## Supplementary Material file for the article:

# Sustainability Analysis of Methane-to-Hydrogen-to-Ammonia Conversion by Integration of High-Temperature Plasma and Non-Thermal Plasma Processes

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This Supplementary Material file presents the results of the techno-economic analyses for each ammonia production pathway in which capital and operating costs and the unitary cost of ammonia production are detailed. The methods, references, and assumptions for the calculation process are described in the main article.

**Contents**

**Table S1**

*Capital costs for the Stand-alone (electrolyser-NTP) plant (106,000 t $NH_3$/year). NTP energy yield: 0.8 g $NH_3$/kWh*

| **CAPITAL COSTS** | **(US $2020)** | **(%)** | |
|---|---|---|---|
| **Purchase Cost of Equipment (PCE)** | **377,201,621** | 100% | |
| Heat exchangers | 1,018,542 | 0.3% | |
| Columns and vessels | 1,371,528 | 0.4% | |
| NTP reactor | 311,076,248 | 82.5% | |
| PSA unit | 2,369,389 | 0.6% | |
| PEM electrolyser | 61,365,913 | 16.3% | |
| **Direct costs** | **645,014,771** | Direct cost factors | |
| Purchase Cost of Equipment (PCE) | 377,201,621 | 100% | of PCE |
| Equipment installation | 94,300,405 | 25% | of PCE |
| Instrumentation/controls installation | 22,632,097 | 6% | of PCE |
| Piping installation | 37,720,162 | 10% | of PCE |
| Electrical systems installation | 37,720,162 | 10% | of PCE |
| Buildings | 37,720,162 | 10% | of PCE |
| Site development | 37,720,162 | 10% | of PCE |
| **Indirect costs** | **308,588,646** | Indirect cost factors | |
| Engineering and supervision | 32,250,739 | 5% | of direct costs |
| Construction expenses | 38,700,886 | 6% | of direct costs |
| Contractor fees | 79,212,340 | 21% | of PCE |
| Contingency fees | 158,424,681 | 42% | of PCE |
| **Fixed Capital Investment (FCI)** | **953,603,417** | Direct costs + Indirect costs | |
| Working Capital Investment (WCI) | 168,282,956 | 15% | of TCI |
| Total Capital Investment (TCI) | 1,121,886,373 | WCI + FCI | |

**Table S2**

*Operating costs for the Stand-alone (electrolyser-NTP) plant (106,000 t $NH_3$/year). NTP energy yield: 0.8 g $NH_3$/kWh*

| **OPERATING COSTS** | **Annual costs (US $2020)** | |
|---|---|---|
| **Raw materials** | **3,357,492** | |
| Deionised Water | 1,435,652 | Electrolyser |
| Catalysts | 1,921,841 | NTP reactor (1.39 g Fe/kg $NH_3$) |
| **Utilities** | **6,687,566,420** | |
| Electricity for Electrolyser | 53,239,819 | |
| Electricity for PSA unit | 498,291 | |
| Electricity for NTP | 6,632,261,000 | |
| Heat | 1,567,310 | |
| **Total variable costs** | **6,690,923,912** | Raw materials + Utilities |
| **Total fixed costs** | **50,787,378** | |
| Maintenance | 19,072,068 | 2% of FCI |
| Operating labour | 800,0 | Actuals ($) |

| | | |
|---|---|---|
| Plan overheads | 7,948,827 | 5% of total operating costs |
| Laboratory charges | 780,000 | 10% of operating labour |
| Insurance | 3,814,414 | 0.4% of FCI |
| Taxes and royalties | 19,072,068 | 2% of FCI |
| General expenses | 749,079,032 | 10% of total operating costs |
| **Total Operating costs** | **7,490,790,322** | Variable costs + Fixed Costs + General expenses |

**Table S3**

*Total annual costs for the Stand-alone (electrolyser-NTP) plant (106,000 t $NH_3$/year) by sections. NTP energy yield: 0.8 g $NH_3$/kWh*

| **Electrolysis section** | | **PSA section** | | **NTP section** | | **TOTAL (US$)** |
|---|---|---|---|---|---|---|
| **Annualised capital costs*** | **20,396,732** | | **787,535** | | **104,189,576** | **125,373,843** |
| **Capital costs** | **155,139,164** | | **5,990,053** | | **792,474,200** | |
| Electrolyser | 61,365,913 | PSA unit | 2,369,389 | Reactor and aux. | 313,466,319 | |
| Installation | 93,773,251 | Installation | 3,620,664 | Installation | 479,007,882 | |
| **Operating costs** | **69,233,090** | | **873,084** | | **7,420,684,149** | **7,490,790,322** |
| Process Water | 1,435,652 | | | Catalyst | 1,921,841 | |
| Electricity | 53,239,819 | Electricity | 498,291 | Electricity | 6,632,261,000 | |
| | | | | Heat | 1,567,310 | |
| Fixed & general | 14,557,619 | Fixed & general | 374,793 | Fixed & general | 784,933,998 | |
| **TOTAL** | **89,631,296** | | **1,660,632** | | **7,524,872,237** | **7,616,164,165** |

* Only the Fixed Capital Investment (FCI) is annualised because the Working Capital Investment (WCI) is recovered at the end of the project.

**Table S4**

*Unitary cost of production for the Stand-alone (electrolyser-NTP) plant (106,000 t $NH_3$/year) by sections. NTP energy yield: 0.8 g $NH_3$/kWh*

| **Section (cost type)** | | **Unitary cost of production (US$/t $NH_3$)** |
|---|---|---|
| Electrolysis section | $H_2$ production (capex) | 192 |

| | | |
|---|---|---|
| | $H_2$ production (opex) | 653 |
| PSA section | $N_2$ production (capex) | 7 |
| | $N_2$ production (opex) | 8 |
| NTP section | $NH_3$ synthesis (capex) | 983 |
| | $NH_3$ synthesis (opex) | 70,006 |
| | **TOTAL** | **71,851** |

**Table S5**

*Capital costs for the non-integrated HTP-NTP plant (106,000 t $NH_3$/year). NTP energy yield: 0.8 g $NH_3$/kWh*

| **CAPITAL COSTS** | **(US $2020)** | **(%)** | |
|---|---|---|---|
| **Purchase Cost of Equipment (PCE)** | **386,429,738** | 100% | |
| Heat exchangers | 1,018,542 | 0.3% | |
| Methanator | 10,296,599 | 2.7% | |
| NTP Reactor | 311,076,248 | 80.5% | |
| Columns and vessels | 1,371,528 | 0.4% | |
| PSA unit | 2,369,389 | 0.6% | |
| HTP reactors | 60,297,431 | 15.6% | |
| **Direct costs** | **660,794,851** | Direct cost factors | |
| Purchase Cost of Equipment (PCE) | 386,429,738 | 100% | of PCE |
| Equipment installation | 96,607,434 | 25% | of PCE |
| Instrumentation/controls installation | 23,185,784 | 6% | of PCE |
| Piping installation | 38,642,974 | 10% | of PCE |
| Electrical systems installation | 38,642,974 | 10% | of PCE |
| Buildings | 38,642,974 | 10% | of PCE |
| Site development | 38,642,974 | 10% | of PCE |
| **Indirect costs** | **316,138,168** | Indirect cost factors | |
| Engineering and supervision | 33,039,743 | 5% | of direct costs |
| Construction expenses | 39,647,691 | 6% | of direct costs |
| Contractor fees | 81,150,245 | 21% | of PCE |
| Contingency fees | 162,300,490 | 42% | of PCE |
| **Fixed Capital Investment (FCI)** | **976,933,020** | Direct costs + Indirect costs | |
| Working Capital Investment (WCI) | 172,399,945 | 15% | of TCI |
| Total Capital Investment (TCI) | 1,149,332,964 | WCI + FCI | |

**Table S6**

*Operating costs for the non-integrated HTP-NTP plant (106,000 t $NH_3$/year). NTP energy yield: 0.8 g $NH_3$/kWh*

| OPERATING COSTS | Annual costs (US $2020) | |
|---|---|---|
| **Raw materials** | **18,532,757** | |
| Natural gas | 16,334,049 | HTP reactors |
| Nickel | 276,896 | Methanator (0.0033 g Ni/kg $NH_3$) |
| Catalysts | 1,921,841 | NTP reactor (1.39 g Fe/kg $NH_3$) |
| **Utilities** | **6,660,794,329** | |
| Electricity for HTP | 26,467,728 | |
| Electricity for PSA unit | 498,291 | |
| Electricity for NTP | 6,632,261,000 | |
| Heat | 1,567,310 | |
| **Total variable costs** | **6,679,327,086** | Raw materials + Utilities |
| **Total fixed costs** | **52,000,517** | |
| Maintenance | 19,538,660 | 2% of FCI |
| Operating labour | 800,000 | Actuals ($) |
| Plan overheads | 8,135,464 | 5% of total operating costs |
| Laboratory charges | 80,000 | 10% of operating labour |
| Insurance | 3,907,732 | 0.4% of FCI |
| Taxes and royalties | 19,538,660 | 2% of FCI |
| General expenses | 747,925,289 | 10% of total operating costs |
| **Total Operating costs** | **7,490,790,322** | Variable costs + Fixed Costs + General expenses |
| Credits | 58,210,308 | Carbon black co-product |
| **Total Operating costs (-credits)** | **7,421,042,585** | Total operating cost - credits |

**Table S7**

*Total annual costs for the non-integrated HTP-NTP plant (106,000 t $NH_3$/year) by sections. NTP energy yield: 0.8 g $NH_3$/kWh*

| HTP section | | PSA section | | NTP section | | TOTAL (US$) |
|---|---|---|---|---|---|---|
| **Annualised capital costs*** | **23,463,963** | | **78,535** | | **104,189,576** | **128,441,074** |
| **Capital costs** | **178,468,766** | | **5,990,053** | | **792,474,200** | |
| HTP reactors | 70,594,029 | PSA unit | 2,369,389 | Reactor and aux. | 313,466,319 | |
| Installation | 107,874,736 | Installation | 3,620,664 | Installation | 479,007,882 | |
| **Operating costs** | **57,402,052** | | **87,2928** | | **7,420,977,913** | **7,479,252,893** |
| Methane | 16,334,049 | | | Catalyst | 1,921,812 | |
| Electricity | 26,467,728 | Electricity | 498,291 | Electricity | 6,632,261,000 | |
| Nickel catalyst | 276,896 | | | Heat | 1,567,310 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Fixed & general | 14,323,379 | Fixed & general | 374,637 | Fixed & general | 785,227,790 | |
| Carbon black credits | -58,210,308 | | | | | |
| **TOTAL** | **22,655,707** | | **1,660,463** | | **7,525,167,489** | **7,549,483,659** |

* Only the Fixed Capital Investment (FCI) is annualised because the Working Capital Investment (WCI) is recovered at the end of the project.

**Table S8**

*Unitary cost of production for the non-integrated HTP-NTP plant (106,000 t $NH_3$/year) by sections. NTP energy yield: 0.8 g $NH_3$/kWh*

| Section (cost type) | | Unitary cost of production (US$/t $NH_3$) |
|---|---|---|
| HTP section | $H_2$ production (capex) | 221 |
| | $H_2$ production (opex) | 542 |
| PSA section | $N_2$ production (capex) | 7 |
| | $N_2$ production (opex) | 8 |
| NTP section | $NH_3$ synthesis (capex) | 983 |
| | $NH_3$ synthesis (opex) | 70,009 |
| Credits | Carbon black | -549 |
| | **TOTAL** | **71,222** |

**Table S9**

*Capital costs for the integrated HTP-NTP plant (106,000 t $NH_3$/year). NTP energy yield: 1.09 g $NH_3$/kWh*

| CAPITAL COSTS | (US $2020) | (%) |
|---|---|---|
| **Purchase Cost of Equipment (PCE)** | **333,798,611** | 100% |
| Heat exchangers | 1,018,542 | 0.3% |
| Methanator | 10,296,599 | 3.1% |
| NTP Reactor | 258,445,122 | 77.4% |
| Columns and vessels | 1,371,528 | 0.4% |
| PSA unit | 2,369,389 | 0.7% |
| HTP reactors | 60,297,431 | 18.1% |
| **Direct costs** | **570,795,62** | Direct cost factors |

| | 5 | | |
|---|---|---|---|
| Purchase Cost of Equipment (PCE) | 333,798,611 | 100% | of PCE |
| Equipment installation | 83,449,653 | 25% | of PCE |
| Instrumentation/controls installation | 20,027,917 | 6% | of PCE |
| Piping installation | 33,379,861 | 10% | of PCE |
| Electrical systems installation | 33,379,861 | 10% | of PCE |
| Buildings | 33,379,861 | 10% | of PCE |
| Site development | 33,379,861 | 10% | of PCE |
| **Indirect costs** | **273,080,644** | Indirect cost factors | |
| Engineering and supervision | 28,539,781 | 5% | of direct costs |
| Construction expenses | 34,247,738 | 6% | of direct costs |
| Contractor fees | 70,097,708 | 21% | of PCE |
| Contingency fees | 140,195,417 | 42% | of PCE |
| **Fixed Capital Investment (FCI)** | **843,876,269** | Direct costs + Indirect costs | |
| Working Capital Investment (WCI) | 148,919,342 | 15% | of TCI |
| Total Capital Investment (TCI) | 992,795,610 | WCI + FCI | |

**Table S10**

*Operating costs for the integrated HTP-NTP plant (106,000 t $NH_3$/year). NTP energy yield: 1.09 g $NH_3$/kWh*

| **OPERATING COSTS** | **Annual costs (US $2020)** | |
|---|---|---|
| **Raw materials** | **18,532,757** | |
| Natural gas | 16,334,049 | HTP reactors |
| Nickel | 276,896 | Methanator (0.0033 g Ni/kg $NH_3$) |
| Catalysts | 1,921,841 | NTP reactor (1.39 g Fe/kg $NH_3$) |
| **Utilities** | **4,896,612,340** | |
| Electricity for HTP | 26,467,728 | |
| Electricity for PSA unit | 498,291 | |
| Electricity for NTP | 4,869,646,321 | |
| **Total variable costs** | **4,915,145,097** | Raw materials + Utilities |
| **Total fixed costs** | **45,081,566** | |
| Maintenance | 16,877,525 | 2% of FCI |
| Operating labour | 800,000 | Actuals ($) |
| Plan overheads | 7,071,010 | 5% of total operating costs |
| Laboratory charges | 80,000 | 10% of operating labour |
| Insurance | 3,375,505 | 0.4% of FCI |
| Taxes and royalties | 16,877,525 | 2% of FCI |
| General expenses | 551,136,296 | 10% of total operating costs |
| **Total Operating costs** | **5,511,362,959** | Variable costs + Fixed Costs + General expenses |
| Credits | 58,210,308 | Carbon black co-product |
| **Total Operating costs (-credits)** | **5,453,152,651** | Total operating cost - credits |

**Table S11**

*Total annual costs for the integrated HTP-NTP plant (106,000 t $NH_3$/year) by sections. NTP energy yield: 1.09 g $NH_3$/kWh*

| | **HTP section** | **PSA section** | **NTP section** | **TOTAL (US$)** |
|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| **Annualised capital costs*** | **23,463,963** | | **78,7535** | | **86,696,103** | **110,947,600** |
| **Capital costs** | **178,468,766** | | **5,990,053** | | **659,417,449** | |
| HTP reactors | 70,594,029 | PSA unit | 2,369,389 | Reactor and aux. | 260,835,192 | |
| Installation | 107,874,736 | Installation | 3,620,664 | Installation | 398,582,257 | |
| **Operating costs** | **57,443,254** | | **874,165** | | **5,453,045,540** | **5,511,362,959** |
| Methane | 16,334,049 | | | Catalyst | 1,921,812 | |
| Electricity | 26,467,728 | Electricity | 498,291 | Electricity | 4,869,646,321 | |
| Nickel catalyst | 276,896 | | | | | |
| Fixed & general | 14,364,581 | Fixed & general | 375,874 | Fixed & general | 581,477,407 | |
| Carbon black credits | -58,210,308 | | | | | |
| **TOTAL** | **22,696,909** | | **1,661,700** | | **5,539,741,642** | **5,564,100,251** |

* Only the Fixed Capital Investment (FCI) is annualised because the Working Capital Investment (WCI) is recovered at the end of the project.

**Table S12**

*Unitary cost of production for the integrated HTP-NTP plant (106,000 t $NH_3$/year) by sections. NTP energy yield: 1.09 g $NH_3$/kWh*

| Section (cost type) | | Unitary cost of production (US$/t $NH_3$) |
|---|---|---|
| HTP section | $H_2$ production (capex) | 221 |
| | $H_2$ production (opex) | 542 |
| PSA section | $N_2$ production (capex) | 7 |
| | $N_2$ production (opex) | 8 |
| NTP section | $NH_3$ synthesis (capex) | 818 |
| | $NH_3$ synthesis (opex) | 51,444 |
| Credits | Carbon black | -549 |
| | **TOTAL** | **52,492** |

**Table S13**

*Capital costs for the integrated HTP-NTP plant (106,000 t $NH_3$/year). NTP energy yield: 35.7 g $NH_3$/kWh*

| **CAPITAL COSTS** | **(US $2020)** | **(%)** | |
|---|---|---|---|
| **Purchase Cost of Equipment (PCE)** | **108,108,456** | 100% | |
| Heat exchangers | 1,018,542 | 0.9% | |
| Methanator | 10,296,599 | 9.5% | |
| NTP Reactor | 32,754,967 | 30.3% | |
| Columns and vessels | 1,371,528 | 1.3% | |
| PSA unit | 2,369,389 | 2.2% | |
| HTP reactors | 60,297,431 | 55.8% | |
| **Direct costs** | **184,865,460** | Direct cost factors | |
| Purchase Cost of Equipment (PCE) | 108,108,456 | 100% | of PCE |
| Equipment installation | 27,027,114 | 25% | of PCE |
| Instrumentation/controls installation | 6,486,507 | 6% | of PCE |
| Piping installation | 10,810,846 | 10% | of PCE |
| Electrical systems installation | 10,810,846 | 10% | of PCE |
| Buildings | 10,810,846 | 10% | of PCE |
| Site development | 10,810,846 | 10% | of PCE |
| **Indirect costs** | **88,443,528** | Indirect cost factors | |
| Engineering and supervision | 9,243,273 | 5% | of direct costs |
| Construction expenses | 11,091,928 | 6% | of direct costs |
| Contractor fees | 22,702,776 | 21% | of PCE |
| Contingency fees | 45,405,552 | 42% | of PCE |
| **Fixed Capital Investment (FCI)** | **273,308,988** | Direct costs + Indirect costs | |
| Working Capital Investment (WCI) | 48,230,998 | 15% | of TCI |
| Total Capital Investment (TCI) | 321,539,986 | WCI + FCI | |

**Table S14**

*Operating costs for the integrated HTP-NTP plant (106,000 t $NH_3$/year). NTP energy yield: 35.7 g $NH_3$/kWh*

| **OPERATING COSTS** | **Annual costs (US $2020)** | |
|---|---|---|
| **Raw materials** | **18,532,757** | |
| Natural gas | 16,334,049 | HTP reactors |
| Nickel | 276,896 | Methanator (0.0033 g Ni/kg $NH_3$) |
| Catalysts | 1,921,841 | NTP reactor (1.39 g Fe/kg $NH_3$) |
| **Utilities** | **182,686,402** | |
| Electricity for HTP | 26,467,728 | |
| Electricity for PSA unit | 498,291 | |
| Electricity for NTP | 155,720,384 | |
| **Total variable costs** | **201,219,160** | Raw materials + Utilities |
| **Total fixed costs** | **15,412,067** | |
| Maintenance | 5,466,180 | 2% of FCI |
| Operating labour | 800,000 | Actuals ($) |
| Plan overheads | 2,506,472 | 5% of total operating costs |
| Laboratory charges | 80,000 | 10% of operating labour |
| Insurance | 1,093,236 | 0.4% of FCI |
| Taxes and royalties | 5,466,180 | 2% of FCI |
| General expenses | 24,070,136 | 10% of total operating costs |
| **Total Operating costs** | **240,701,363** | Variable costs + Fixed Costs + General expenses |
| Credits | 58,210,308 | Carbon black co-product |
| **Total Operating costs (-credits)** | **182,491,056** | Total operating cost - credits |

**Table S15**
*Total annual costs for the integrated HTP-NTP plant (106,000 t $NH_3$/year) by sections. NTP energy yield: 35.7 g $NH_3$/kWh*

| | HTP section | | PSA section | | NTP section | | TOTAL (US$) |
|---|---|---|---|---|---|---|---|
| **Annualised capital costs*** | **23,463,963** | | **787,535** | | **11,681,467** | | **35,932,965** |
| **Capital costs** | **178,468,766** | | **5,990,053** | | **88,850,169** | | |
| HTP reactors | 70,594,029 | PSA unit | 2,369,389 | Reactor and aux. | 35,145,037 | | |
| Installation | 107,874,736 | Installation | 3,620,664 | Installation | 53,705,132 | | |
| **Operating costs** | **58,295,776** | | **895,680** | | **181,509,908** | | **240,701,363** |
| Methane | 16,334,049 | | | Catalyst | 1,921,812 | | |
| Electricity | 26,467,728 | Electricity | 498,291 | Electricity | 155,720,384 | | |
| Nickel catalyst | 276,896 | | | | | | |
| Fixed & general | 15,217,102 | Fixed & general | 397,389 | Fixed & general | 23,867,712 | | |
| Carbon black credits | -58,210,308 | | | | | | |
| **TOTAL** | **23,549,431** | | **1,683,215** | | **193,191,375** | | **218,424,021** |

* Only the Fixed Capital Investment (FCI) is annualised because the Working Capital Investment (WCI) is recovered at the end of the project.

**Table S16**
*Unitary cost of production for the integrated HTP-NTP plant (106,000 t $NH_3$/year) by sections. NTP energy yield: 35.7 g $NH_3$/kWh*

| Section | Cost type | Unitary cost of production (US$/t $NH_3$) |
|---|---|---|
| HTP section | $H_2$ production (capex) | 221 |
| | $H_2$ production (opex) | 550 |
| PSA section | $N_2$ production (capex) | 7 |
| | $N_2$ production (opex) | 8 |
| NTP section | $NH_3$ synthesis (capex) | 110 |
| | $NH_3$ synthesis (opex) | 1,712 |
| Credits | Carbon black | -549 |

| | | |
|---|---|---|
| **TOTAL** | **2,061** | |

**Table S17**

*Capital costs for the integrated HTP-NTP plant (106,000 t $NH_3$/year). NTP energy yield: 900 g $NH_3$/kWh*

| **CAPITAL COSTS** | **(US $2020)** | **(%)** | |
|---|---|---|---|
| **Purchase Cost of Equipment (PCE)** | **82,787,499** | 100% | |
| Heat exchangers | 1,018,542 | 1.2% | |
| Methanator | 10,296,599 | 12.4% | |
| NTP Reactor | 7,434,010 | 9.0% | |
| Columns and vessels | 1,371,528 | 1.7% | |
| PSA unit | 2,369,389 | 2.9% | |
| HTP reactors | 60,297,431 | 72.8% | |
| **Direct costs** | **141,566,624** | Direct cost factors | |
| Purchase Cost of Equipment (PCE) | 82,787,499 | 100% | of PCE |
| Equipment installation | 20,696,875 | 25% | of PCE |
| Instrumentation/controls installation | 4,967,250 | 6% | of PCE |
| Piping installation | 8,278,750 | 10% | of PCE |
| Electrical systems installation | 8,278,750 | 10% | of PCE |
| Buildings | 8,278,750 | 10% | of PCE |
| Site development | 8,278,750 | 10% | of PCE |
| **Indirect costs** | **67,728,453** | Indirect cost factors | |
| Engineering and supervision | 7,078,331 | 5% | of direct costs |
| Construction expenses | 8,493,997 | 6% | of direct costs |
| Contractor fees | 17,385,375 | 21% | of PCE |
| Contingency fees | 34,770,750 | 42% | of PCE |
| **Fixed Capital Investment (FCI)** | **209,295,077** | Direct costs + Indirect costs | |
| Working Capital Investment (WCI) | 36,934,425 | 15% | of TCI |
| Total Capital Investment (TCI) | 246,229,502 | WCI + FCI | |

**Table S18**

*Operating costs for the integrated HTP-NTP plant (106,000 t $NH_3$/year). NTP energy yield: 900 g $NH_3$/kWh*

| **OPERATING COSTS** | **Annual costs (US $2020)** | |
|---|---|---|
| **Raw materials** | **18,532,757** | |
| Natural gas | 16,334,049 | HTP reactors |
| Nickel | 276,896 | Methanator (0.0033 g Ni/kg $NH_3$) |
| Catalysts | 1,921,841 | NTP reactor (1.39 g Fe/kg $NH_3$) |
| **Utilities** | **40,115,908** | |
| Electricity for HTP | 26,467,728 | |
| Electricity for PSA unit | 498,291 | |
| Electricity for NTP | 13,149,889 | |
| **Total variable costs** | **58,648,665** | Raw materials + Utilities |
| **Total fixed costs** | **12,083,344** | |

| | | |
|---|---|---|
| Maintenance | 4,185,902 800,0 | 2% of FCI |
| Operating labour | 00 | Actuals ($) |
| Plan overheads | 1,994,361 80,0 | 5% of total operating costs |
| Laboratory charges | 00 | 10% of operating labour |
| Insurance | 837,180 | 0.4% of FCI |
| Taxes and royalties | 4,185,902 | 2% of FCI |
| General expenses | 7,859,112 | 10% of total operating costs |
| **Total Operating costs** | **78,591,121** | Variable costs + Fixed Costs + General expenses |
| Credits | 58,210,308 | Carbon black co-product |
| **Total Operating costs (-credits)** | **20,380,813** | Total operating cost - credits |

**Table S19**

*Total annual costs for the integrated HTP-NTP plant (106,000 t $NH_3$/year) by sections. NTP energy yield: 900 g $NH_3$/kWh*

| | **HTP section** | | **PSA section** | | **NTP section** | | **TOTAL (US$)** |
|---|---|---|---|---|---|---|---|
| **Annualised capital costs*** | **23,463,963** | | **7,535** | | **3,265,317** | | **27,516,814** |
| **Capital costs** | **178,468,766** | | **5,990,053** | | **24,836,258** | | |
| HTP reactors | 70,594,029 | PSA unit | 2,369,389 | Reactor and aux. | 9,824,080 | | |
| Installation | 107,874,736 | Installation | 3,620,664 | Installation | 15,012,177 | | |
| **Operating costs** | **59,154,988** | | **910,890** | | **18,525,243** | | **78,591,121** |
| Methane | 16,334,049 | | | Catalyst | 1,921,812 | | |
| Electricity | 26,467,728 | Electricity | 498,291 | Electricity | 13,149,889 | | |
| Nickel catalyst | 276,896 | | | | | | |
| Fixed & general | 16,076,315 | Fixed & general | 412,600 | Fixed & general | 3,453,542 | | |
| Carbon black credits | -58,210,308 | | | | | | |
| **TOTAL** | **24,408,643** | | **1,698,425** | | **21,790,559** | | **47,897,627** |

* Only the Fixed Capital Investment (FCI) is annualised because the Working Capital Investment (WCI) is recovered at the end of the project.

**Table S20**

*Unitary cost of production for the integrated HTP-NTP plant (106,000 t $NH_3$/year) by sections. NTP energy yield: 900 g $NH_3$/kWh*

| **Section (cost type)** | **Unitary cost of production** |
|---|---|

| | | (US$/t $NH_3$) |
|---|---|---|
| HTP section | $H_2$ production (capex) | 221 |
| | $H_2$ production (opex) | 558 |
| PSA section | $N_2$ production (capex) | 7 |
| | $N_2$ production (opex) | 9 |
| NTP section | $NH_3$ synthesis (capex) | 31 |
| | $NH_3$ synthesis (opex) | 175 |
| Credits | Carbon black | -549 |
| | **TOTAL** | **452** |

**Table S21**

*Capital costs for the conventional SMR-HB plant (106,000 t $NH_3$/year).*

| **CAPITAL COSTS*** | **(US $2020)** | **(%)** | |
|---|---|---|---|
| **Purchase Cost of Equipment (PCE)** | **31,925,974** | 100% | |
| Heat exchangers | 1,309,406 | 4.1% | |
| Columns and vessels | 2,686,506 | 8.4% | |
| Reactors | 1,497,849 | 4.7% | |
| Compressors and expanders | 26,318,385 | 82.4% | |
| Membrane | 113,829 | 0.4% | |
| **Direct costs** | **108,548,312** | Direct cost factors | |
| Purchase Cost of Equipment (PCE) | 31,925,974 | 100% | of PCE |
| Equipment installation | 15,005,208 | 47% | of PCE |
| Instrumentation/controls installation | 5,746,675 | 18% | of PCE |
| Piping installation | 21,071,143 | 66% | of PCE |
| Electrical systems installation | 3,511,857 | 11% | of PCE |
| Buildings | 5,746,675 | 18% | of PCE |
| Site development | 3,192,597 | 10% | of PCE |
| Utilities/services | 22,348,182 | 70% | of PCE |
| **Indirect costs** | **43,738,585** | Indirect cost factors | |
| Engineering and supervision | 10,535,571 | 33% | of direct costs |
| Construction expenses | 13,089,649 | 41% | of direct costs |
| Contractor fees | 6,704,455 | 21% | of PCE |
| Contingency fees | 13,408,909 | 42% | of PCE |
| **Fixed Capital Investment (FCI)** | **152,286,897** | Direct costs + Indirect costs | |
| Working Capital Investment (WCI) | 26,874,158 | 15% | of TCI |
| Total Capital Investment (TCI) | 179,161,055 | WCI + FCI | |

**Table S22**

*Operating costs for the conventional SMR-HB plant (106,000 t $NH_3$/year).*

| **OPERATING COSTS** | **Annual costs (US $2020)** | |
|---|---|---|
| **Raw materials** | **10,459,182** | **Consumption per kg $NH_3$** |
| Natural gas | 7,771,717 | 0.01833 MMBTU |
| Cobalt molybdenum | 621,305 | 0.00133 g |
| Zinc oxide | 254,776 | 0.01961 g |
| Nickel 1 | 692,333 | 0.00833 g |
| Nickel 2 | 553,977 | 0.00667 g |
| Chromium oxide | 91,195 | 0.01039 g |
| Copper oxide | 40,817 | 0.03098 g |
| Nickel 3 | 276,896 | 0.00333 g |
| Iron | 98,319 | 0.05294 g |
| Process Water | 57,846 | 0.00831 $m^3$ |
| **Utilities** | **17,071,849** | |
| Cooling | 4,459,986 | 0.68 $m^3$ |
| Electricity | 2,720,822 | 0.513 kWh |
| Steam | 3,559,683 | 1.84 kg |
| Heat | 6,331,358 | 0.018 GJ |
| **Total variable costs** | **27,531,041** | Raw materials + Utilities |
| **Total fixed costs** | **19,383,559** | |
| Maintenance | 7,614,345 | 5% of FCI |
| Operating labour | 1,400,000 | Actuals ($) |
| Supervision | 280,000 | 20% of operating labour |
| Plan overheads | 3,717,738 | 7% of total operating costs |
| Laboratory charges | 280,000 | 20% of operating labour |
| Operating supplies | 1,522,869 | 1% of FCI |
| Insurance | 1,522,869 | 1% of FCI |
| Taxes and royalties | 3,045,738 | 2% of FCI |

| | | |
|---|---|---|
| General expenses | 5,212,732 | 10% of total operating costs |
| **Total Operating costs** | **52,127,380** | Variable costs + Fixed Costs + General expenses |
| Credits 1 | 9,098,960 | Steam by-products |
| Credits 2 | 1,145,083 | Hydrogen by-products |
| **Total Operating costs (-credits)** | **41,883,279** | Total operating cost - credits |

**Table S23**

*Total annual costs for the conventional SMR-HB plant (106,000 t $NH_3$/year).*

| | SMR-HB costs | TOTAL (US$) |
|---|---|---|
| **Annualised capital costs*** | **20,021,733** | **20,021,733** |
| **Capital costs** | **152,286,897** | |
| Equipment costs | 31,925,974 | |
| Installation | 120,360,923 | |
| **Operating costs** | **52,127,322** | **52,127,322** |
| Materials | 10,459,182 | |
| Utilities | 17,071,849 | |
| Fixed & general | 24,596,291 | |
| Steam & $H_2$ credits | -10,244,043 | |
| **TOTAL** | **61,905,012** | **61,905,012** |

* Only the Fixed Capital Investment (FCI) is annualised because the Working Capital Investment (WCI) is recovered at the end of the project.

**Table S24**

*Unitary cost of production for the conventional SMR-HB plant (106,000 t $NH_3$/year)*

| Section (cost type) | | Unitary cost of production (US$/t $NH_3$) |
|---|---|---|
| SMR-HB | $NH_3$ production (capex) | 189 |
| | $NH_3$ production (opex) | 492 |
| Credits | Steam and $H_2$ by-products | -97 |
| | **TOTAL** | **584** |

**Table S25**

*Capital costs for the integrated (pre-separation) HTP-NTP plant (106,000 t $NH_3$/year). NTP energy yield: 35.7 g $NH_3$/kWh*

| **CAPITAL COSTS** | **(US $2020)** | **(%)** | |
|---|---|---|---|
| **Purchase Cost of Equipment (PCE)** | **114,553,900** | 100% | |
| Heat exchangers | 1,018,542 | 1% | |
| Membrane separator | 16,742,043 | 15% | |
| NTP Reactor | 32,754,967 | 29% | |
| Columns and vessels | 1,371,528 | 1% | |
| PSA unit | 2,369,389 | 2% | |
| HTP reactors | 60,297,431 | 53% | |
| **Direct costs** | **195,887,170** | Direct cost factors | |
| Purchase Cost of Equipment (PCE) | 114,553,900 | 100% | of PCE |
| Equipment installation | 28,638,475 | 25% | of PCE |
| Instrumentation/controls installation | 6,873,234 | 6% | of PCE |
| Piping installation | 11,455,390 | 10% | of PCE |
| Electrical systems installation | 11,455,390 | 10% | of PCE |
| Buildings | 11,455,390 | 10% | of PCE |
| Site development | 11,455,390 | 10% | of PCE |
| **Indirect costs** | **93,716,546** | Indirect cost factors | |
| Engineering and supervision | 9,794,358 | 5% | of direct costs |
| Construction expenses | 11,753,230 | 6% | of direct costs |
| Contractor fees | 24,056,319 | 21% | of PCE |
| Contingency fees | 48,112,638 | 42% | of PCE |
| **Fixed Capital Investment (FCI)** | **289,603,716** | Direct costs + Indirect costs | |

| | | |
|---|---|---|
| Working Capital Investment (WCI) | 51,106,538 | 15% of TCI |
| Total Capital Investment (TCI) | 340,710,254 | WCI + FCI |

**Table S26**

*Operating costs for the integrated (pre-separation) HTP-NTP plant (106,000 t $NH_3$/year). NTP energy yield: 35.7 g $NH_3$/kWh*

| **OPERATING COSTS** | **Annual costs (US $2020)** | |
|---|---|---|
| **Raw materials** | **18,255,861** | |
| Natural gas | 16,334,049 | HTP reactors |
| Catalysts | 1,921,841 | NTP reactor (1.39 g Fe/kg $NH_3$) |
| **Utilities** | **184,455,912** | |
| Electricity for HTP | 28,237,238 | |
| Electricity for PSA unit | 498,291 | |
| Electricity for NTP | 155,720,384 | |
| **Total variable costs** | **202,711,773** | Raw materials + Utilities |
| **Total fixed costs** | **16,259,393** | |
| Maintenance | 5,792,074 | 2% of FCI |
| Operating labour | 800,000 | Actuals ($) |
| Plan overheads | 2,636,830 | 5% of total operating costs |
| Laboratory charges | 80,000 | 10% of operating labour |
| Insurance | 1,158,415 | 0.4% of FCI |
| Taxes and royalties | 5,792,074 | 2% of FCI |
| General expenses | 24,330,130 | 10% of total operating costs |
| **Total Operating costs** | **243,301,296** | Variable costs + Fixed Costs + General expenses |
| Credits | 58,210,308 | Carbon black co-product |
| **Total Operating costs (-credits)** | **185,090,988** | Total operating cost - credits |

**Table S27**

*Total annual costs for the integrated (pre-separation) HTP-NTP plant (106,000 t $NH_3$/year) by sections. NTP energy yield: 35.7 g $NH_3$/kWh*

| | **HTP section** | | **PSA section** | | **NTP section** | **TOTAL (US$)** |
|---|---|---|---|---|---|---|
| **Annualised capital costs*** | **25,606,292** | | **787,535** | | **11,681,467** | **38,075,294** |
| **Capital costs** | **194,763,493** | | **5,990,053** | | **88,850,169** | |
| HTP reactors | 77,039,474 | PSA unit | 2,369,389 | Reactor and aux. | 35,145,037 | |
| Installation | 117,724,020 | Installation | 3,620,664 | Installation | 53,705,132 | |
| **Operating costs** | **60,855,600** | | **894,400** | | **181,551,295** | **243,301,296** |
| Methane | 16,334,049 | | | Catalyst | 1,921,812 | |
| Electricity | 28,237,238 | Electricity | 498,291 | Electricity | 155,720,384 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Fixed & general | 16,284,314 | Fixed & general | 396,110 | Fixed & general | 23,909,099 | |
| Carbon black credits | -58,210,308 | | | | | |
| **TOTAL** | **86,461,892** | | **1,681,935** | | **193,232,762** | **223,166,282** |

* Only the Fixed Capital Investment (FCI) is annualised because the Working Capital Investment (WCI) is recovered at the end of the project.

**Table S28**

*Unitary cost of production for the integrated (pre-separation) HTP-NTP plant (106,000 t $NH_3$/year) by sections. NTP energy yield: 35.7 g $NH_3$/kWh*

| Section (cost type) | | Unitary cost of production (US$/t $NH_3$) |
|---|---|---|
| HTP section | $H_2$ production (capex) | 242 |
| | $H_2$ production (opex) | 574 |
| PSA section | $N_2$ production (capex) | 7 |
| | $N_2$ production (opex) | 8 |
| NTP section | $NH_3$ synthesis (capex) | 110 |
| | $NH_3$ synthesis (opex) | 1,713 |
| Credits | Carbon black | -549 |
| | **TOTAL** | **2,105** |