May 1, 2022

List of abbreviations

BF	Blast furnace
BFG	Blast furnace gas
BOF	Basic oxygen furnace
CDQ	Coke dry quenching
CISA	China Iron and Steel Association
COG	Coke oven gas
DRI	Direct reduced iron
EAF	Electric arc furnace
LDG	Linz-Donawitz converter gas
OHF	Open hearth furnace
PCI	Pulverized coal injection
tcs	ton crude steel
TRT	Top pressure recovery turbine
WHR	Waste heat recovery

Estimated energy intensity in 2019:

Iron and steel sector (BF-BOF route)

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Background and purpose

Background

- ✓ In order to promote early and effective GHG emission reduction, it is necessary to understand the energy intensity and the reduction potential of each region in the world.
- ✓ There is increasing mention of carbon neutrality, but before that it is important to share such information widely.

Purpose

- ✓ The purpose is to provide comparable energy intensity estimates for the steel sector in 2019 to contribute to the discussion of climate change mitigation.

※ Although this estimation focuses on the international comparison of 2019 results, it follows the existing assumptions and estimation methods shown in Oda et al. (2012) below, and ensures consistency in time-series transitions.

Oda et al. (2012) International Comparisons of Energy Efficiency in Power, Steel, and Cement Industries, Energy Policy, Vol. 44, pp.118-129.

Estimating method

✓ We estimate energy intensity by region by combining the following methods:

A: Macro-statistics approach (based on IEA World Energy Balances)

B: Micro-data approach

B1: Method based on company reports and association data

B2: Method based on technology diffusion rate

B2-1：Effective utilization rate of by-product gas recovery

B2-2：Diffusion rate of 5 technologies (CDQ, TRT, Sinter cooler WHR, Hot stove WHR, and PCI)

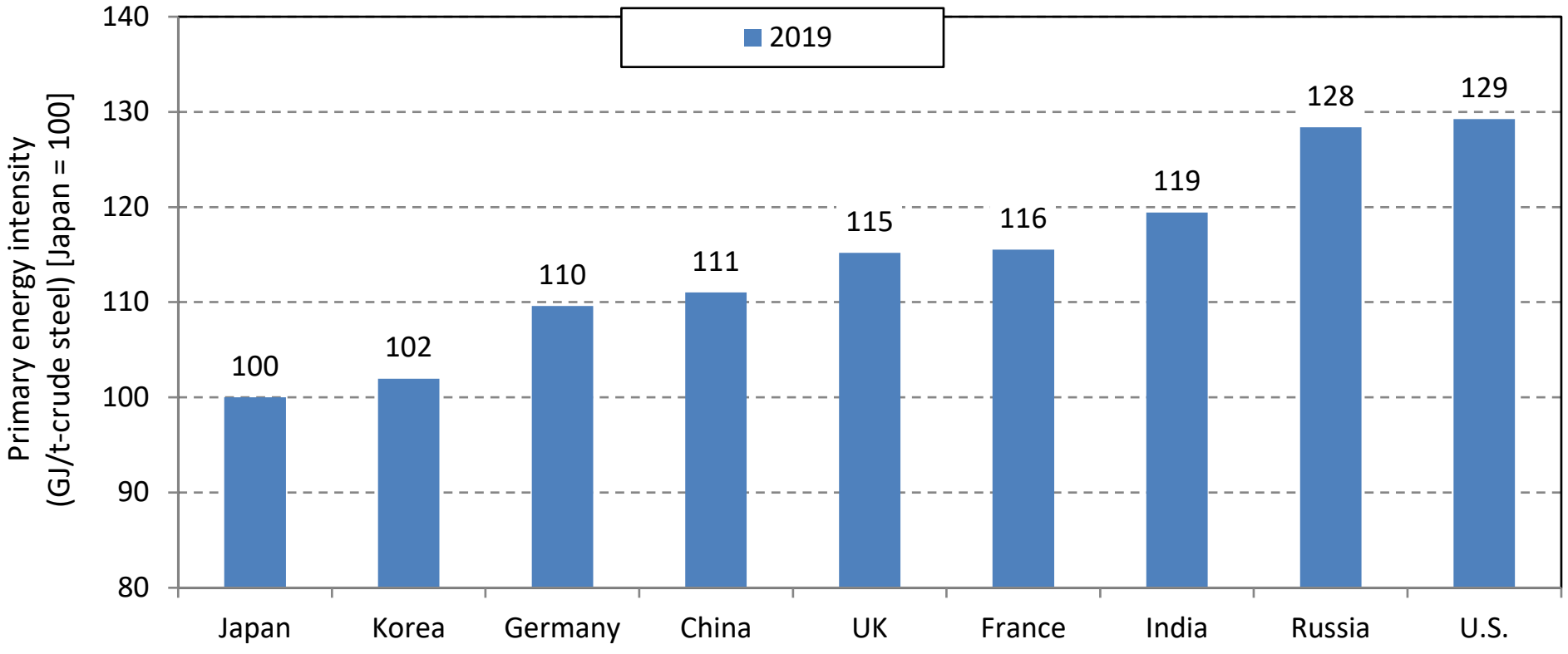
B2-3：Dependence on old technology (OHF and ingot casting)

B3: Method to refer to reducing agent ratio

✓ Features of the above method

	A: Macro-statistics approach (based on IEA World Energy Balances)	B: Micro-data approach
Regional coverage	Superior	Inferior
Causal relationship	Inferior	Superior

Estimated energy intensity in 2019

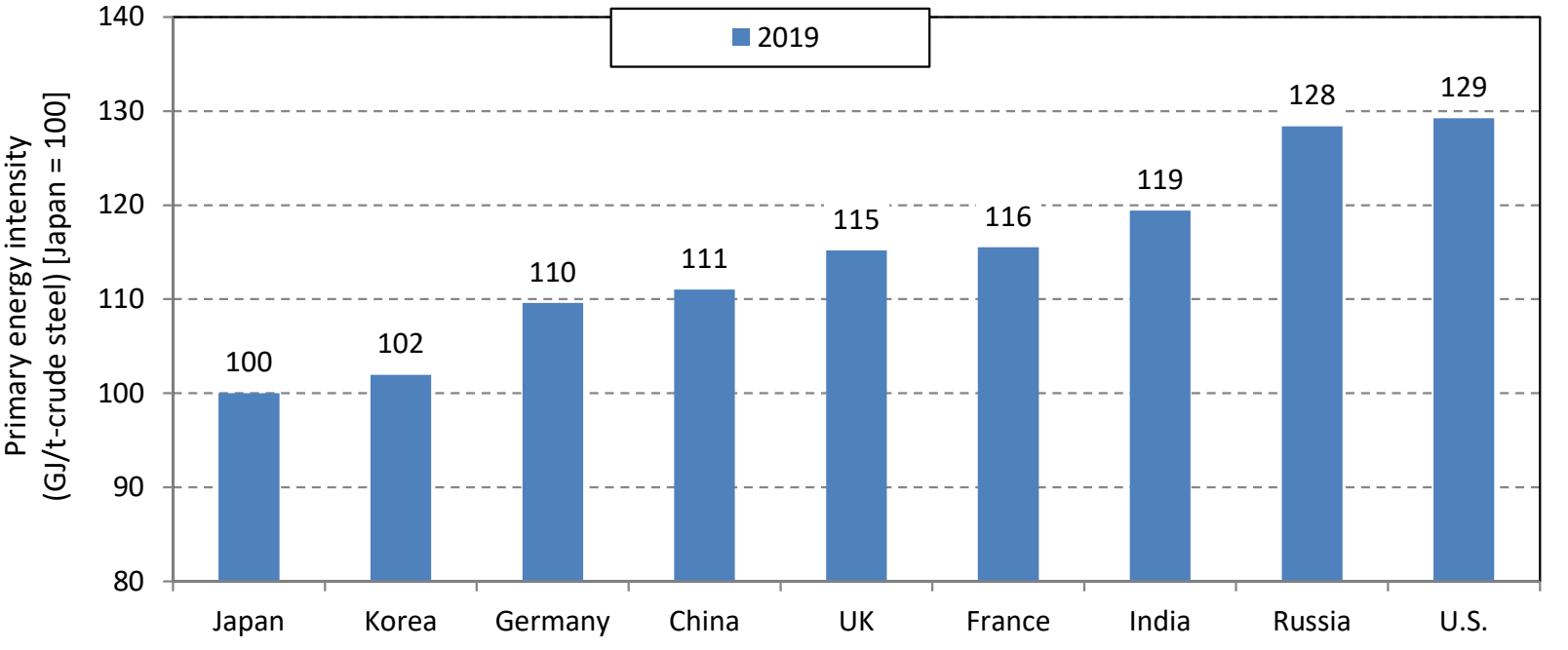


Points

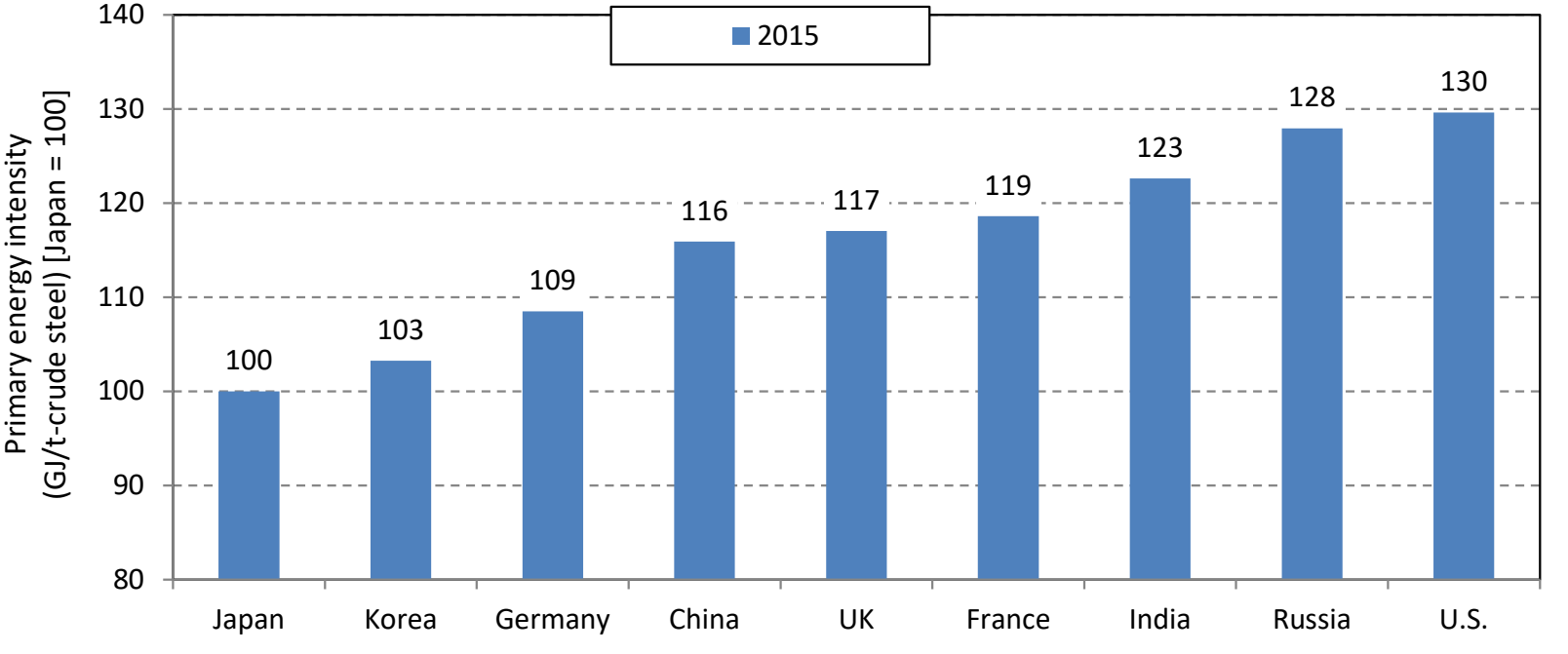
- ✓ Japanese iron and steel industry (BOF steel) maintains the best energy intensity among major countries.
- ✓ In order to promote early CO_2 emission reduction, it is important not only to take domestic measures but also to promote the spread of energy-saving equipment around the world.

1. Introduction

Estimated energy intensity in 2019

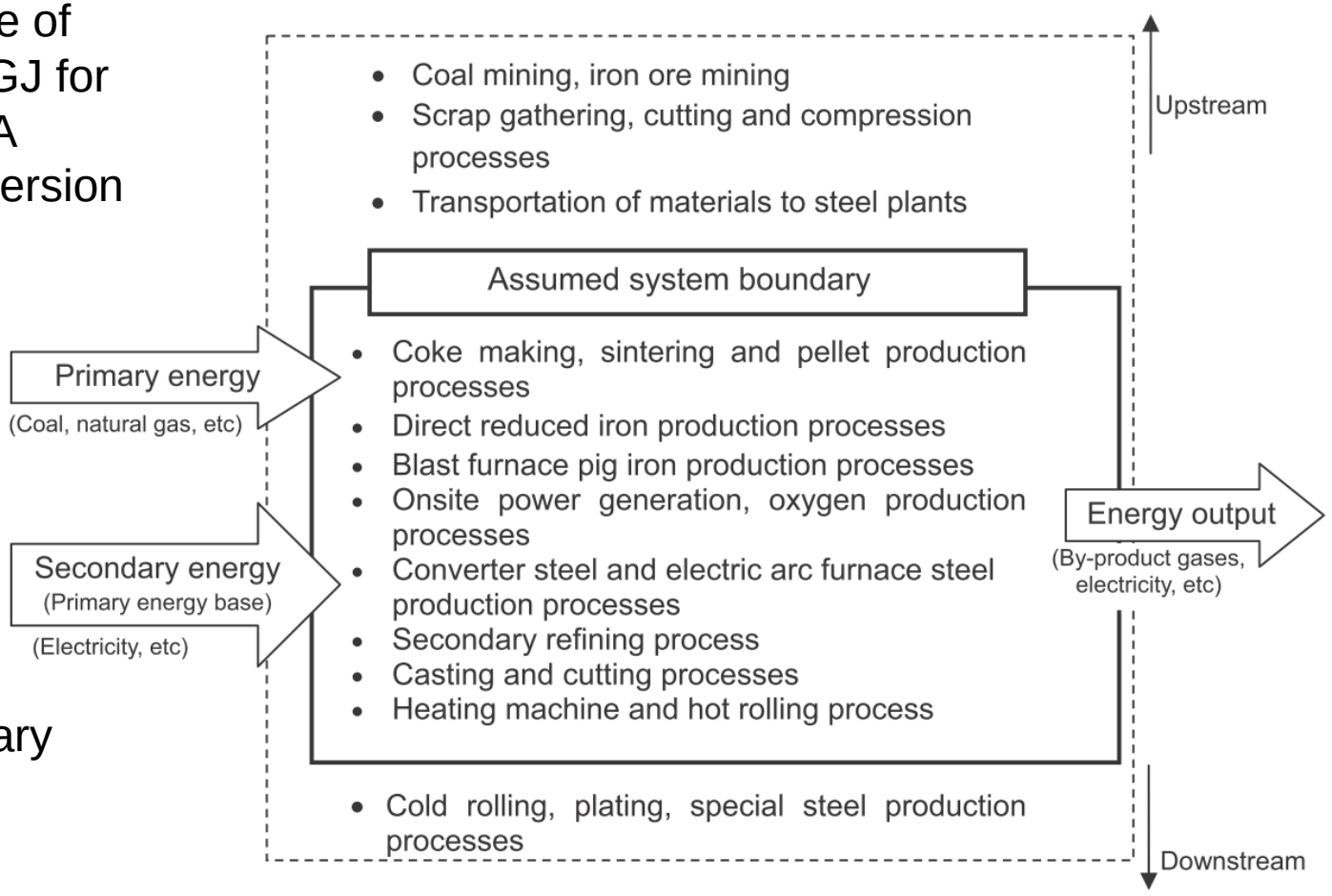


Estimated energy intensity in 2015



Assumption

1. This analysis focuses on comparable energy intensity that reflects energy conservation levels. Correction for hot metal ratios also be carried out.
2. The energy intensity is measured by the energy consumption (GJ) per 1t of crude steel production.
3. Electricity is converted at a rate of 1MWh = 3.6GJ / 0.333 = 10.8GJ for all regions according to the IEA statistical primary energy conversion method.



Assumed system boundary

Ref: Oda et al. (2012)

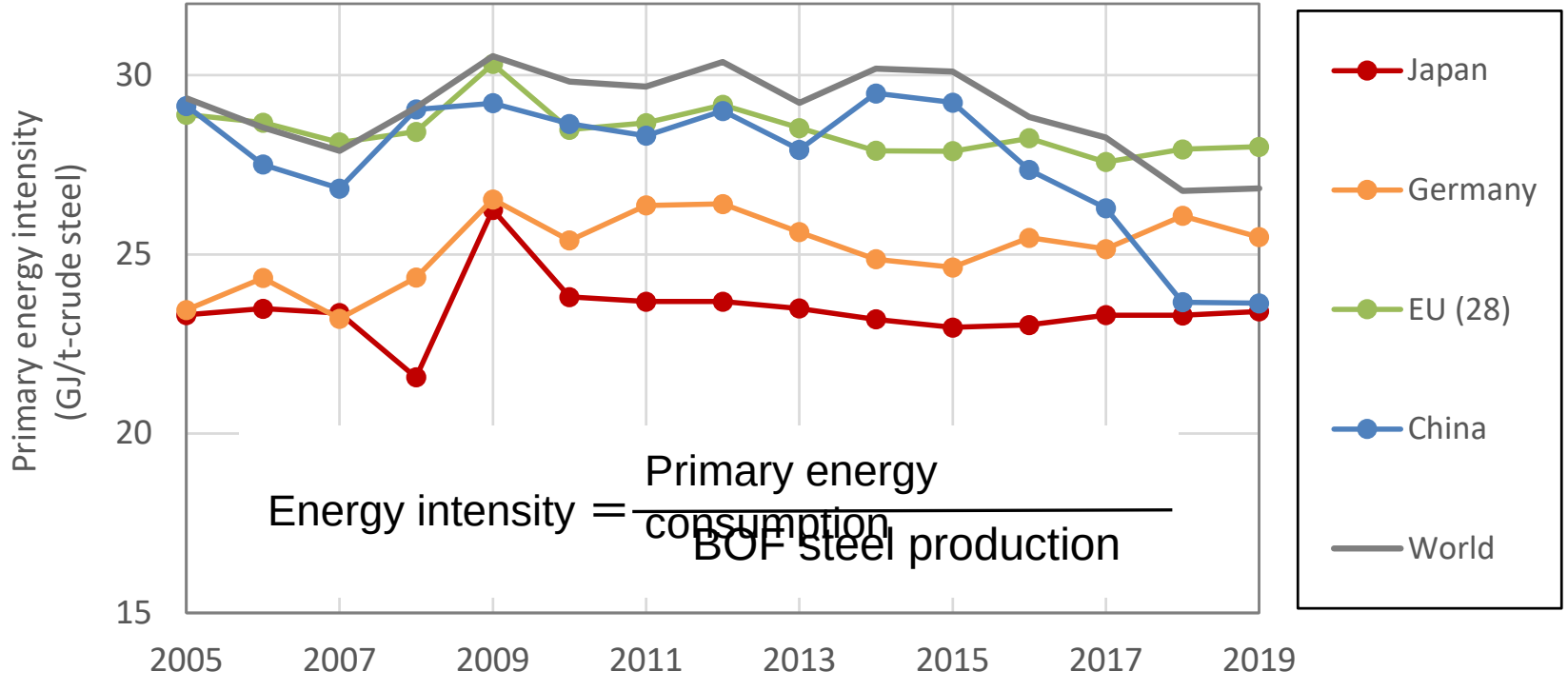
Method based on IEA World Energy Balances (1/3)

- ✓ The net primary energy consumption used in the steel industry is calculated based on IEA World Energy Balances
  - ➢ Considering external sales and purchase of coke, by-product gases, electricity, etc.
  - ➢ Hot metal ratio, defined as pig iron production per unit of BOF crude steel production, corrected to the 2005 world average of 1.025

    <Ratio in 2019: U.S. 0.84, Germany 0.92, EU (28) 0.93, Japan 1.00, China 0.91, India 1.52>

Estimated energy intensity based on IEA World Energy Balances

After hot metal ratio correction



Ref: Pig iron production and BOF steel production are based on worldsteel "Steel Statistical Yearbook" (2020).

Method based on IEA World Energy Balances (2/3)

- ✓ The IEA statistics indicate the total energy consumption of BF-BOF route and EAF route.
- ✓ How to distinguish between BF-BOF and EAF energy consumption
  - ➢ This analysis treats the activity of the iron and steel sector in terms of three routes: BF–BOF, Scrap-EAF and DRI-EAF
  - ➢ We set representative energy intensity (EI) by route as shown below, and calculate the ratio to the representative EI

Ratio to the representative EI for areas that do not produce DRI =

$$\frac{\text{Calculated primary energy consumption based on IEA World Energy Balances (PJ/y)}}{\text{Representative EI of BOF} \times \text{BOF steel production} + \text{Representative EI of scrap-EAF} \times \text{scrap-EAF steel production}}$$

Assumed energy intensity (EI) for representative value

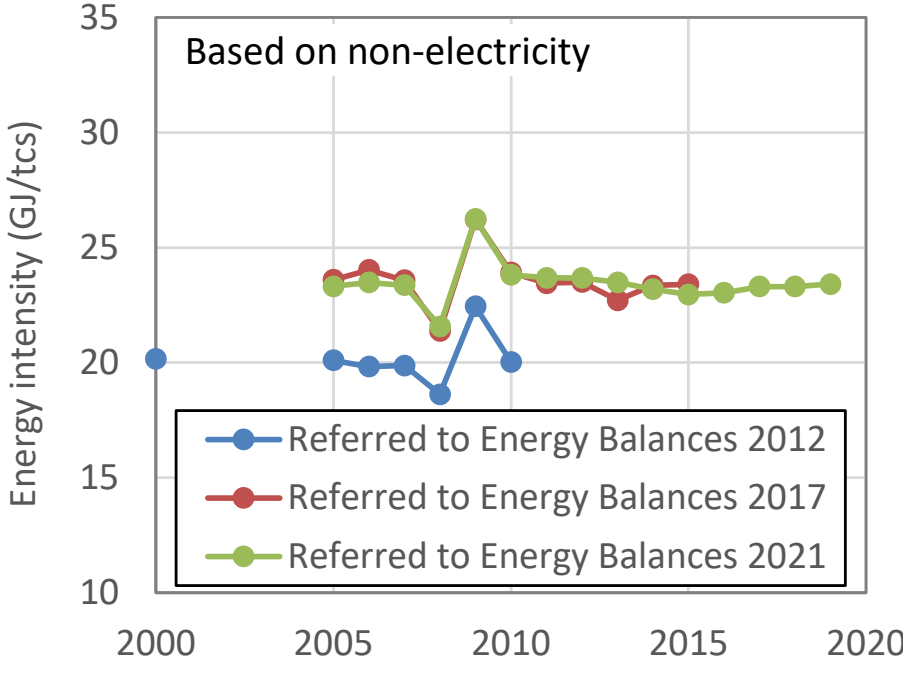
(GJ/t-crude steel)	Non-electricity	Electricity	Total
BF-BOF route	22.3	4.8	27.1
Scrap-EAF route	2.5	6.3	8.8
DRI-EAF route	15.9	7.6	23.5

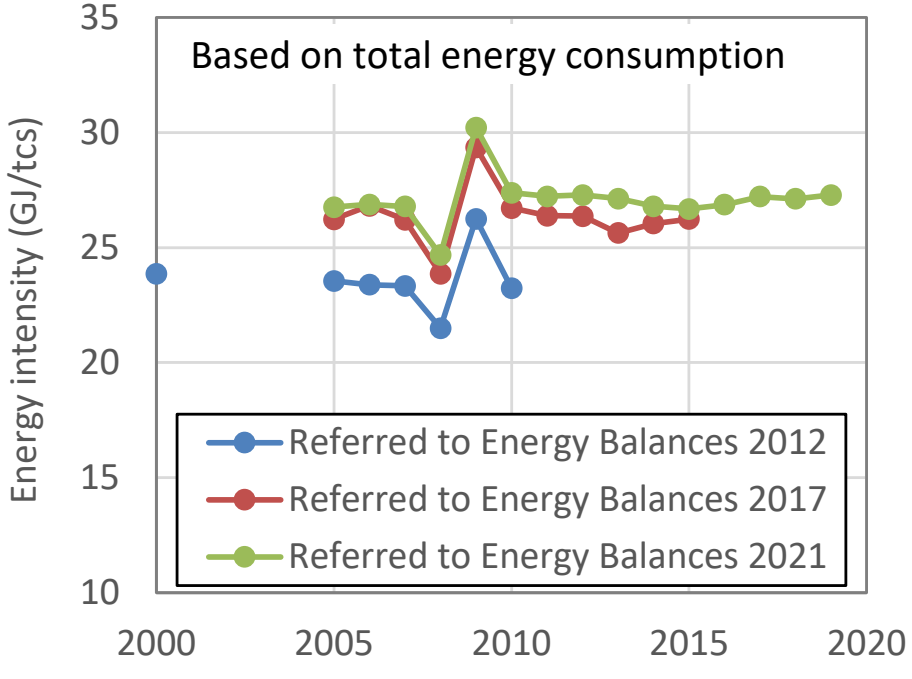
Method based on IEA World Energy Balances (3/3)

- ✓ Estimation by non-electricity and total energy consumption
- ✓ Not only the latest IEA “World Energy Balances 2021” but also the old Energy Balance are focused on and organized

Japan

Estimated energy intensity (BF-BOF route)





Method based on company reports and association data

Japan

- ✓ Based on the basic unit published with the Voluntary Action Plan, it is estimated to deteriorate by 0.5% in the four years from 2015 to 2019 (after correcting the impact of hot metal ratio and the impact of the steel product mix).

Korea

- ✓ Considering the deterioration of POSCO's CO_2 intensity (after correcting the impact of production activities outside Korea) and the expansion of the market share of Hyundai Steel, it is estimated to deteriorate by 1.25%.

Ref: POSCO “Corporate Citizenship Report” (2018-2020)
http://corporatecitizenship.posco.com/citizen/eng/report/s919e3000307l.jsp

Germany

- ✓ We calculate energy intensity changes over the last 4 years based on thyssenkrupp’s Annual report.
- ✓ In addition, the ODYSSEE-MURE project has presented energy intensity (without correction). Hot metal ratio correction is implemented for this.
- ✓ Based on the above, German energy intensity is evaluated to have deteriorated by 2.4% in the past

Ref: https://www.thyssenkrupp.com/en/investors/reporting-and-publications/reporting-2019-2020.html
https://www.odyssee-mure.eu/publications/efficiency-trends-policies-profiles/germany.html
https://www.odyssee-mure.eu/publications/efficiency-by-sector/industry/steel-unit-consumption.html

UK, France, and Italy

- ✓ Hot metal ratio correction is implemented for the data of the ODYSSEE-MURE project. With reference to the EU improvement rate of 0.5%, it is evaluated as 0.8% improvement, 0.5% improvement, and 1.4% deterioration, respectively.
- ✓ For France, ArcelorMittal's CO_2 intensity is also referred.

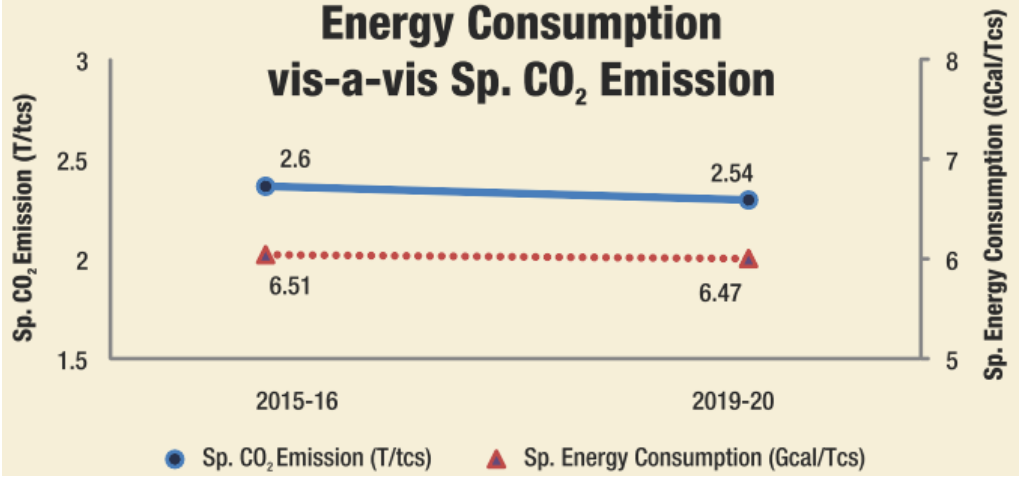
Ref: ArcelorMittal, Climate Action Report 2019, p.32

Method based on company reports and association data

India

- ✓ The improvement rate of the energy intensity of SAIL and TATA of India Steel Authority is calculated. It is calculated to improve by 0.6% and 3.2%, respectively, over the last four years.
- ✓ Weighted averaged by the crude steel production of the two companies, it can be evaluated as an improvement of 1.6% in the past 4 years (after subtracting the influence of the hot metal ratio).

SAIL energy intensity and CO_2 intensity



Ref: SAIL “Corporate Sustainability Report 2020”
https://sail.co.in/en/sustainability-report

Method based on company reports and association data

Energy intensity indicators of CISA members based on China Steel Yearbook

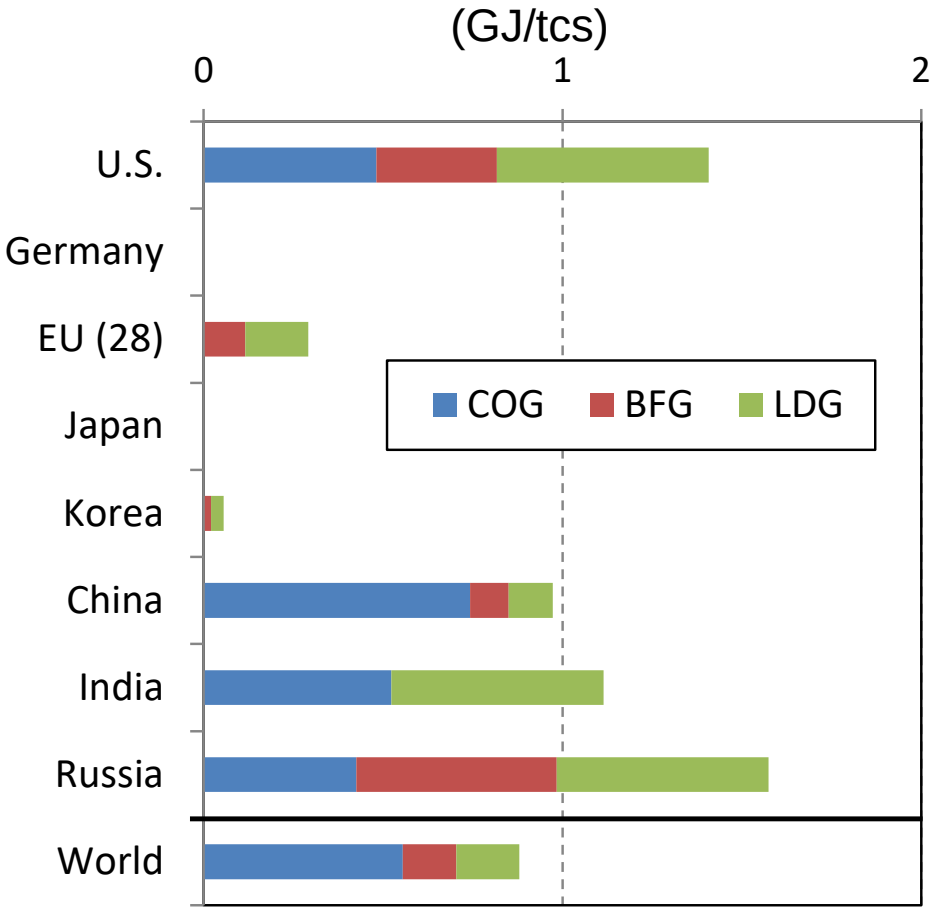
	Comprehensive energy consumption (kgce/t)	Sintering (kgce/t)	Pellet (kgce/t)	Coke (kgce/t)	Pig iron (kgce/t)	EAF (kgce/t)	BOF (kgce/t)	Rolling (kgce/t)
2005	694	65	40	142	457	97	36	76
2006	645	56	33	123	433	81	9	65
2007	628	55	30	122	427	81	6	63
. . .								
2010	605	53	29	106	408	74	0	62
. . .								
2015	572	47	28	100	387	60	-12	58
. . .								
2019	550	45	25	98	387	57	-15	60

4.3% improvement rate

Note 1: Data of "Priority Large and Medium-sized Companies" until 2010, and data of "Members of CISA" after 2015
Note 2: There are discontinuous parts from 2005 to 2007 (final energy base after 2006, excluding energy consumption required for continuous casting and secondary refining after 2007)
Ref: China Steel Yearbook (2006-2021)

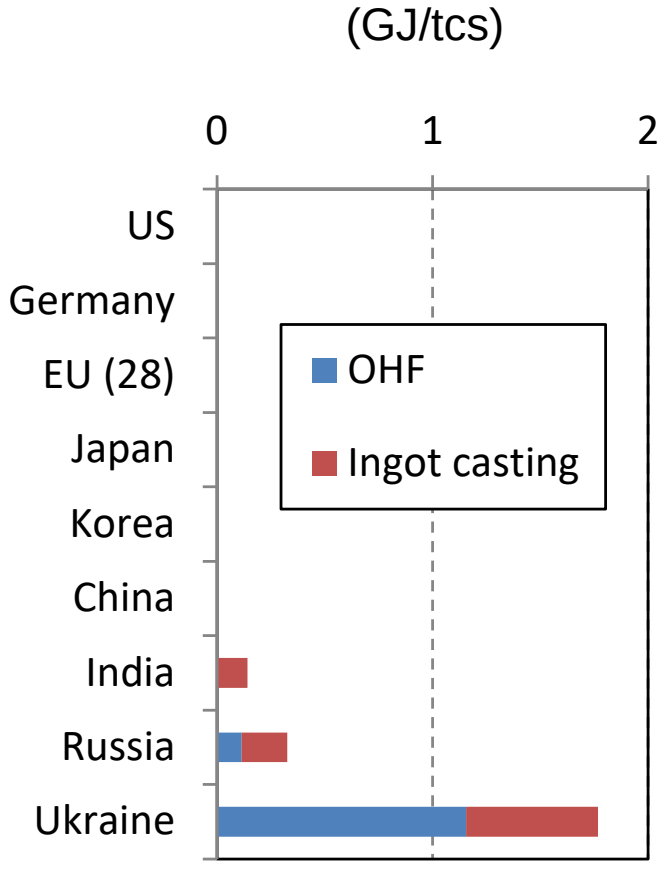
Method based on diffusion ratio (1/2)

B2-1: Evaluation result of effective utilization potential for recovery of by-product gases in 2019



Ref: Estimation based on IEA “World Energy Balances 2021”

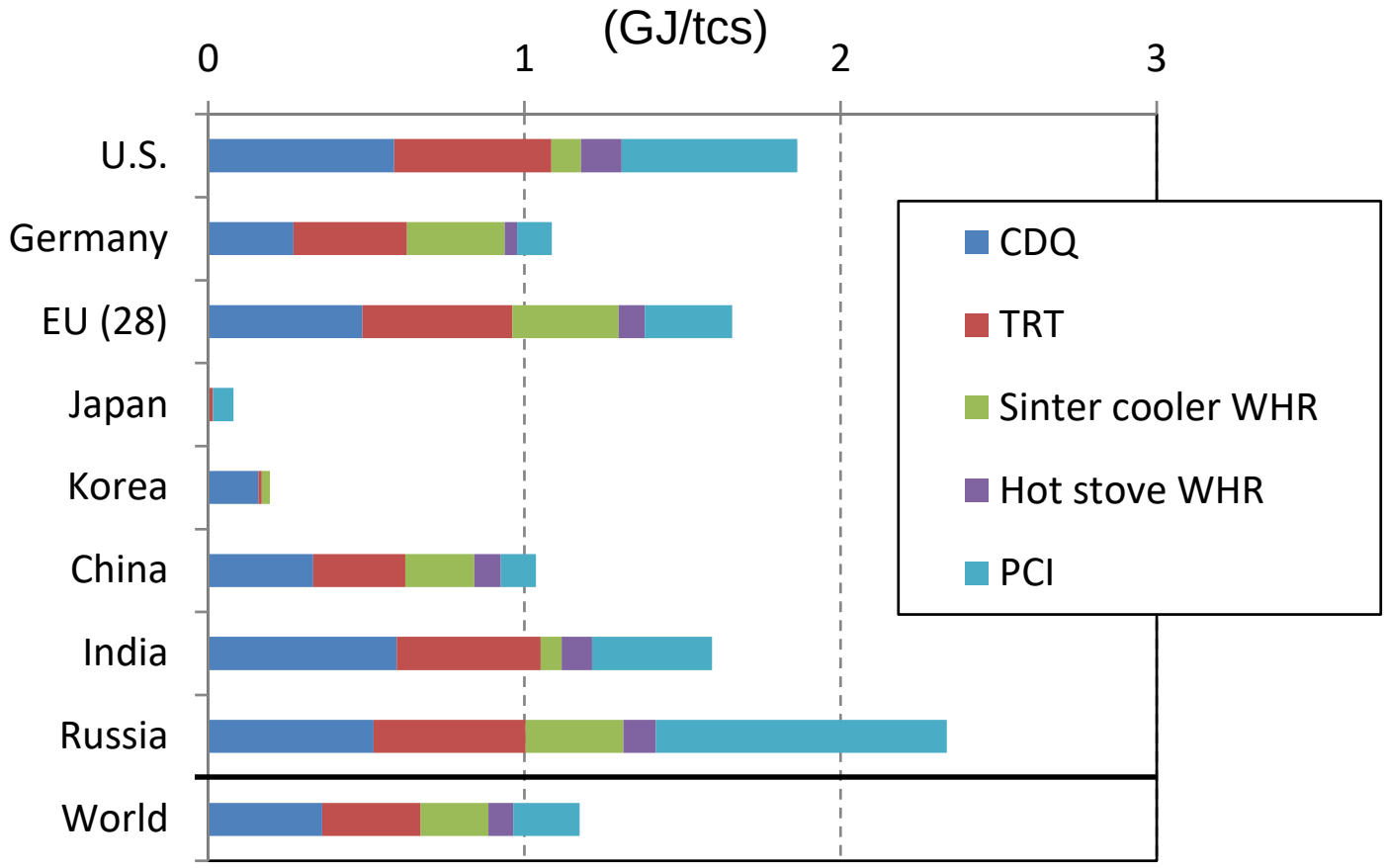
B2-3: Evaluation result of energy saving potential by replacing old technology in 2019



Ref: Estimation based on worldsteel “Steel Statistical Yearbook” (2020)

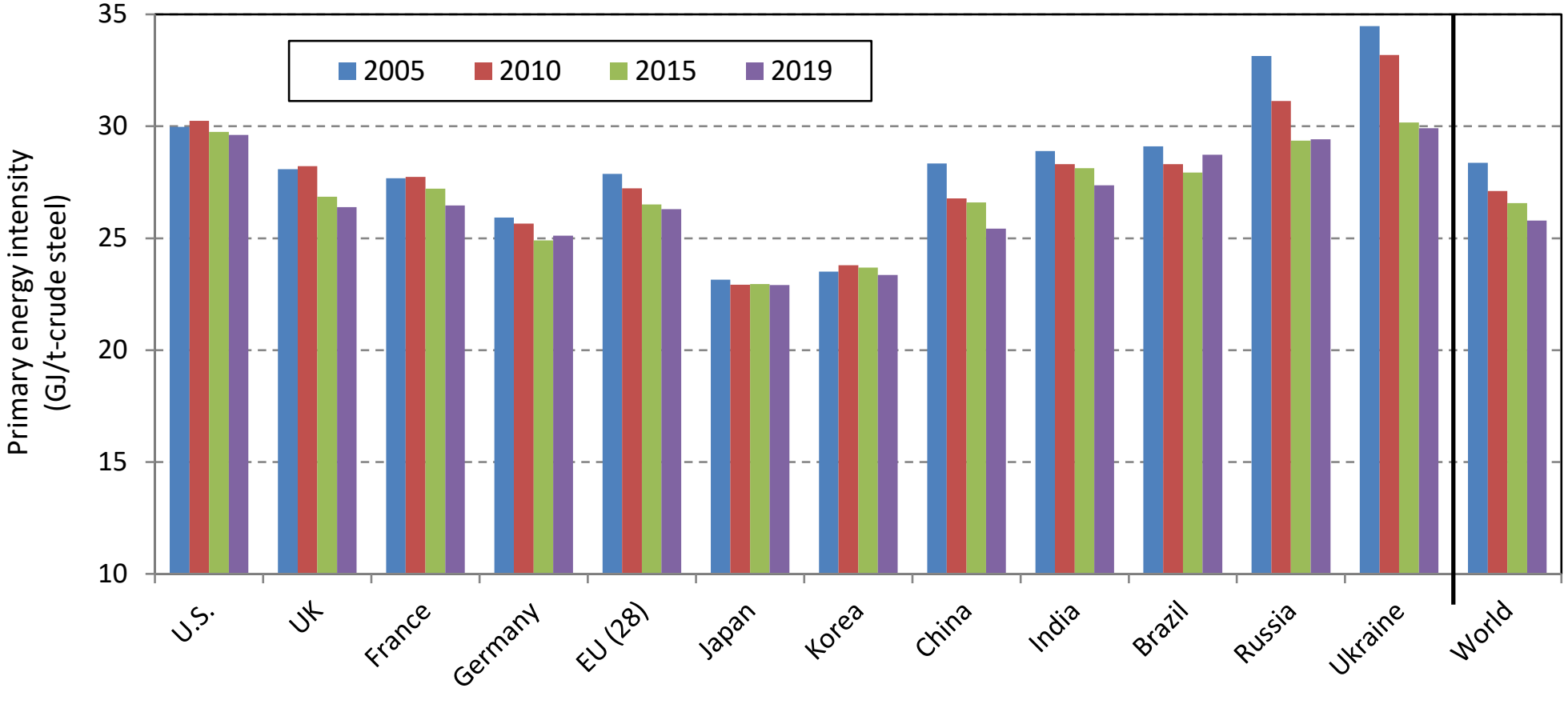
Method based on diffusion ratio (2/2)

B2-2：Evaluation results of energy-saving potential by diffusing five technologies (CDQ, TRT, Sinter cooler WHR, Hot stove WHR, and PCI)



Ref: PCI - Estimation based on Japan Iron and Steel Federation “Handbook for Iron and Steel Statistics 2021,” and Stahlinstitut VDEh (2013).
Other four technologies - Estimation based on the 2015 penetration rate <Arens et al. (2017), Schulz et al. (2015), China Steel Yearbook (2016), etc.>
and the subsequent introduction results <Shipping information and China Steel Yearbook (2021)>

Estimated energy intensity (2005-2019)



Note

- ✓ It is noted that there are differences in the transition of the occupancy rate depending on the region, and the influence is also large

Capacity factor of the steel industry

	Japan	China
2015	83.5%	71.3%
2019	82.1%	93.2%

Ref: Japan – Oda and Akimoto (2022)
China - China Steel Yearbook (2016-2021)

It is estimated that the energy intensity improved by a little less than 5 points due to the increase in the capacity factor in China

Summary and future work

Summary

- ✓ Japanese iron and steel industry (BOF steel) maintains the best energy intensity among major countries in 2019
- ✓ In order to promote early CO_2 emission reduction, it is important not only to take domestic measures but also to promote the spread of energy-saving equipment around the world

Future work

- ✓ We plan to evaluate the potential for reducing CO_2 emissions