Results and Model Validation

Levelized Cost of Hydrogen: LCOH

Levelized Cost of Ammonia: LCOA

Levelized Cost of Carbon Dioxide: $LCOCO_2$

Levelized Cost of Urea: LCOU

					Local Natural Gas		Imported Natural Gas	
	Current/ 2025	\$2/kg H_2	\$560/t NH_3	\$1/kg H_2	Grey	Blue	Grey	Blue
LCOH	\$4,007	\$2,000		\$1,000				
LCOA	\$1,239	\$882	\$560	\$704				
$LCOCO_2$	\$1,097	\$977	\$869	\$917				
LCOU	\$1,800	\$1,432	\$1,100	\$1,249	\$347	\$457	\$557	\$657

Table S1: Levelized cost of product at facility gate with no additional expenditures or profit margins. All values shown in 2025 USD.

Validation of Green Chemical Costs

Obtained intermediate values for green hydrogen, green ammonia, and direct air capture (DAC) carbon dioxide align closely with real observed costs of products using the same technologies.

Green Hydrogen (\$4/kg):

- The U.S. Department of Energy's December 2024 Hydrogen Liftoff Report updates cost estimates for electrolytic hydrogen from \$3-6/kg in the March 2023 report to \$5-7/kg in the up-to-date version.
- The U.S. National Renewable Energy Laboratory's 2024 Updated PEM Manufacturing Costs estimates hydrogen produced from proton exchange membrane (PEM) electrolyzers to be \$5-6/kg.

Green Ammonia (\$1,200/t):

- Market forecasts for 2030 from Argus Media report the lowest price of green ammonia to be \$1,080/t with prices getting as high as \$2,800/t.

DAC CO_2 ($1,097):

Carbon dioxide captured using exclusively renewable energy, as modeled in this study, is not common practice; rather, much of current DAC uses fossil fuels in some capacity to meet thermal energy needs. Reports for traditional DAC costs are $500-1000/t.

- Climeworks' Orca plant reports costs above $1,000/t
- Herzog reports $1,200/t prices for a DAC facility with negative emissions

Validation of Grey/Blue Urea Costs

The price for imported natural gas was assumed to be $12.50/MMBtu to align with natural gas prices in import-heavy nations like Japan and South Korea.

The price for local natural gas used in calculations was assumed equal to the natural gas price set by Nigeria's Midstream and Domestic Petroleum Regulatory Authority, USD $2.42/MMBtu. Close alignment between simulated urea production costs and real Nigerian retail urea prices substantiates the accuracy of the model (see Figure 3 in the main text).

Variable Assumptions & Methodology

Converting From Facility-Gate to Retail Prices

An additional $100/t were added to calculated LCOU values to account for additional expenses of transport, logistics, and profit margins. $100/t was obtained from assessing the average difference between historical free on board (fob) costs for urea produced in Nigeria and retail urea prices in Nigeria (Figure S1).

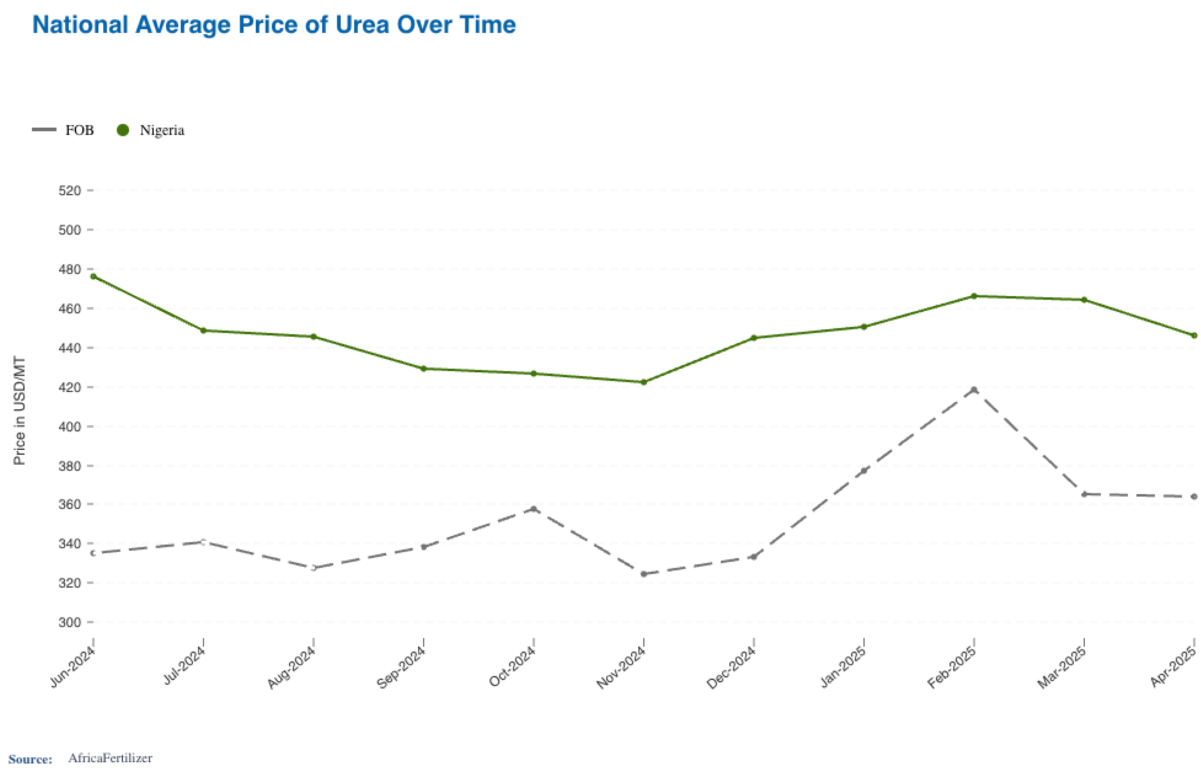

Figure S1: Historical fob and retail prices of urea in Nigeria obtained from AfricaFertilizer.

Methodology & Main Sources

Physical operating parameters of hydrogen production, ammonia synthesis, direct air capture (DAC), and urea synthesis were obtained from various academic publications that utilize chemical engineering computational simulation programs.

Hydrogen: Joana Sousa, Wendelin Waiblinger, and Kaspar Andreas Friedrich, *Techno-economic Study of an Electrolysis-Based Green Ammonia Production Plant* and NREL's Updated Manufactured Cost Analysis for Proton Exchange Membrane Water Electrolyzers
Ammonia: Joana Sousa, Wendelin Waiblinger, and Kaspar Andreas Friedrich, *Techno-economic Study of an Electrolysis-Based Green Ammonia Production Plant*
DAC and Green Urea: Albert Pujol, Mads Heuckendorff, Thomas Helmer Pedersen, *Techno-economic analysis of two novel direct air capture-to-urea concepts based on process intensification*
Grey/Blue Urea: IEA Greenhouse Gas Research & Development Program

In the absence of detailed first-hand data, the financial analyses performed in these studies were supplemented by economic evaluation procedures outlined in Towler & Sinnott, *Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design* that account for the unique operations and finances of chemical facilities. Such auxiliary variables that add onto the bare module costs of the primary process equipment include inside battery limit (ISBL) and outside battery limit (OSBL) costs outlined below.

ISBL variables:

- Equipment erection
- Piping
- Instrumentation & control
- Electrical systems
- Civil costs
- Structures & buildings
- Lagging & paint

OSBL variables:

- Offsite costs
- Design & engineering
- Contingency

The guidelines offered by Towler & Sinnott are still rough approximations meant for early-stage preliminary cost estimates of chemical manufacturing facilities. The specific calculations used for individual metrics are shown in the supplementary spreadsheet.

When necessary, financial and operational data from the simulation sources were adapted to account for the specific assumptions made for this model (e.g., calculating the catalyst mass in the ammonia synthesis reactor, modifying annual operating time, implementing a standard economic model).

Assumed Financial Variables

Utilities

Costs for electricity were assumed based on extremely low prices generated from renewables. Of salient mention is the lack of consideration for costs associated with interruptions in electricity supply, grid interconnection costs, and other costs associated with the utilization of variable renewable energy sources like solar and wind in sub-Saharan Africa's electric grid.

Electricity	USD/kWh	0.05
External Heat	USD/kWh	0.0496
Process Water	USD/m^3	0.2

Table S2: Utility prices used in the financial model

Operational & General Economic Variables

Levelized costs were obtained by setting the price of each chemical equal to the net production prices, including payments for upfront capital costs. A discount/interest rate of 8% was chosen to resemble the potential for more favorable rates offered by multilateral banks, development finance institutions, or special rates offered with government support. Real values are much higher in select sub-Saharan African countries, according to the World Bank.

Discount/Interest Rate	%	8
Project Operational Lifetime	Years	20
Capital Recovery Factor	n/a	0.102 (calculated)
Operating Time	Days/year	333
	Hours/day	24
	Hours/year	8000
Average Salary	$/year	25,000

Table S3: Operational & general economic assumptions used in the financial model

Process Diagrams of Primary Simulations

Green Hydrogen/Ammonia:

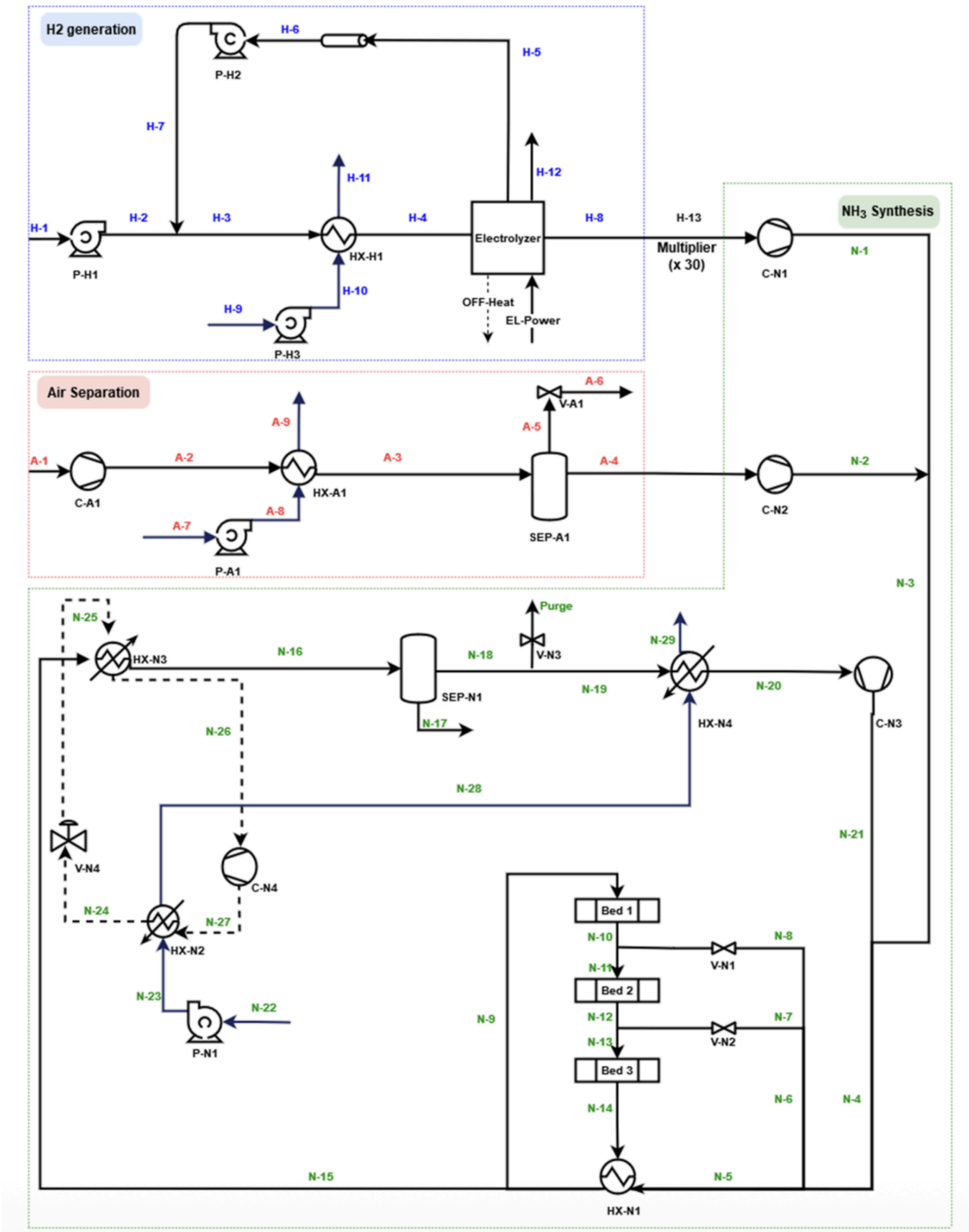

Figure S2: Process flow diagram for green hydrogen/ammonia production from [Sousa et al.](#)

DAC/Green Urea:

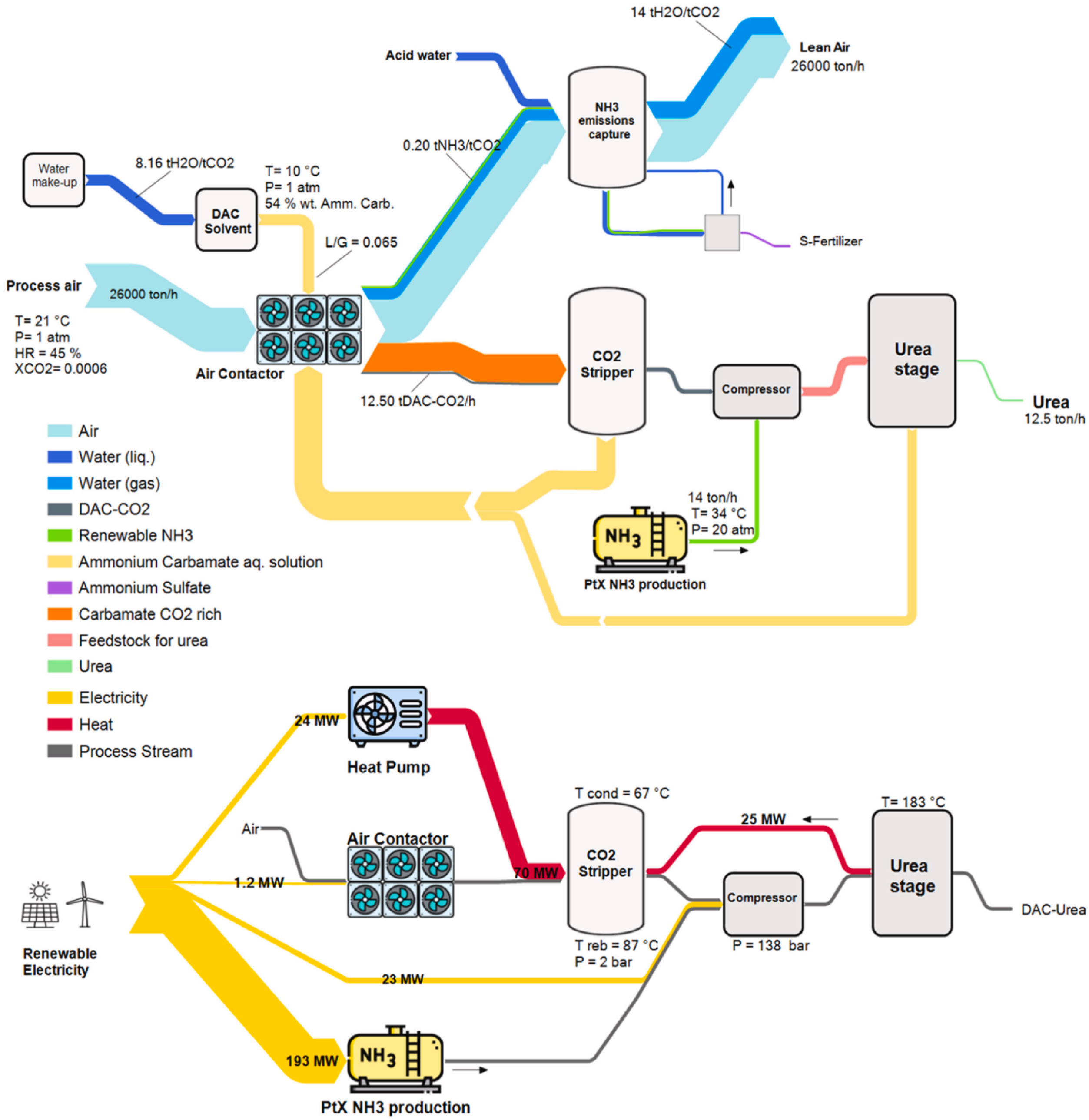

Figure S3: Process diagram for DAC and green urea production from Pujol et al.

Grey Urea:

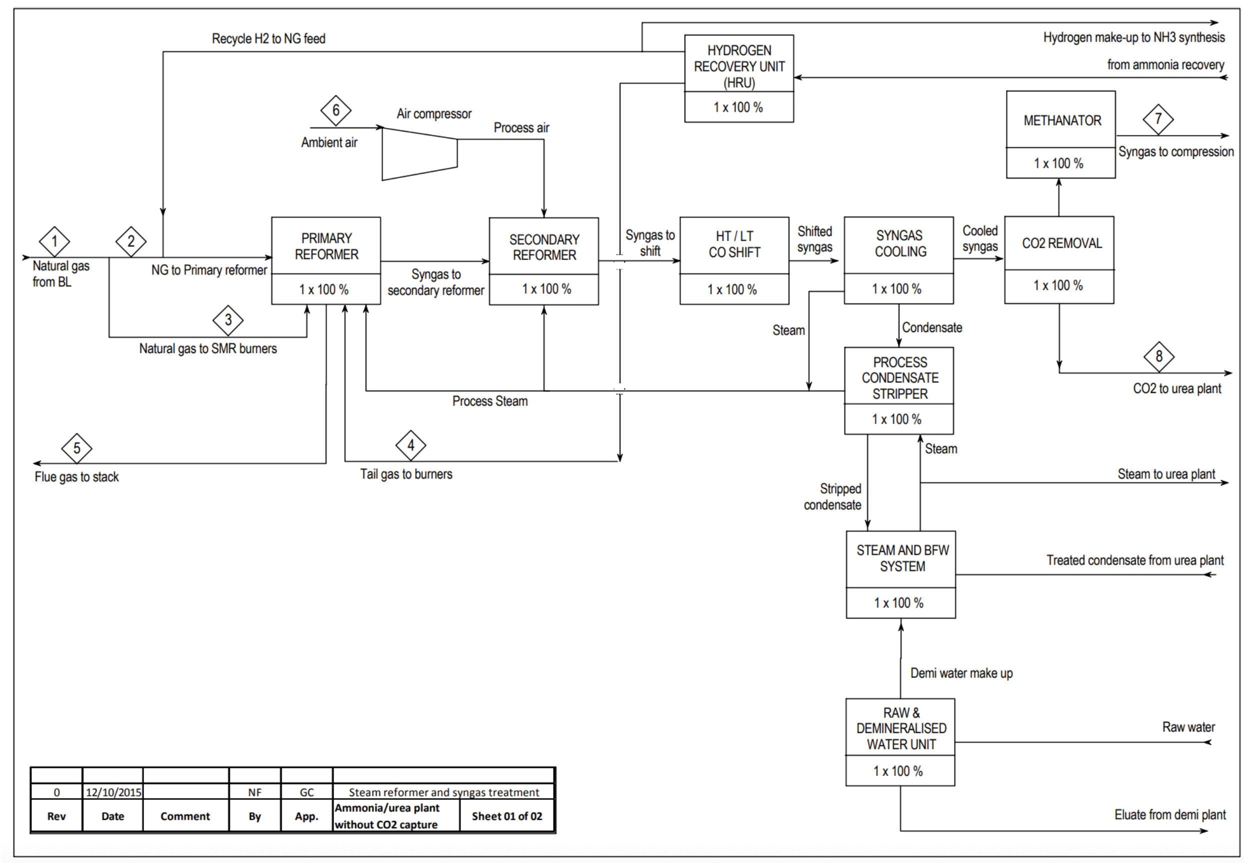

Figure S4a: Process diagram for grey urea production from IEAGHG

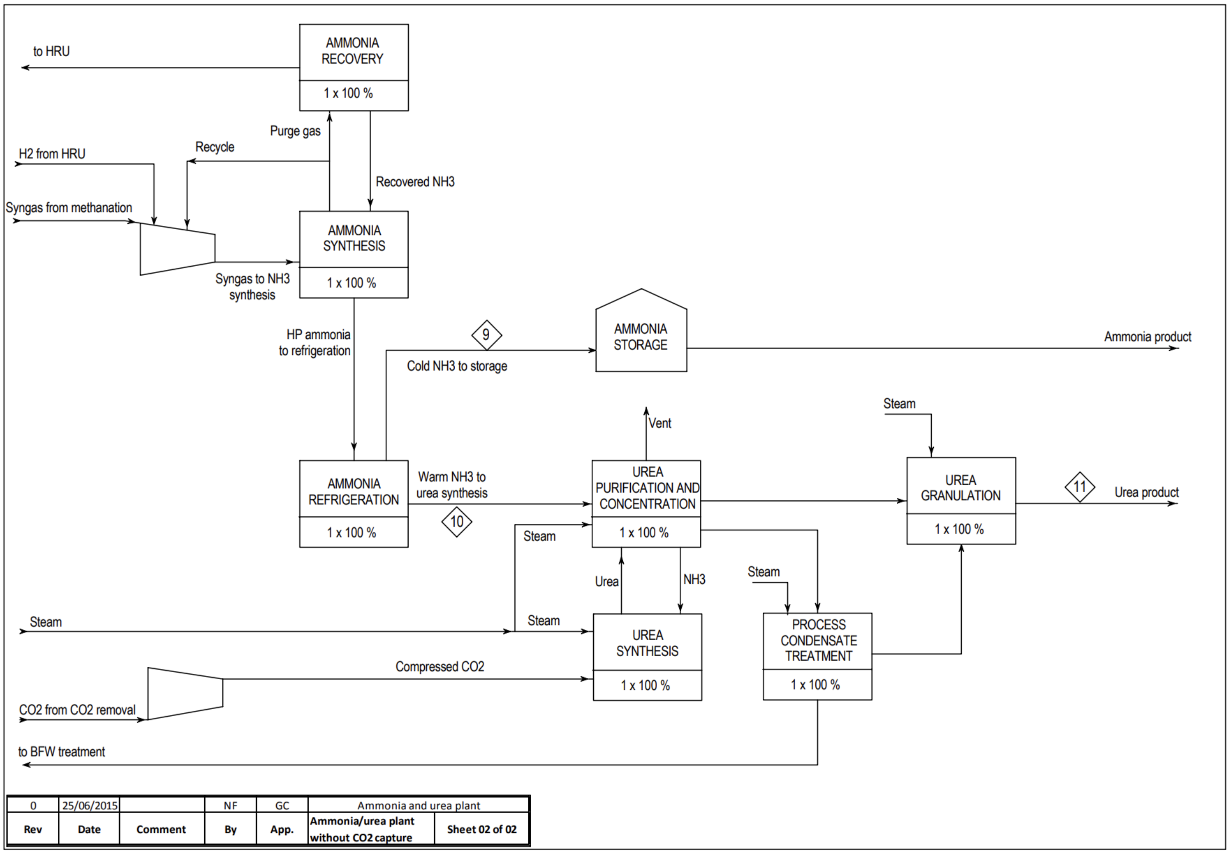

Figure S4b: Process diagram for grey urea production from IEAGHG

Blue Urea:

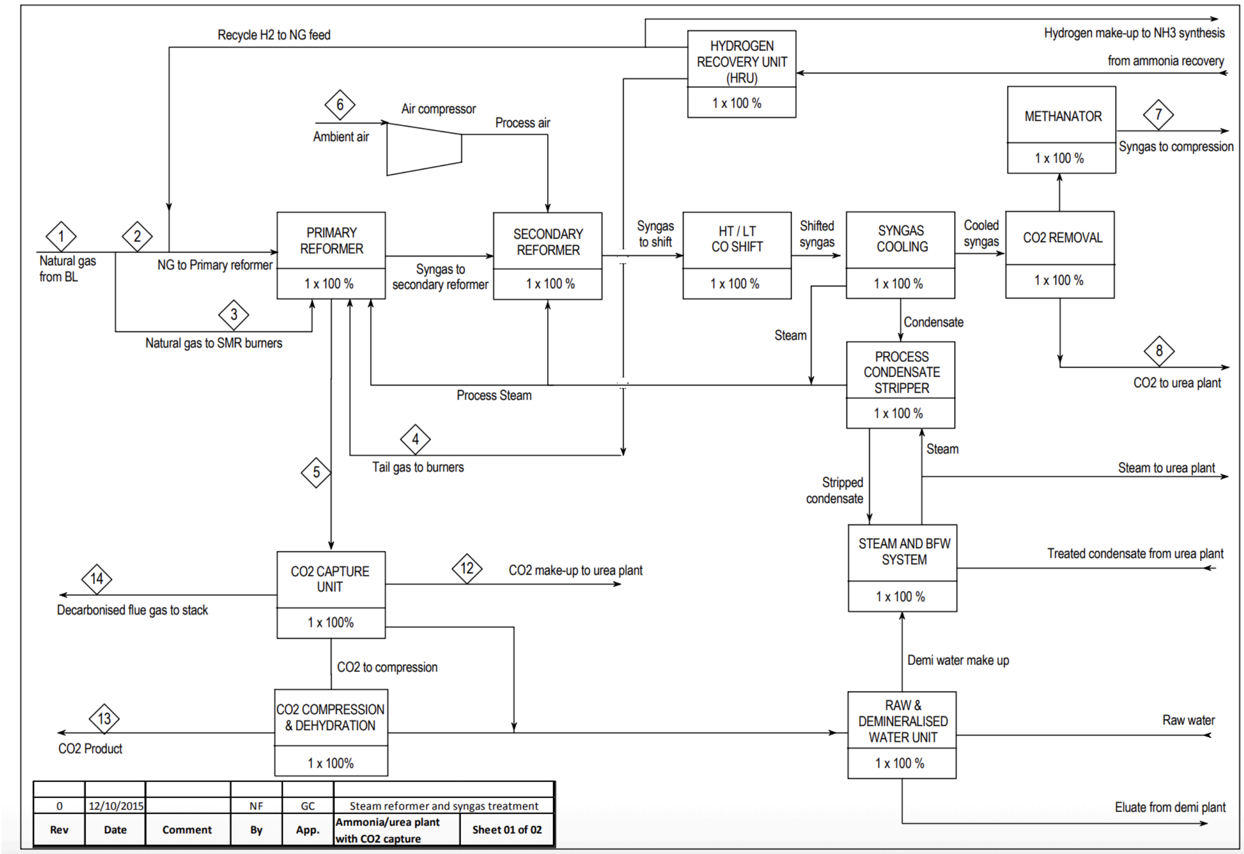

Figure S5a: Process diagram for blue urea production from IEAGHG

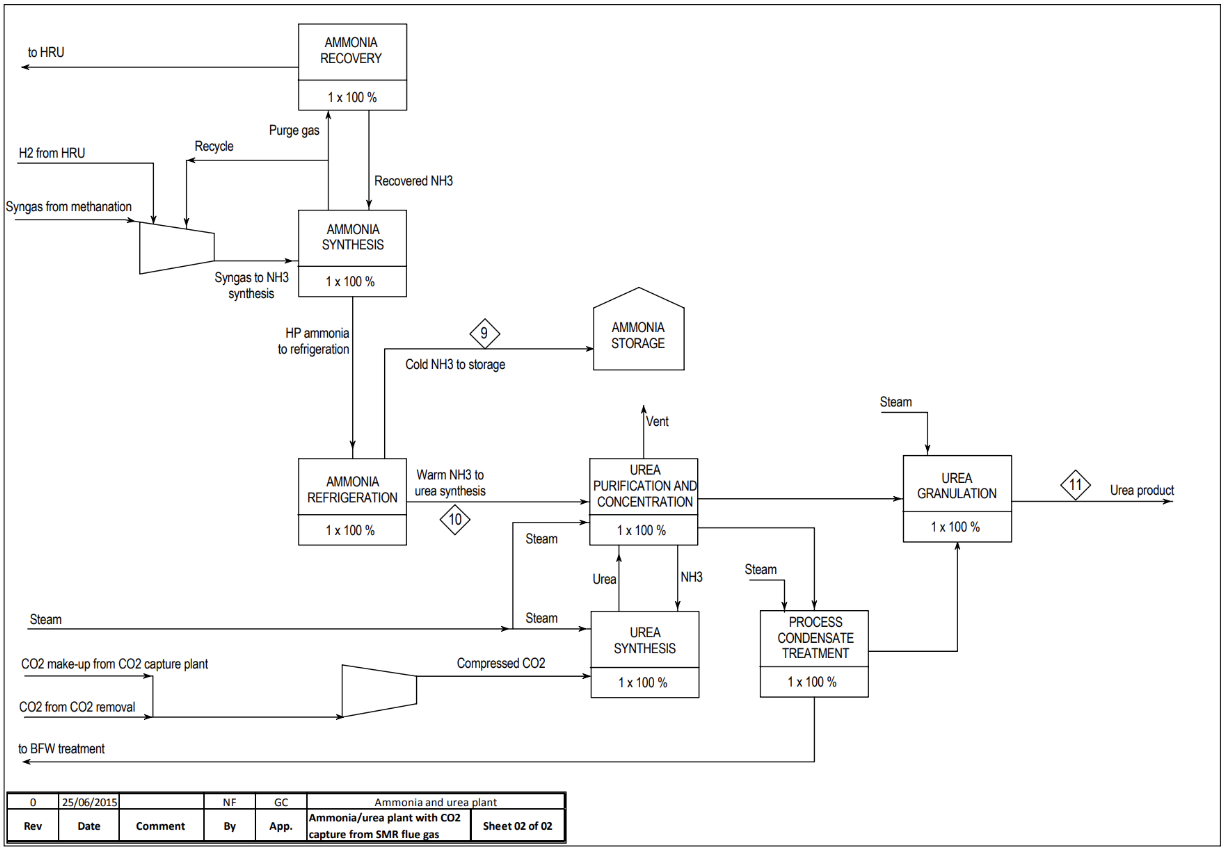

Figure S5b: Process diagram for blue urea production from [IEAGHG]