Annexures

Annexure 1

The key assumptions used in the estimation of the delivered prices of natural gas and the estimation of grey ammonia costs for the production of urea and non-urea fertilisers are presented in this annexure.

Table A1 shows the base prices of domestic gas in India, and Table A2 presents the import prices of LNG in India, both obtained from the Petroleum Planning & Analysis Cell (2023a). Lately, the domestic price of gas in India has increased to reflect global trends. However, there have been large historical deviations. It should be noted that these are not the prices of natural gas delivered to fertiliser plants. The delivered cost depends on multiple factors that are discussed in Section 3.1.

Table A1 Base prices of domestic gas in India

Period	Year	Financial year	Actual domestic price (USD/MMBtu)
Apr-Sep	2019	FY 2019–20	3.69
Oct-Mar	2019	FY 2019–20	3.23
Apr-Sep	2020	FY 2020–21	2.39
Oct-Mar	2020	FY 2020–21	1.79
Apr-Sep	2021	FY 2021–22	1.79
Oct-Mar	2021	FY 2021–22	2.90
Apr-Sep	2022	FY 2022–23	6.10
Oct-Mar	2022	FY 2022–23	8.57

Source: Petroleum Planning & Analysis Cell (2023a)

Note: Apr, April; Sep, September; Oct, October; Mar, March

Table A2 Import prices of LNG in India

Financial year	Import price of gas (USD/MMBtu)
FY 2019–20	7.60
FY 2020–21	6.00
FY 2021–22	10.90
FY 2022–23	16.40

Source: Petroleum Planning & Analysis Cell (2023a)

Table A3 presents the key assumptions used for the price build-up of the delivered natural gas. The taxes and tariff components are taken from official sources of the Ministry of Petroleum and Natural Gas (Petroleum Planning & Analysis Cell n.d.). The authors have derived the share of domestic gas production based on data presented in Petroleum Planning & Analysis Cell (2021, 2022, 2020, 2023b).

Table A3 Key assumptions used for the price build-up of natural gas

Particular	Unit	Value	Source
Import duty on imported gas	Percentage	2.5%	(Petroleum Planning & Analysis Cell n.d.)
Social welfare surcharge on import duty	Percentage of import duty	10%	
Re-gasification tariff	USD/MMBtu	0.8	Authors' analysis of (GAIL India Ltd. 2023)
GST on re-gasification tariff	USD/MMBtu	0.14	(GST Council n.d.)
Average pipeline transmission tariff	USD/MMBtu	0.41	

Average supplier margins	USD/MMBtu	0.21	Authors' analysis of (GAIL India Ltd. 2023)
Share of domestic gas in urea production (FY 2019–20)	Percentage	43%	(Petroleum Planning & Analysis Cell 2020)
Share of domestic gas in urea production (FY 2020–21)	Percentage	39%	(Petroleum Planning & Analysis Cell 2021)
Share of domestic gas in urea production (FY 2021–22)	Percentage	33%	(Petroleum Planning & Analysis Cell 2022)
Share of domestic gas in urea production (FY 2022–23)	Percentage	22%	(Petroleum Planning & Analysis Cell 2023b)

Source: Authors' analysis

Table A4 presents the parameters used in a line-fit model developed by the authors to translate the delivered price of natural gas into grey ammonia costs. The proportion of amortised ammonia production units is derived from information regarding the vintage of fertiliser plants in India.

Table A4 Key assumptions used in the estimation of grey ammonia costs

Particular	Unit	Value
The line-fit equation for deriving grey ammonia costs from natural gas prices		
The slope of the line fit	MMBtu/tonne	30.387
Intercept of the line fit	USD/tonne	145.81
Proportion of amortised ammonia production units	Percentage	86.4%
Build-up components for imported ammonia		
Import duty	Percentage	5%
Social welfare surcharge	Percentage	10%

Source: Authors' analysis; Cybex Exim Solutions (n.d.)

Table A5 presents the data sourced from the export import database of the Ministry of Commerce, Government of India, regarding the import of ammonia under HS code: 28140000 (Department of Commerce n.d.). It can be observed that the cost of imported ammonia rose sharply in FY 2021–22 and FY 2022–23.

Table A5 Import volumes and import value of ammonia in India

Financial Year	Volume of imported ammonia (MTPA)	Value of imported ammonia (USD million)	Cost of imported ammonia (USD/tonne)
2019–20	2.63	713	271
2020–21	2.41	659	273
2021–22	2.30	1,575	683
2022–23	2.34	2,195	939

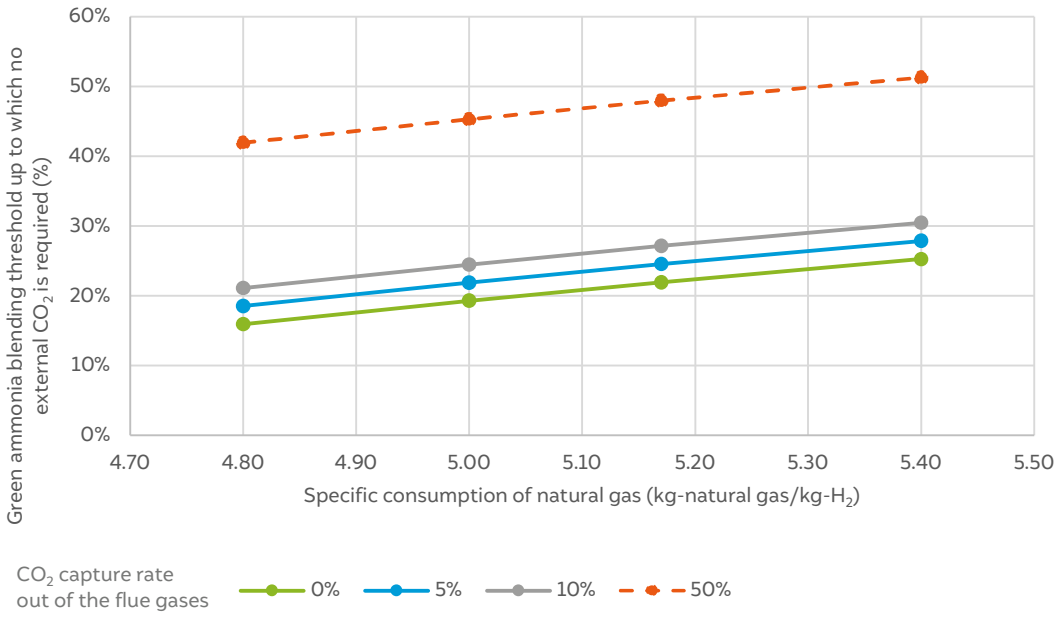
Source: Department of Commerce (n.d.)

Annexure 2

We estimate the threshold for blending green ammonia without adding external CO_2 to range between 16 per cent and 30 per cent if a maximum of 10 per cent capture rate of the CO_2 from flue gases is considered. This range is dependent on the specific natural gas consumption for urea production and the capture rate of CO_2 out of the flue gases emerging from the heating units. The higher the specific natural gas consumption per unit of urea produced, the higher the availability of CO_2. Capturing CO_2 out of flue gases requires capturing at low concentrations, which increases the costs substantially. Hence, we have modelled scenarios that consider a capture of at most 10 per cent. We have also indicated the calculated limits in an aggressive scenario where up

to 50 per cent of the CO_2 from flue gases gets captured. Based on inputs from industry experts, we have considered a nearly 100 per cent capture rate of CO_2 from the reformers.

Figure A1 Green ammonia can be blended in urea production up to a threshold of 16% to 30% with minimal CO_2 captured out of the flue gas



Source: Authors' analysis

Assumptions used in estimating the threshold for green ammonia blending when no external CO_2 is required are presented in Table A6.

Table A6 Key assumptions in the estimation of the threshold for green ammonia blending when no external CO_2 is required

Particulars	Unit	Value	Remarks
Total urea production	kg	100	Indexed to 100
Stoichiometric hydrogen requirement	kg	10	Stoichiometry
Stoichiometric ammonia requirement	kg	57	Stoichiometry
Stoichiometric CO_2 absorbed during urea manufacturing	kg	73	Stoichiometry
Specific consumption of natural gas as feedstock and fuel	kg natural gas/kg H_2	5.17	Based on the current analysis of consumption in the Indian fertiliser sector
Specific consumption of natural gas as feedstock	kg natural gas/kg H_2	3.4	Based on (IEAGHG 2017)
Specific consumption of natural gas as fuel	kg natural gas/kg H_2	1.77	Calculation
Production of CO_2 by reforming or combustion of natural gas	kg CO_2/kg NG	2.75	Stoichiometry

Source: Authors' analysis

Annexure 3

We present the key assumptions used in estimating the incremental cost of hydrogen in Sections 4.3 and 4.4 in Table A7 and Table A8. CO_2 costs are only factored in for the case of urea as CO_2 is not required in non-urea fertiliser production. The base case CO_2 costs for capture are taken from Baylin-Stern and Berghout (2021), and transport and handling costs are taken from Smith et al. (2021). Full capacity production is assumed for urea, whereas average production levels in the period between FY 2019–20 and FY 2022–23 are assumed for non-urea fertiliser production to factor in yearly variations in the product mix.

Table A7 Assumptions in estimating the incremental cost of blended ammonia for urea production

Particulars	Value	Unit
Total production capacity of urea	28.3	MTPA
Total ammonia requirement for urea production	16	MTPA
Specific CO_2 consumption for urea production	0.73	kg-CO_2/kg-urea
Market price of CO_2 (base case)	50	USD/tonne
Cost of CO_2 delivery (base case)	15	USD/tonne
Market price of CO_2 (aggressive case)	20	USD/tonne
Cost of CO_2 delivery (aggressive case)	5	USD/tonne
USD:INR exchange rate	1:80	USD:INR

Source: Authors' analysis

Table A8 Assumptions in estimating the incremental cost of blended ammonia for non-urea fertiliser production

Particulars	Value	Unit
Total ammonia requirement for non-urea fertiliser production	2.85	MTPA
USD:INR exchange rate	1:80	USD:INR

Source: Authors' analysis