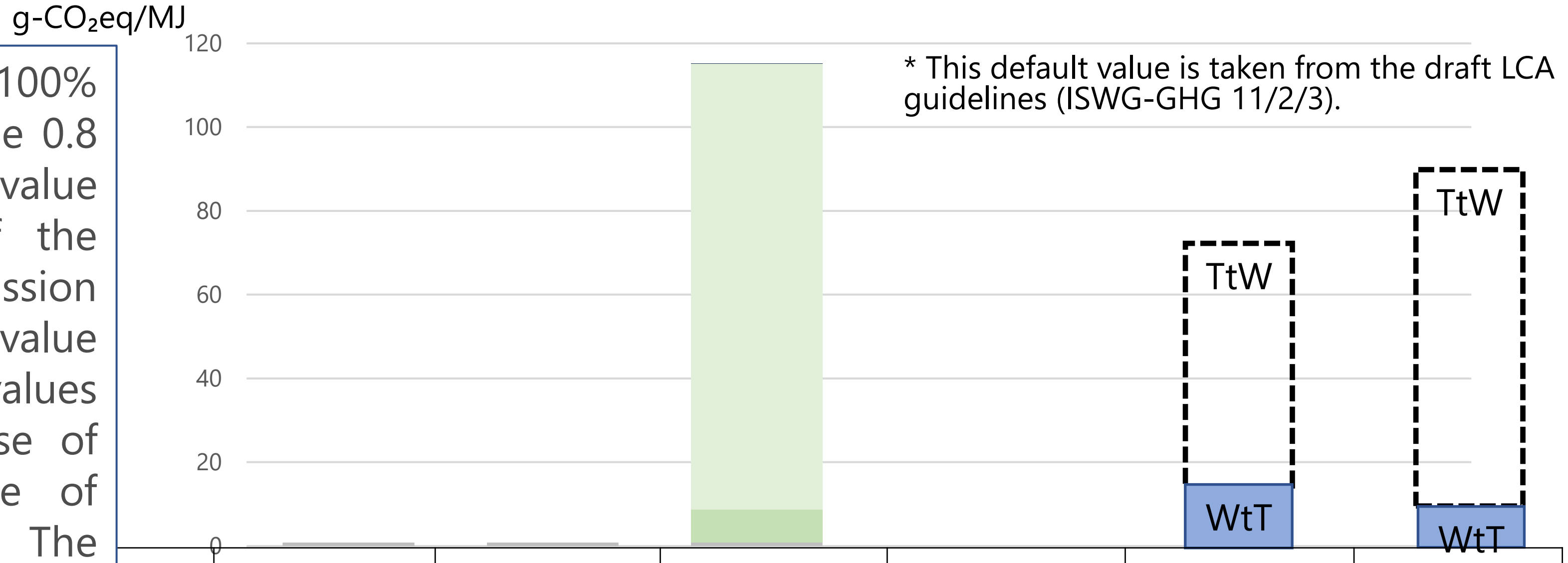
*1 Only in Case 2

*2 Ammonia BOG is used for international and domestic voyage. Fuel oil is used for pilot injection.

*3 Only in Case 3

4.LCA of the target fuels-4.3 LNH$_3$ from electrolysis
-Comparison among the results of LNH$_3$ from electrolysis and the default values of the Fossil Fuels

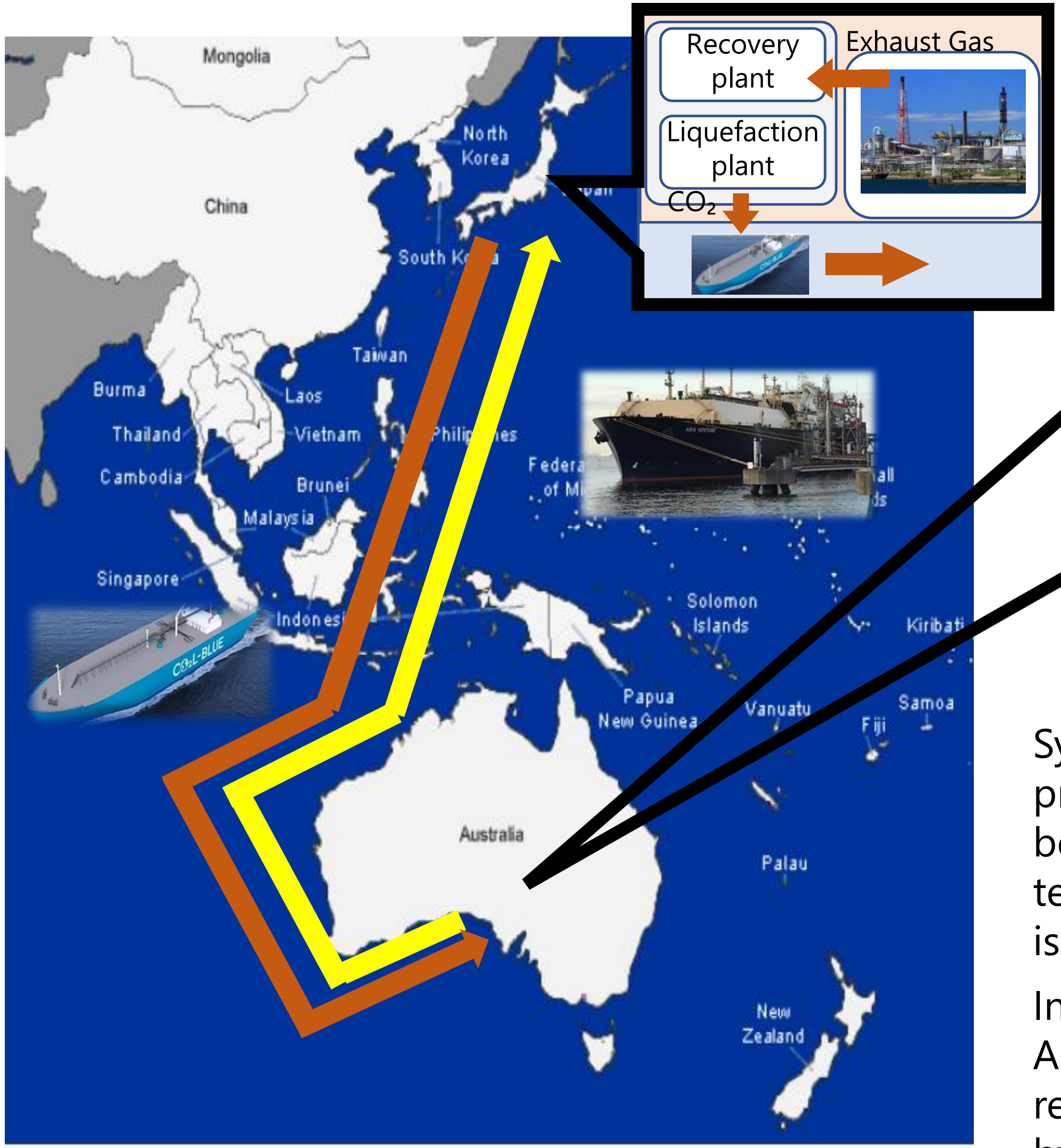
If all the processes used Electricity by 100% renewable energy, the WtT emission would be 0.8 g-CO$_2$eq/MJ (Cases1-2), similar to the default value (0.00 g-CO$_2$eq/MJ). If a small portion of the electricity is supported by Power Grid, the emission will be significantly higher than the default value (Case 3). JTTRI considers that the default values should be separately established for the use of 100% renewable energy and for the use of Electricity mix, as considered in Section 4.2. The observations in the 2nd para. of 4.2 is applicable to this Section as well.

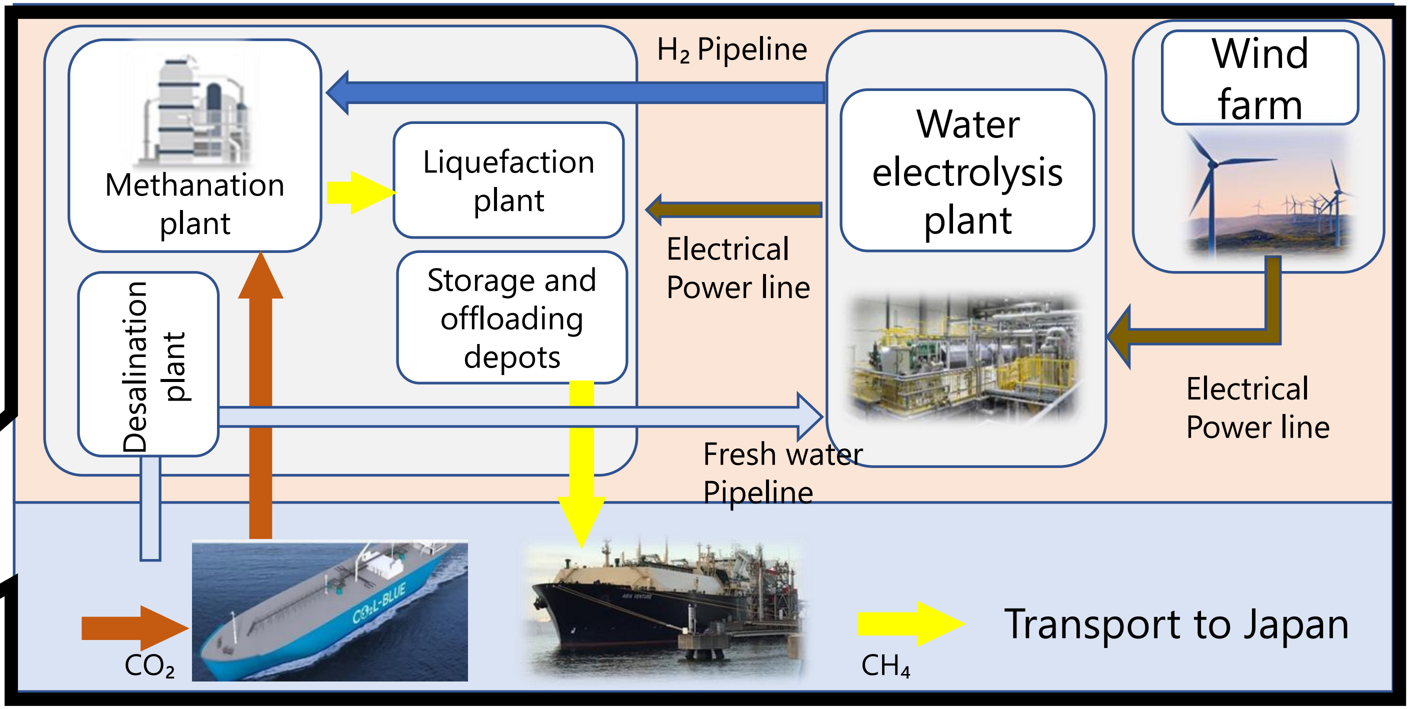


* This default value is taken from the draft LCA guidelines (ISWG-GHG 11/2/3).

		Case1	Case2	Case3	NH$_3$ Electrolysis（Default *）	LNG（Default）	LSFO（Default）
🟦	1. Desalination	0.0	0.0	0.1			
🟩	2. Water electrolysis	0.0	0.0	106.4			
🟩	3. N$_2$ production, 4. N$_2$ Compression, 5. H$_2$ compression, 6. NH$_3$ Synthesis	0.0	0.0	7.9			
⬛	7. Liquefaction and storage, 8. International transport, 9. Unloading / NH$_3$ storage / Loading, 10. Domestic transport / Bunkering	0.8	0.8	0.8			
🟦	WtT	0.8	0.8	115.2	0.0	18.5	13.2
⬜	TtW	0.0	0.0	0.0	0.0	57.9	76.8

4.LCA of the target fuels-4.4 Synthetic methane -Supply chain diagram

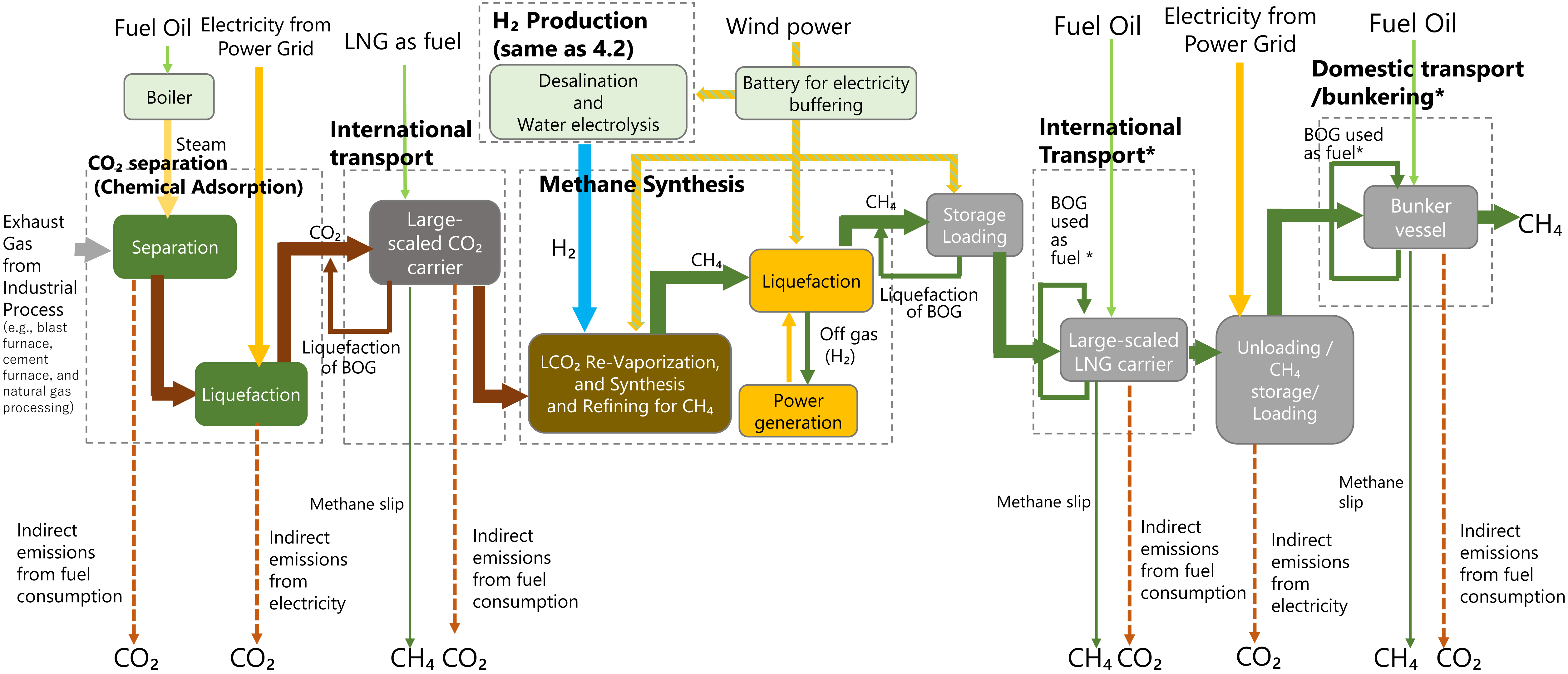




Synthetic methane production from captured CO_2 has not been realized as a project, however, JACCR (Japan Association of Carbon Capture & Reuse) has been assessing its feasibility. JTTRI calculated WtT emissions based on the technical report published by the JACCR. The report translated into English is available at ; https://ccr-tech.org/news/news-357/

In line with the assumptions in 4.2 and 4.3, there would be two sites in Australia, i.e., port site for methanation, liquefaction and offloading and a remote site for water electrolysis and wind farm. They would be connected by H_2 gas pipelines, freshwater pipelines and dedicated power lines.

4.LCA of the target fuels-4.4 Synthetic methane- Process diagram



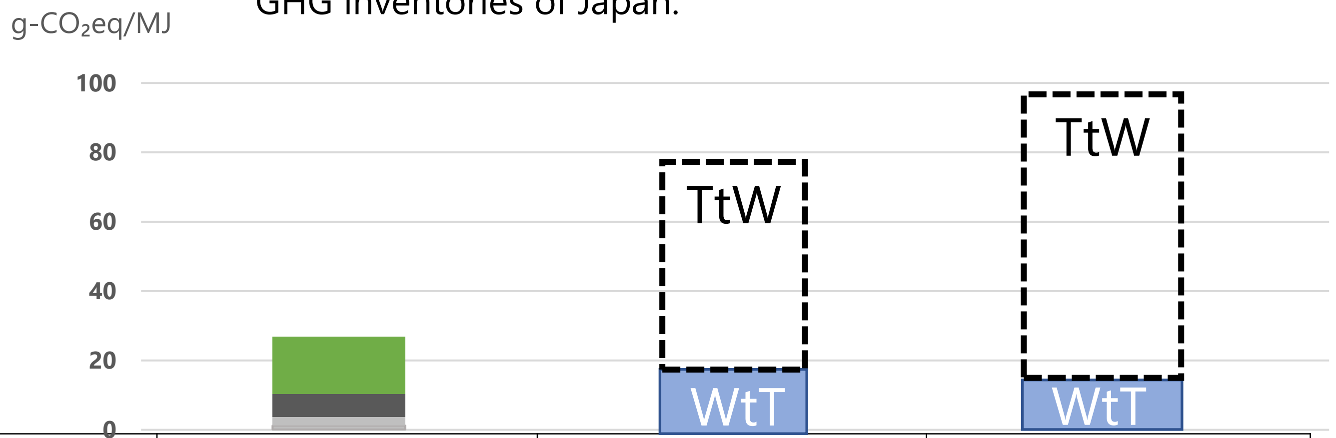
*BOG of synthetic methane is used for international and domestic voyage. Fuel oil is used for pilot injection. CO_2 emission by the onboard combustion should NOT be counted, but only the methane slip emission should be counted.

4.LCA of the target fuels-4.4 Synthetic methane
- Comparison among the results of Synthetic methane and the default values of the Fossil Fuels

Most of WtT emissions come from CO_2 separation, recovery and liquefaction processes in Japan and International Transportation to Australia; this is because the fossil fuel is used to produce high-pressure steam, the current efficiency for CO_2 liquefaction is assumed, and LNG is used as fuel for CO_2 transportation.

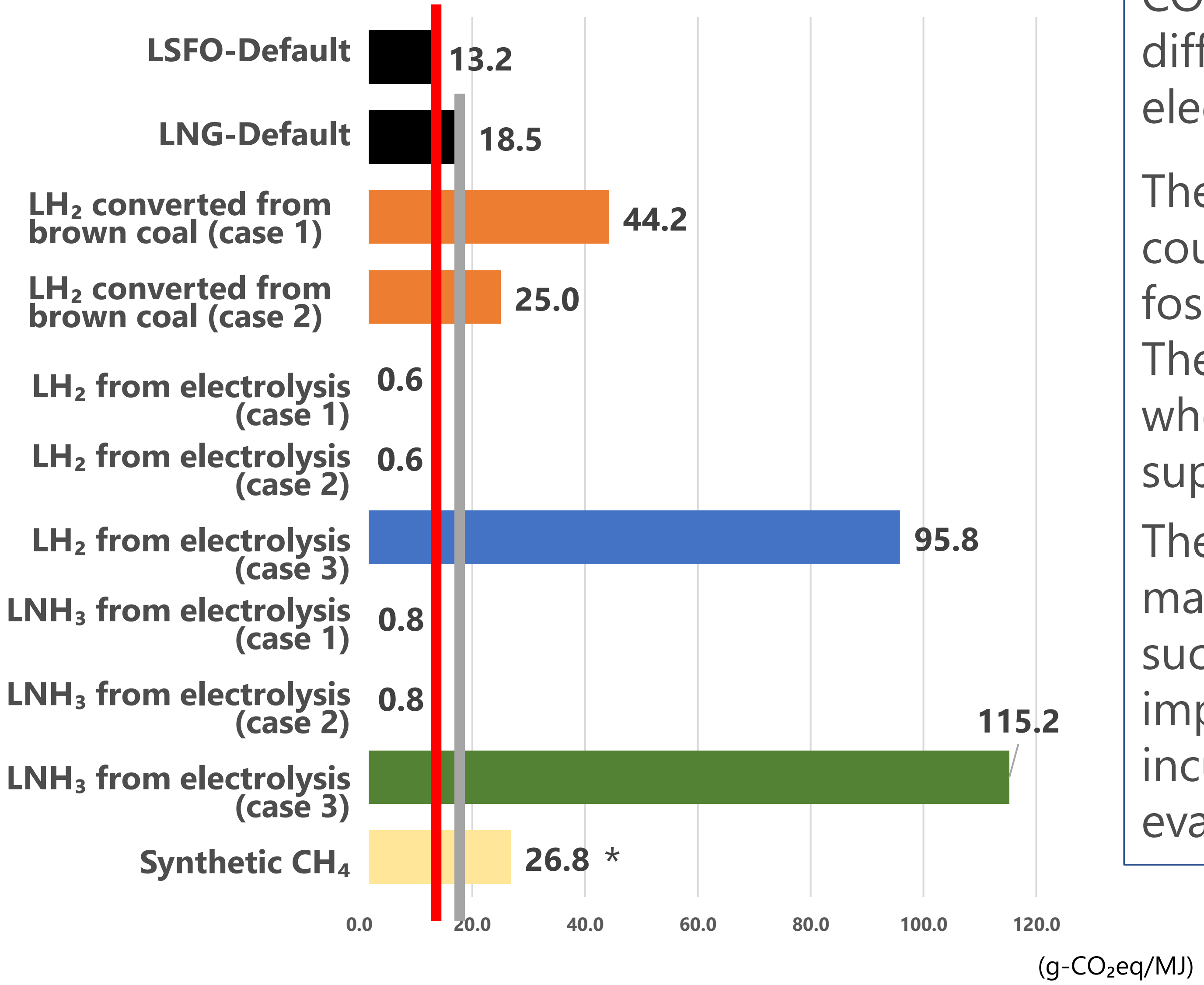
The utilization of thermal in the plant complex in the CO_2 separation and recovery process, higher efficiency for liquefaction and the use of zero-carbon fuel for transportation could reduce the WtT emission to nearly zero.

*TtW emissions should be Zero (S_F=0), on the condition that the amount of CO_2 captured is accounted in the National GHG inventories of Japan.



		Synthetic methane	LNG（Default）	LSFO（Default）
🟩	1. CO_2 separation, 2. Liquefaction	16.5		
⬛	3. International transport（CO_2）	6.5		
🟫	4. LCO_2 Re-Vaporization, and Synthesis and Refining for CH_4	0.0		
🟨	5. Methane liquefaction	0.0		
⬜	6. International transport（CH_4）	2.6		
⬜	7. Unloading, 8. Storage, 9. Loading	1.1		
⬜	10. Methane transportation (domestic)	0.0		
🟦	WtT	26.8	18.5	13.2
	TtW	0.0*	57.9	76.8

4.LCA of the target fuels-4.5 Comparison of WtT emissions



CO_2 Intensity of Power Grid significantly differs between countries, regions and electric power suppliers.

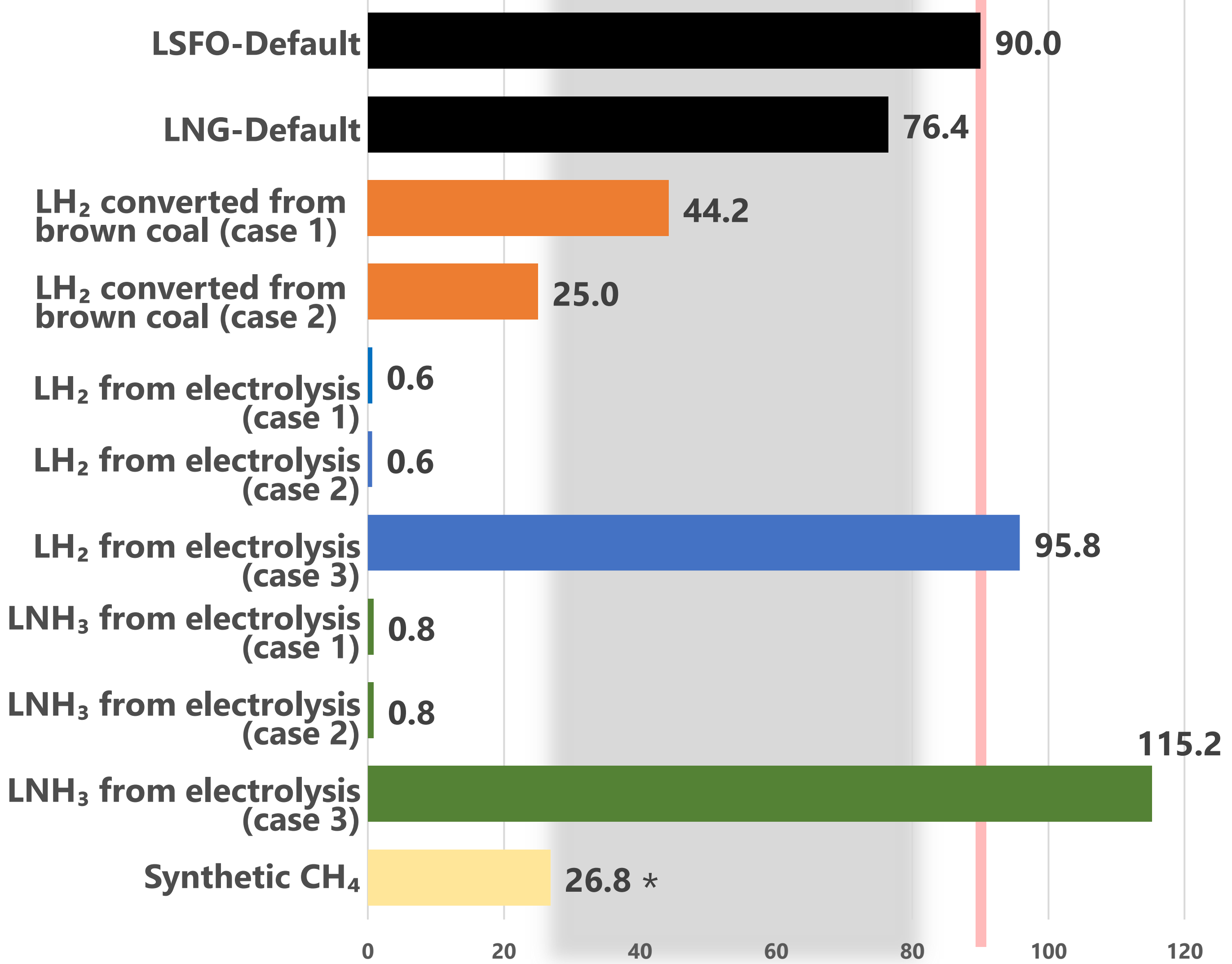
The WtT emissions of decarbonized fuels could be higher than the default values of fossil fuels (LSFO and LNG/Natural gas). The emissions would be particularly high when a part of the necessary electricity supply is supported by the Power Grid.

The use of 100% renewable energy could make the emissions nearly zero, however, such plant concept may have negative implications on stable operation and costs incurred. JTTRI did not quantitatively evaluate this point.

*TtW emissions should be Zero (S_F=0), when the amount of CO_2 captured is accounted in the National GHG inventories of Japan.

4.LCA of the target fuels-4.6 Comparison of WtW emissions

[at least XX%] lower than for LSFO?
(see para.6.4 of ISWG-GHG 11/2/3)



Compared to the Default WtW emission of LSFO, the WtW emissions are **72% lower** in **LH_2 from Brown Coal**, more than **99%** lower either in **LH_2 and LNH_3 from electrolysis**, and **70%** lower in the case of **Synthetic Methane**, respectively.

JTTRI considers that all these fuels have sufficient sustainability when applying the improved technologies for liquefying Hydrogen and capturing CO_2 under development by 2030.

*TtW emissions should be Zero (S_F=0), when the amount of CO_2 captured is accounted in the National GHG inventories of Japan.

Contents

5. Variation of LNG WtT emissions - Existing Studies

A scientific article* showed that WtT emissions among the natural gas used in China significantly vary by a factor of >5. Large variation was reported in other papers as well.

JTTRI considers that careful aggregation calculation would be necessary to establish the default value by each country or region.

In general, there are several key factors for the variation of WtT emissions of LNG.

1. Composition of raw gas extracted;

   CO_2, Condensate, and gas with higher molecular than CH_4 in Reservoir vary among gas fields.

2. Conventional or Unconventional technologies in Extraction influencing the required energy;
3. Ambient temperature affecting the efficiency of liquefaction process;
4. Pipeline transmission/sea transport distance;
5. Possible application of CCS and/or of Electricity by renewable energy.

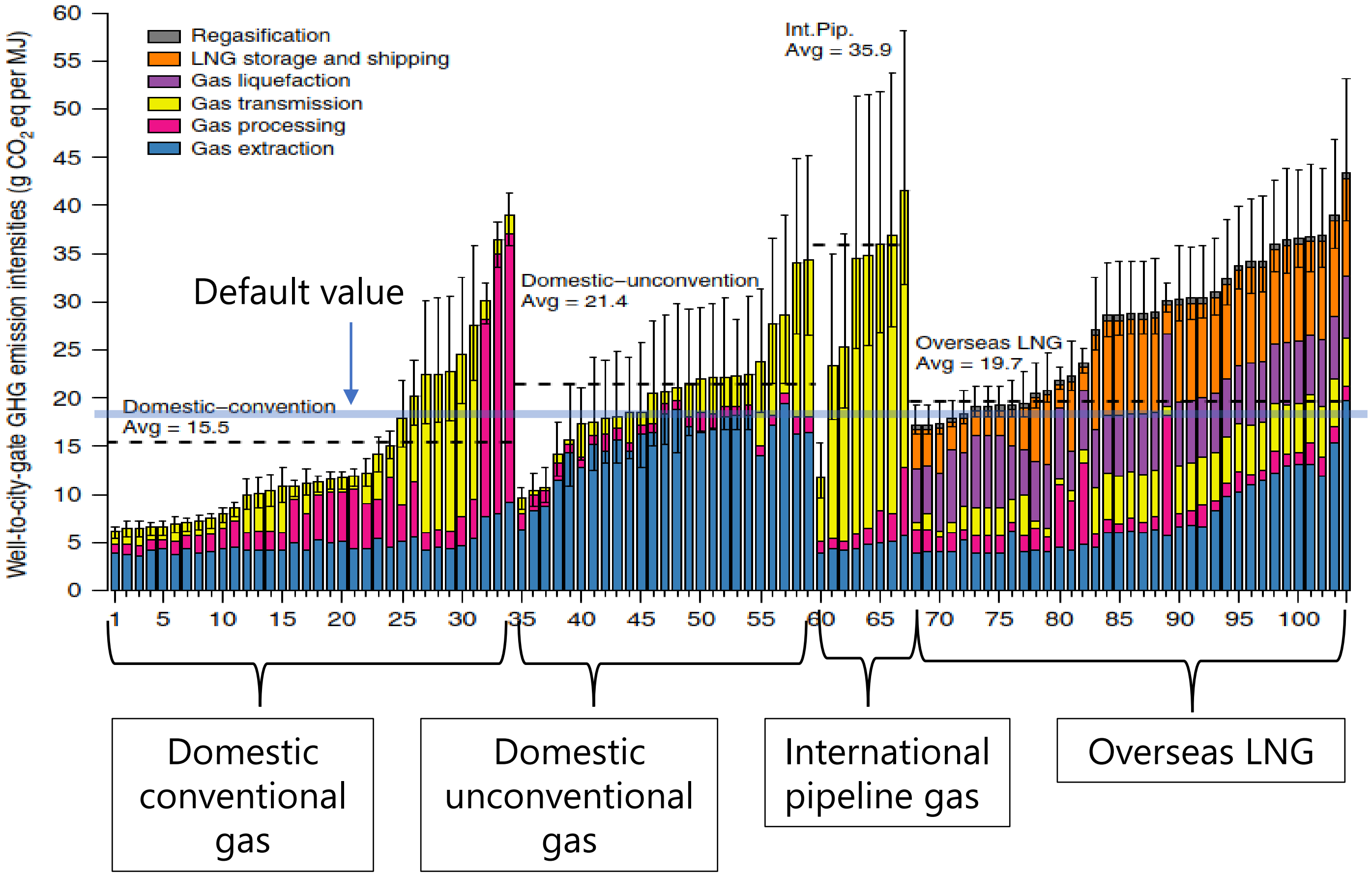


Fig. Well-to-city-gate GHG intensities of natural gas supplies from individual fields to China using 100-year timeframe global warming potential (GWP100) *

* Source: Yu Gan et al., "Carbon footprint of global natural gas supplies to China", NATURE COMMUNICATIONS | (2020)11:824 | https://doi.org/10.1038/s41467-020-14606-4

5. Variation of LNG WtT emissions - Potential Improvements

WtT emissions of LNG could be significantly reduced by applying various technologies.

For example, in case of the Ichthys LNG project in Australia, WtT emissions have been reduced by gradually applying;

1. Highly efficient gas turbines for compressor drivers/power generation
2. Recovery of waste heat to minimize supplemental fired heating
3. Superior solvent for CO_2 removal
4. Combined cycle power generation

The Ichthys LNG project recently announced the **application of CCS** in the late 2020s, which will start the CO_2 storage of over 2 million tons of per year, as the initial phase, and the scale will be increased.

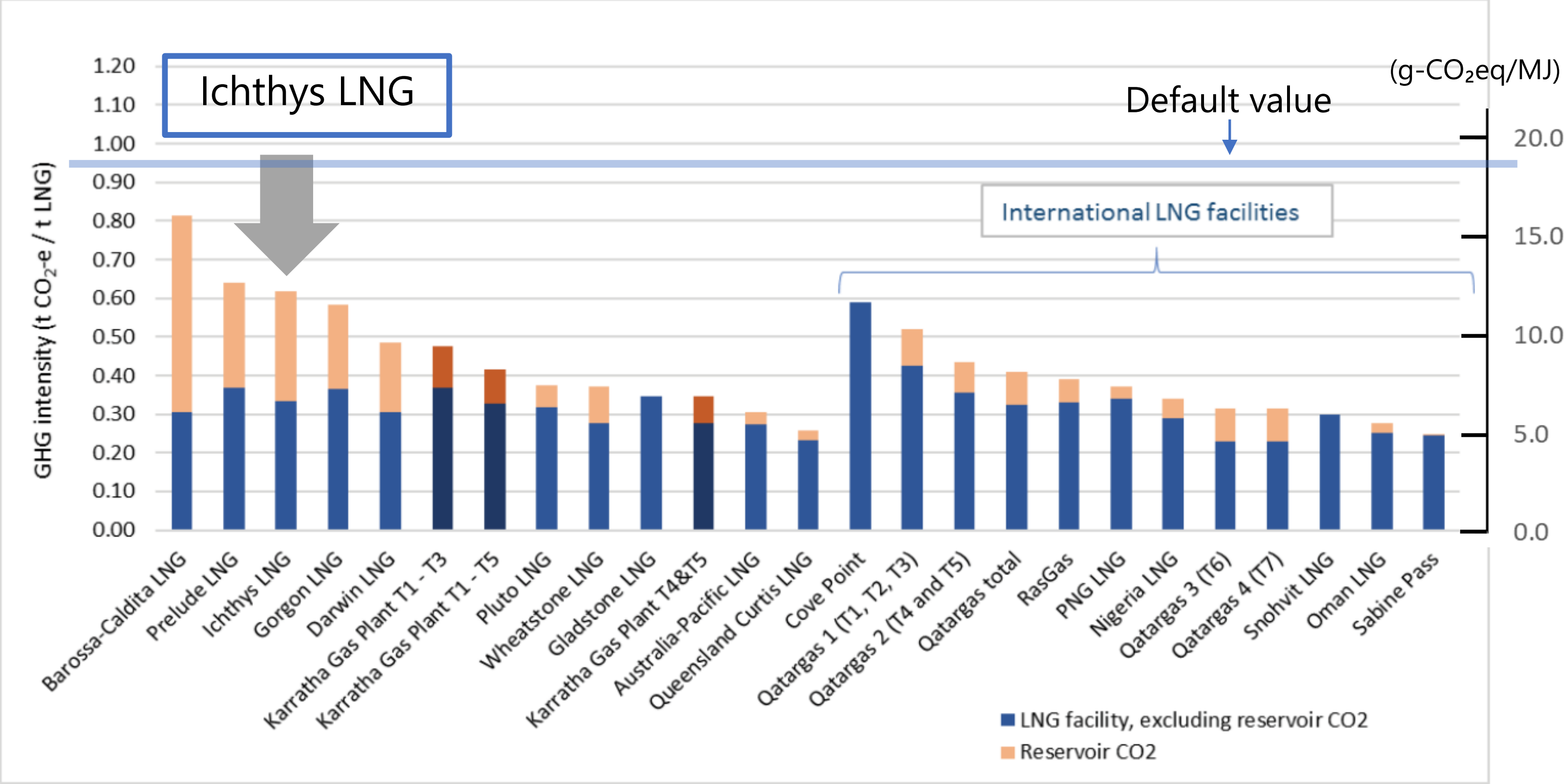


Fig. GHG Intensity of Australian and International LNG Facilities *

* Source: APPENDIX F NORTH WEST SHELF PROJECT EXTENSION GREENHOUSE GAS BENCHMARKING REPORT, https://www.epa.wa.gov.au/sites/default/files/PER_documentatioN₂/NWS%20Project%20Extension%20-%20Appendix%20F%20-%20Greenhouse%20Gas%20Benchmarking%20Report.pdf

Contents

6. Conclusion - Estimation of WtT Emissions- observations and implications

1. Compared to Default WtW emission of LSFO, the WtW emissions of the studied fuels are:

   - 72% lower in **LH_2 from Brown Coal**,

   -more than 99% lower either in **LH_2 and LNH_3 from electrolysis**, and

   - 71% lower in the case of **Synthetic Methane.**

   Therefore, JTTRI concluded that all the studied fuels have sufficient sustainability when applying the efficiency and mitigation measures under development by 2030.

2. CO_2 Intensity of Power Grid significantly differs between countries, regions and even electricity suppliers. In addition, considerable improvements are expected by 2030, taking into account the pledges by countries as contained in National Determined Contributions under the Paris Agreement.

   Therefore, the efficiency for fuel production, including LNG, should be established on a case-by-case basis, using local parameters and expected future improvements.

3. With the view above, an alternative to fixing a single default value for each fuel may be:

   - to set the default values for electricity consumption of the production process, and then

   - to apply localized CO_2 Intensity in estimating the WtT emissions on a case-by-case basis.

   Such methods can be applied to both decarbonized and carbonized fuel.

6. Conclusion- Default WtT value and verified actual values

4. It is shown that WtT emissions can be significantly reduced, even under similar production pathway, with the efforts by project stakeholders (fuel producers/suppliers, etc.) through the applications of the latest technologies in the production and transportation, and the optimization of plant design and total supply chain.

5. In order to give incentives to such efforts, JTTRI recommends that:
   - The default WtT emissions for Zero/Low carbon fuels should be estimated and set at the higher end of the possible emission range with conservative assumptions.
   - The better values than the defaults should be accepted when they are demonstrated through certification schemes recognized by the Organization. The certification schemes should ensure accountability and traceability.

   This concept should apply not only to zero/lower carbon fuels but also to fossil fuels, including LNG.

6. Conclusion - Other points to note

6. The higher CO_2 recovering rate of CCS directly leads to lower emissions both in material flow and energy flow (power generation). The rate will be project-specific and variable at the discretion of the fuel producers. Therefore, the draft Guideline should NOT presume a fixed recovery rate in the default WtT emission values. .

7. The processes for liquefying Hydrogen and capturing CO_2 need more electric consumption, thus leading to higher WtT emissions, than other processes. The efforts for efficiency improvements in these areas should be encouraged.

8. Also, GHG emission from International transportation would not be negligible, if conventional fossil fuel are used. It is crucial to commercialize the main engine which can utilize the BOG of zero carbon fuel for propulsion by 2030.

9. For LNG production, the emissions are largely influenced by the chemical composition of the original Gas extracted (portion of native CO_2 in Reservoir). This makes it difficult to set the globally averaged single default emission value for LNG. Local default value for each region could be established, with careful aggregation of different project sites in the same region.

Supplemental information #1: Assumptions and results of international transportation

		LH_2 converted from brown coal		LH_2 from renewable energy		LNH_3 from renewable energy		Synthetic methane	CO_2
Year		2025	2030	2025	2030	2025	2030	2025 and 2030	2025 and 2030
Annual production of the Fuel output [t/yr]		238,500	238,500	158,824	158,824	900,000	900,000	54,458	150,000
Annual volume of the Fuel transported [t/yr]		226,181	226,181	147,885	149,157	900,000	856,762	52,583	150,000
Cargo tank capacity [m^3]		160,000	160,000	160,000	160,000	83,000	83,000	19,000	10,000
No. of vessels engaged		2	2	2	2	2	2	1	2
Ship speed [kn]		16.0	16.0	12.0	12.0	16.0	16.0	12.0	12.0
Number of round-trips per year		10.7	10.7	7.2	7.2	8.2	8.2	6.4	7.7
Propulsion system		Steam Turbine	Diesel Engine	Steam Turbine	Diesel Engine	Diesel Engine	Diesel Engine	Diesel Engine	LNG Engine
Result for Outbound voyage [t/voyage]	BOG consumed as Fuel	287 of H_2	287 of H_2	382 of H_2	293 of H_2	-	-	146 of CH_4	-
	Pilot Fuel consumed	-	-	-	-		69(MGO)	8(MGO)	10(MGO)
	Fuel (MGO) consumed	908	151	97	-	742	1545(NH_3)	174	201(LNG)
	Methane emissions	-	-	-	-	-	-	1.1	1.9
	N_2O emissions	-	-	-	-	-	0.8	-	-
Result for Return voyage [t/voyage]	BOG consumed as Fuel	287 of H_2	287 of H_2	382 of H_2	293 of H_2	-	-	146 of CH_4	-
	Pilot Fuel consumed	-	-	-	-	-	41(MGO)	8	8
	Fuel (MGO) consumed	908	151	97	-	515	1088(NH_3)	121	142(LNG)
	Methane emissions	-	-	-	-	-	-	1.1	1.0
	N_2O emissions	-	-	-	-	-	0.5	-	-
GHG emissions [$g\text{-}CO_{2eq}/MJ$]		4.606	0.768	0.503	0.000	3.953	0.734	2.563	-

Supplemental information #2

Engine type	2-stroke Diesel engines				4-stroke reciprocating engine			
Fuel type	Fuel Oil	LNG or Methane	Hydrogen	Ammonia	Fuel Oil	LNG or Methane	Hydrogen	Ammonia
Ratio of Pilot Fuel in % (Low Calorific Value base)	No use	5	No use	5	No use	3	No use	20
Thermal efficiency in %, including pilot fuel	55	50	50	50	45	40	40	40
SFOC of main fuel (g-fuel/kWh)	153	150	60	387	187	188	75	484
Methane emission in g-CH_4/g-fuel	0	0.004	0	0	0	0.02	0	0
CO_2-equivalent emission per output in g-CO_2eq/kWh	0	16	0	0	0	102	0	0
N_2O emission in g-N_2O/g-fuel	0	0	0	0.0005	0	0	0	0.0005
CO_2-equivalent emission per output in g-CO_2eq/kWh	0	0	0	50	0	0	0	53

JTTRI assumed CH_4 emission only from LNG/methane fueled engines and N_2O emission from NH_3 fueled engines. No fugitive emission was considered.