# Green Hydrogen Fund (GHF)

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## Kozminski University

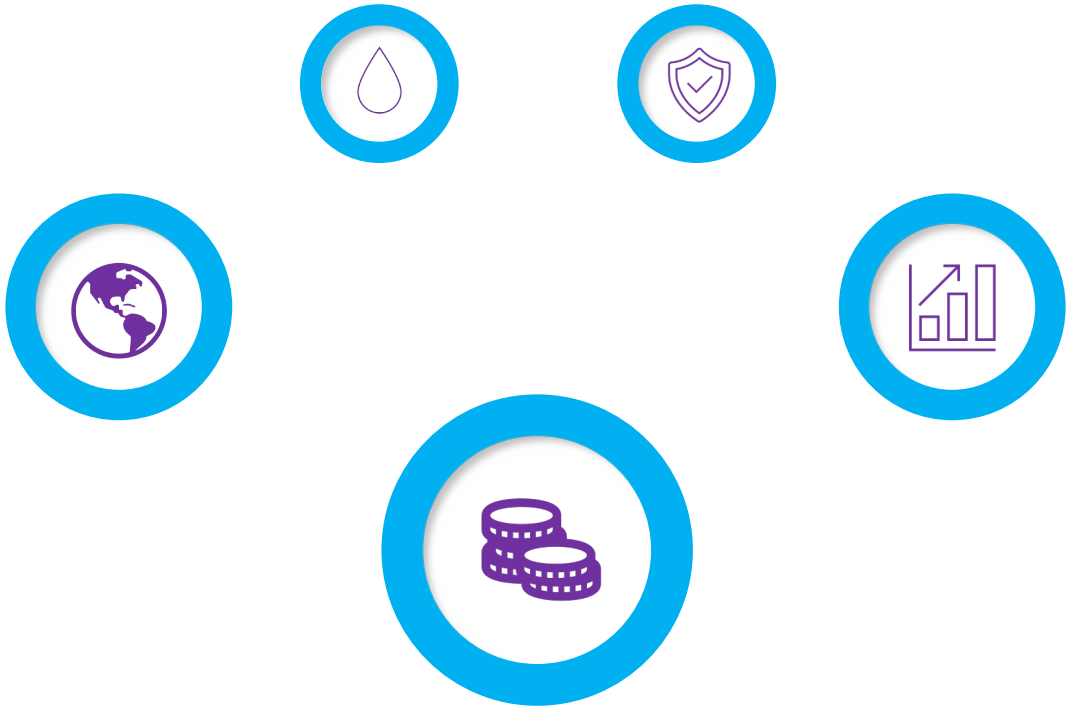
# Green Hydrogen Fund

## Investment in Rising Star Commodity

# Green Hydrogen Fund

## Scalable Solution with Real Impact

# Green Hydrogen Fund



## A New Way to Drive Competitive Returns

# Green Hydrogen Fund

## Supporting Financial Results

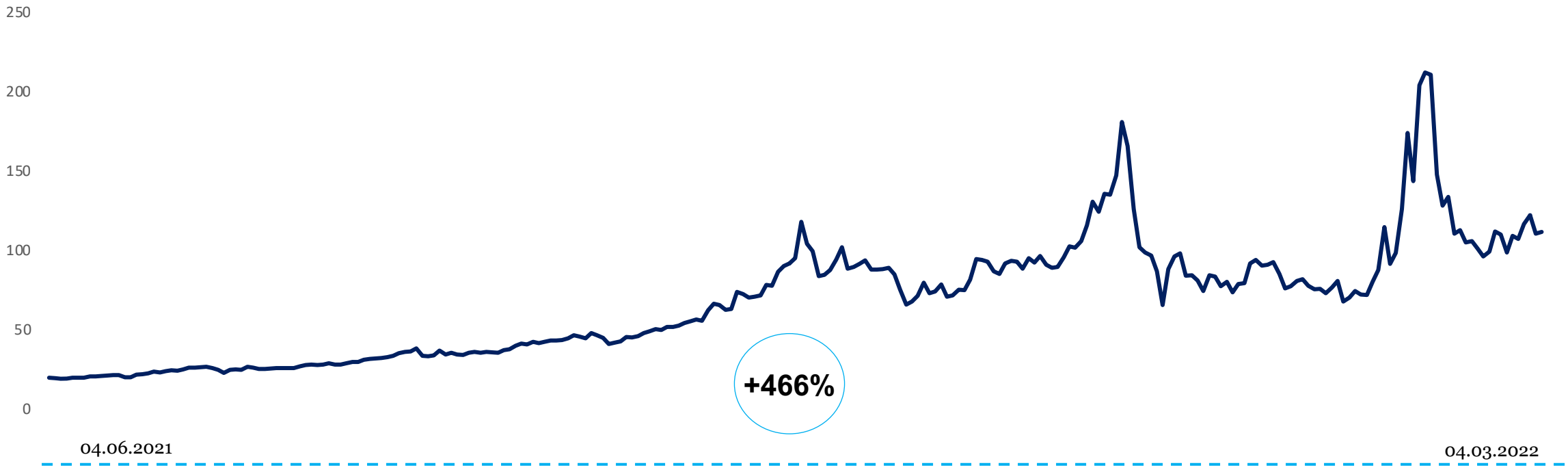
# Green Hydrogen Fund

## Sound Risk Management

# Challenge

## Russia's barbaric invasion of Ukraine exacerbated the problem of increased energy prices in Europe with prices for commodities including gas skyrocketing...

### Dutch TTF Gas Forward 1 Month, EUR/MWh

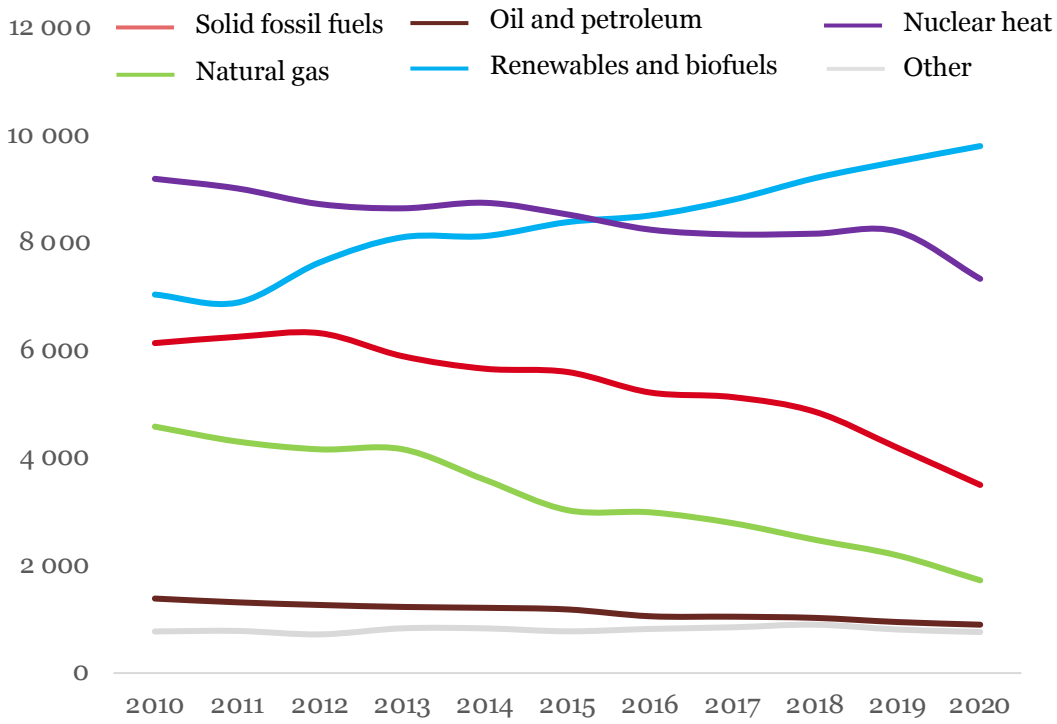



Source: Bloomberg (2022)

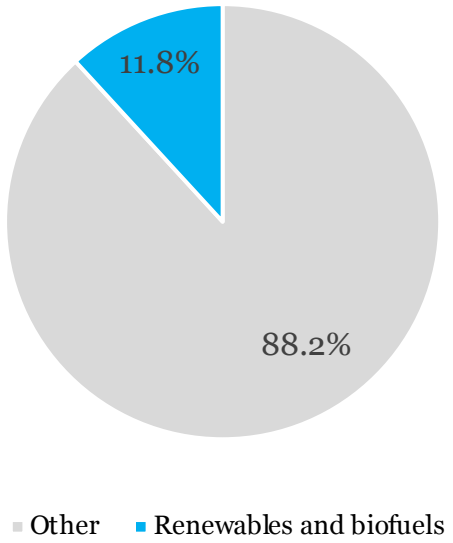
# Challenge

## In 2020, renewables and biofuels were leading in terms of energy production by fuel in the EU, but only 11.8% of final energy consumption was “green”…

**Primary energy production by fuel, EU, 2010-2020, PJ**




**Final energy consumption by fuel in 2020 in the EU, %**

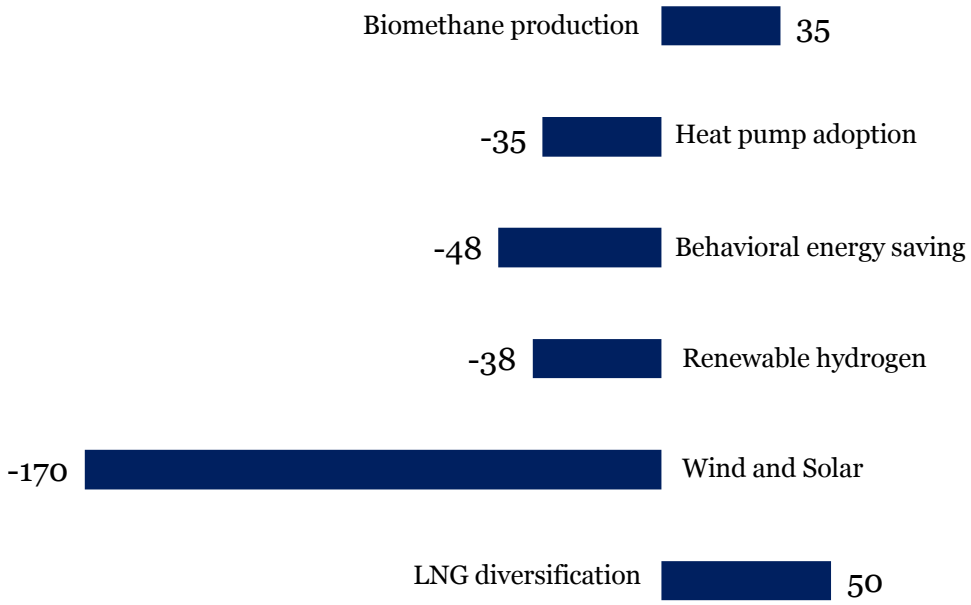



Source: Eurostat (2022)

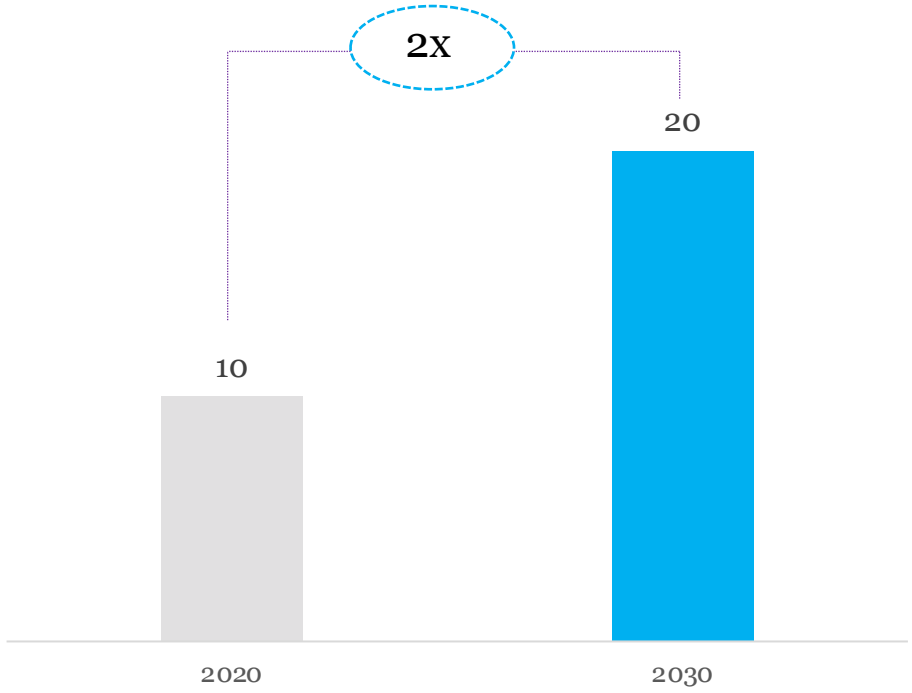
# Opportunity

## While the challenge to transition remains acute, an opportunity to end the EU's overdependence on a single supplier emerges...

**2030 Target Gas Displacement (Fit for 55 + RePower), Bcm**



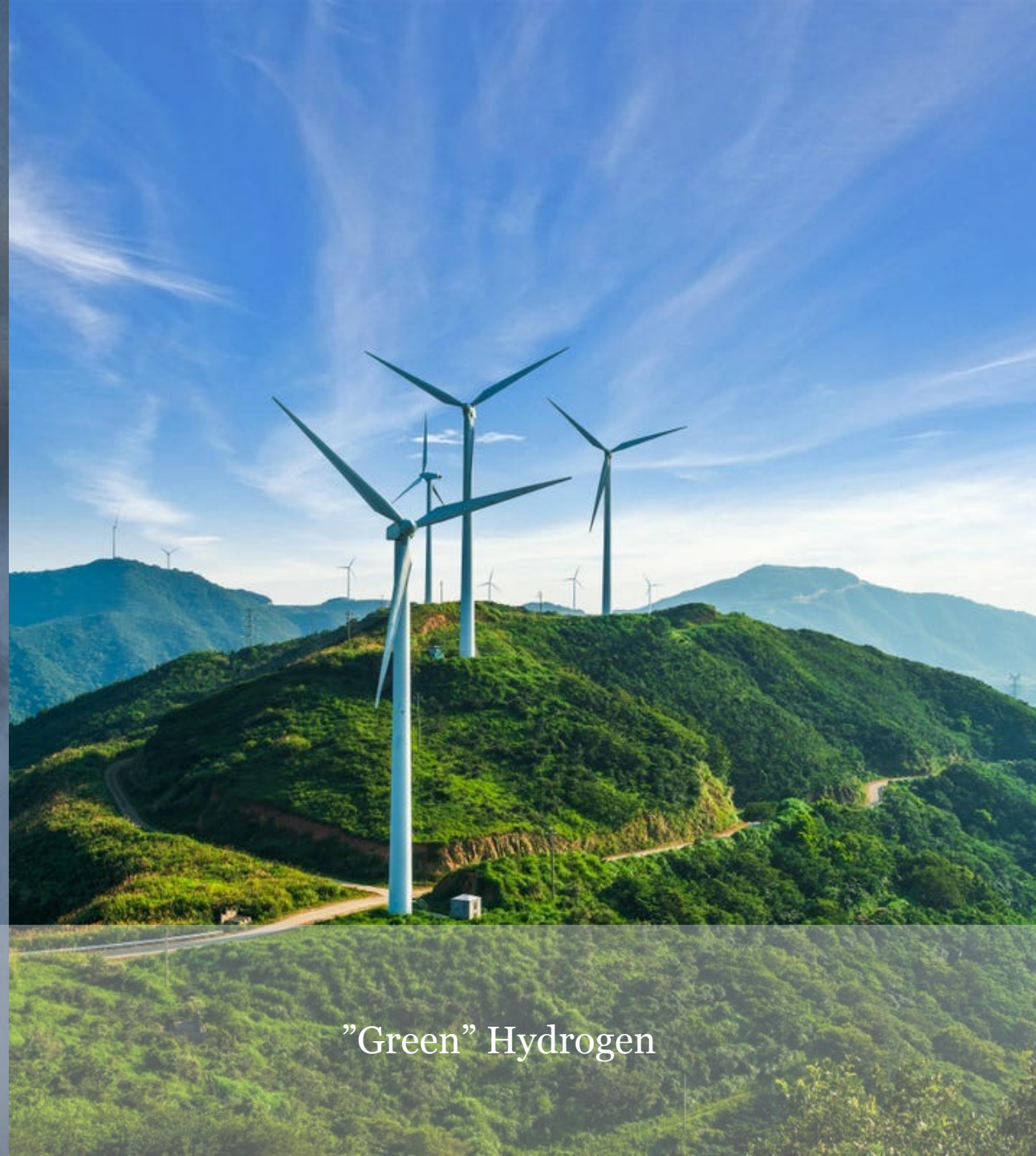

**EU hydrogen demand targets, million metric tons**




Source: BNEF (2022)

Hydrogen Is the Most Plentiful Element in the Universe

”Gray” Hydrogen

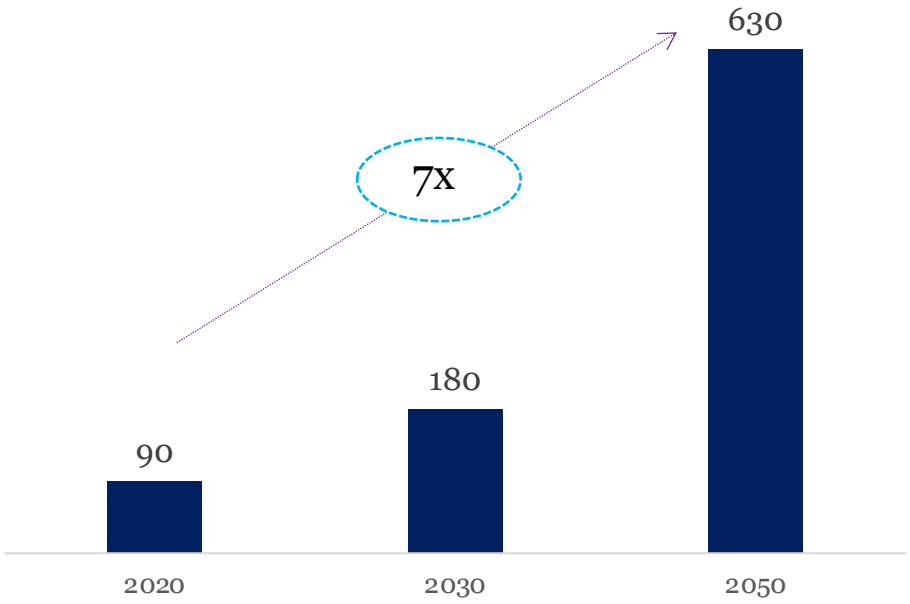


”Green” Hydrogen

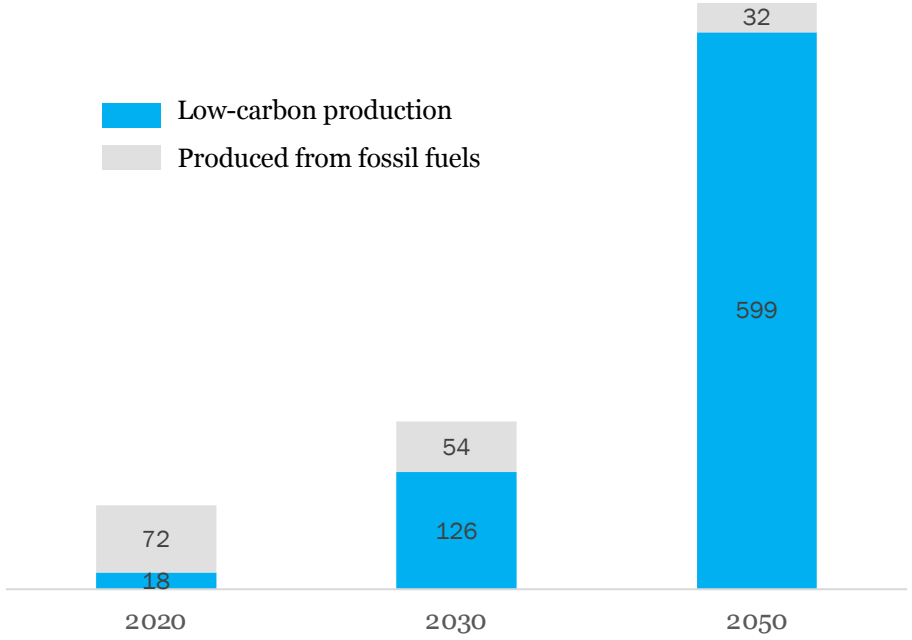
# Green Hydrogen

## Hydrogen's versatility in production, high energy content per unit mass and no emissions at the point of use (combustion) explain its attractiveness as an energy vector and fuel…

**Global hydrogen demand (Mt H2), global net zero by 2050 scenario – 1.5°**




**Estimated hydrogen production (Mt H2), by type of production**

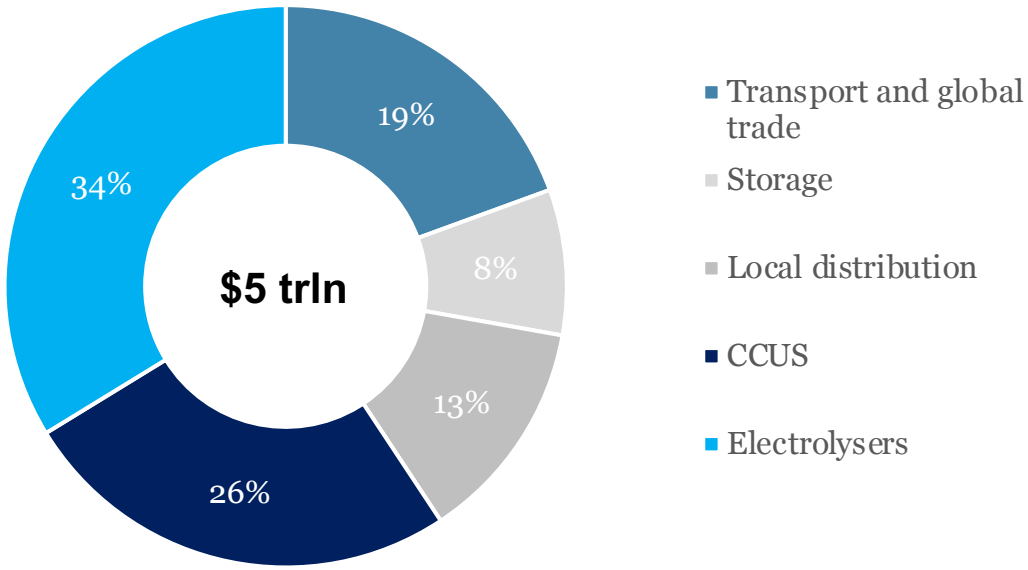



Source: Goldman Sachs Global Investment Research (2021)

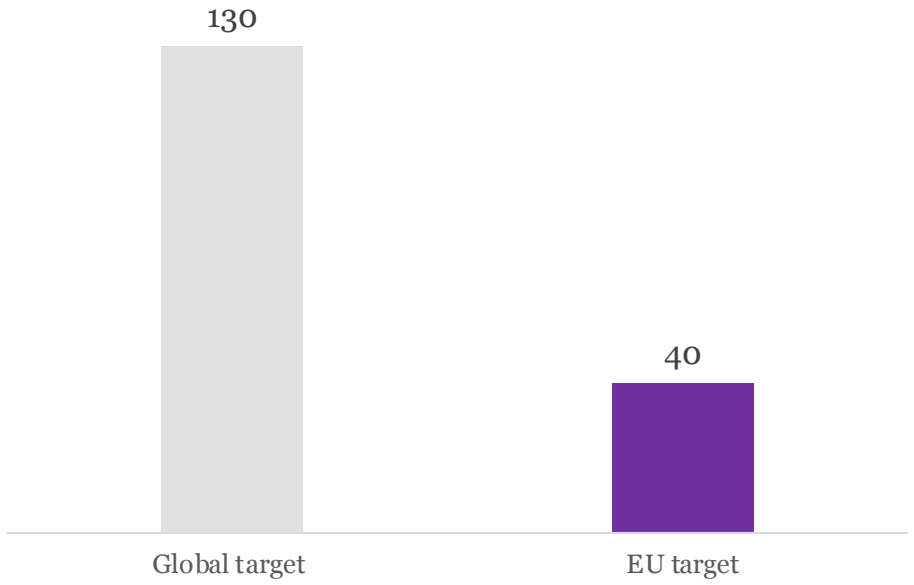
# Green Hydrogen

## Policy support for clean H2 becomes stronger globally with 30+ national strategies pledging 130 GW capacity by 2030 with 40 GW in the EU alone…

**Investments required in the global clean hydrogen supply chain to net zero**

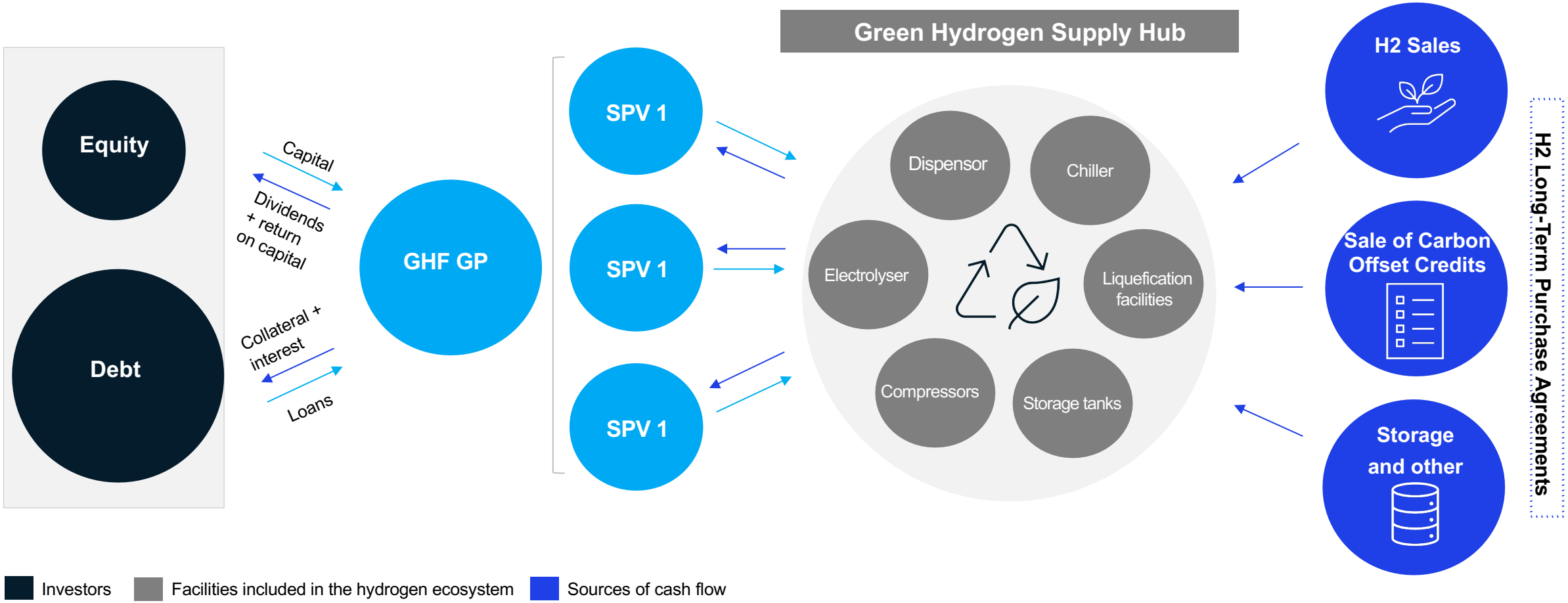



**Current hydrogen capacity pledges explicit in official national hydrogen strategies (2030)**

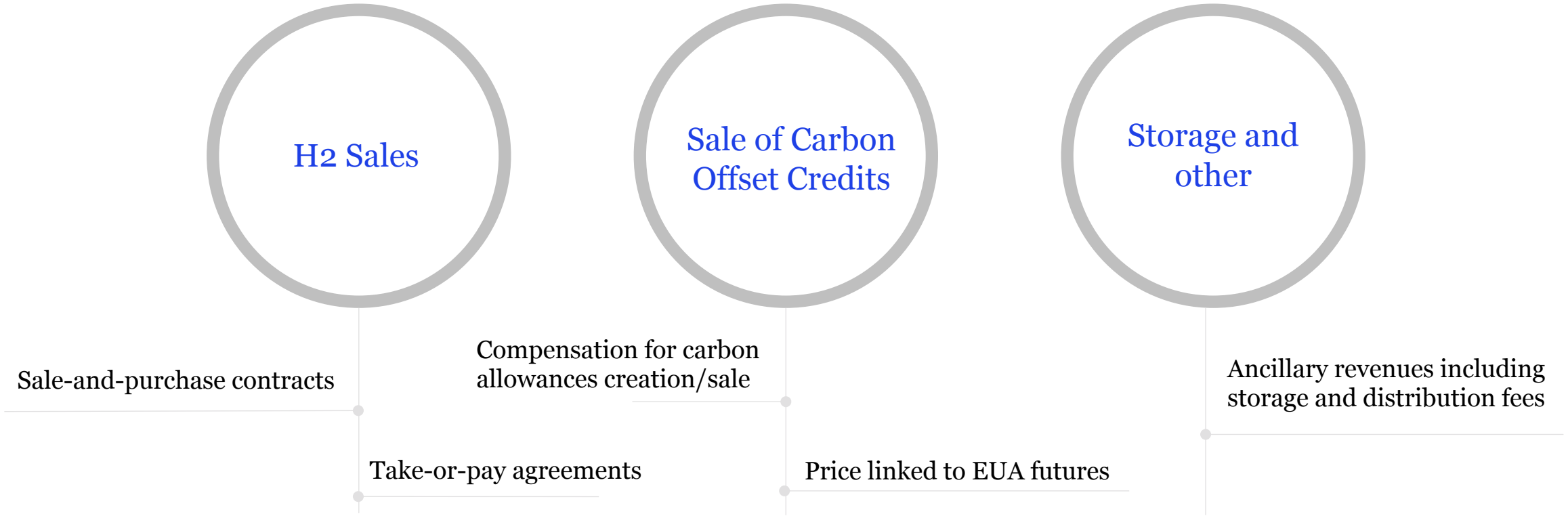



Source: Goldman Sachs Global Investment Research (2021)

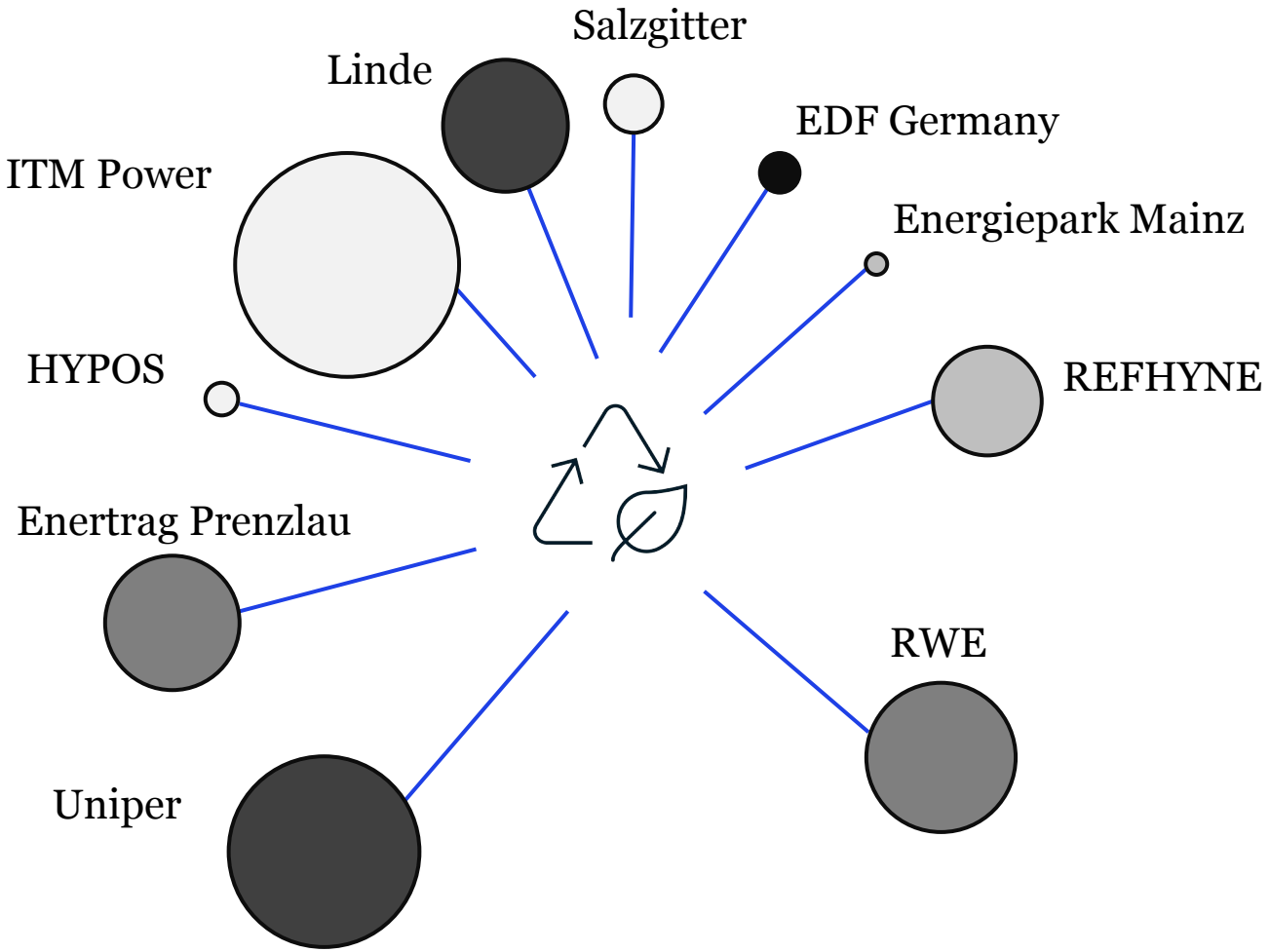
# Financial Vehicle Diagram



# Revenue Streams



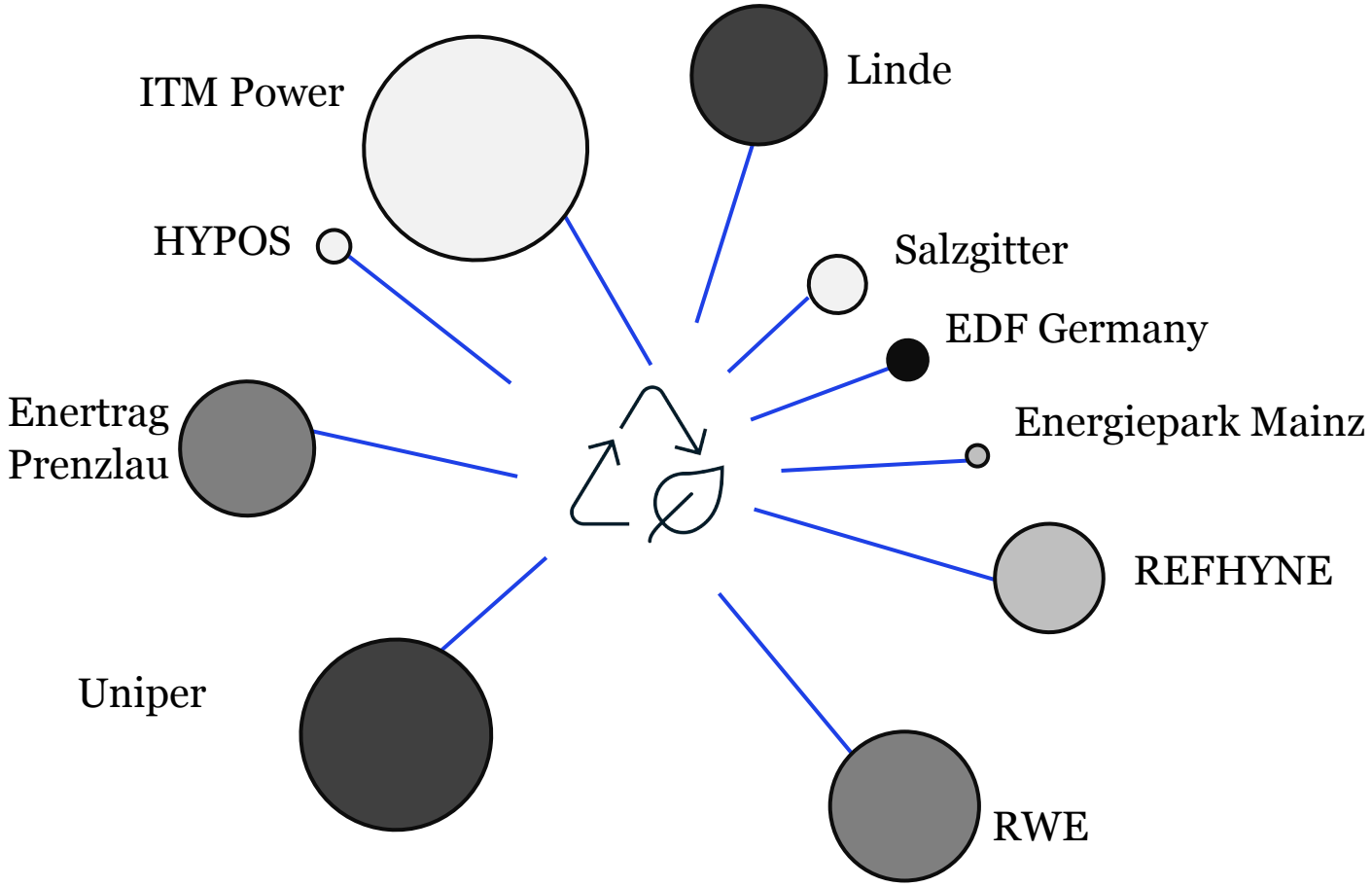
# H2 Supply Hub Operators




**Key selection criteria**

- Commercialized status of technology/processes
- Meets ESG criteria for doing business
- End-use fuel or feedstock: industry
- Financially healthy
- Executed similar projects in the past
- Good reputation and recognized high level of expertise

# H2 Supply Hub Operators

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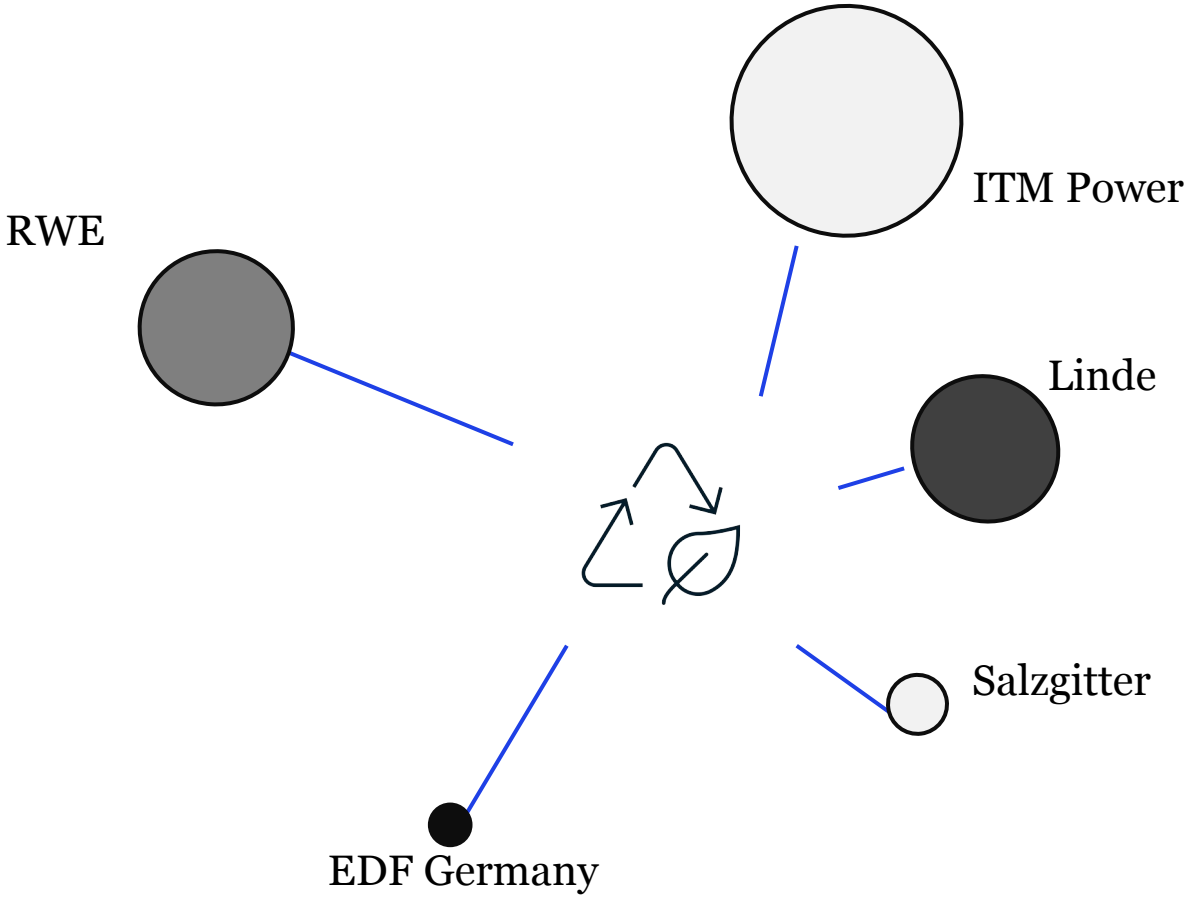


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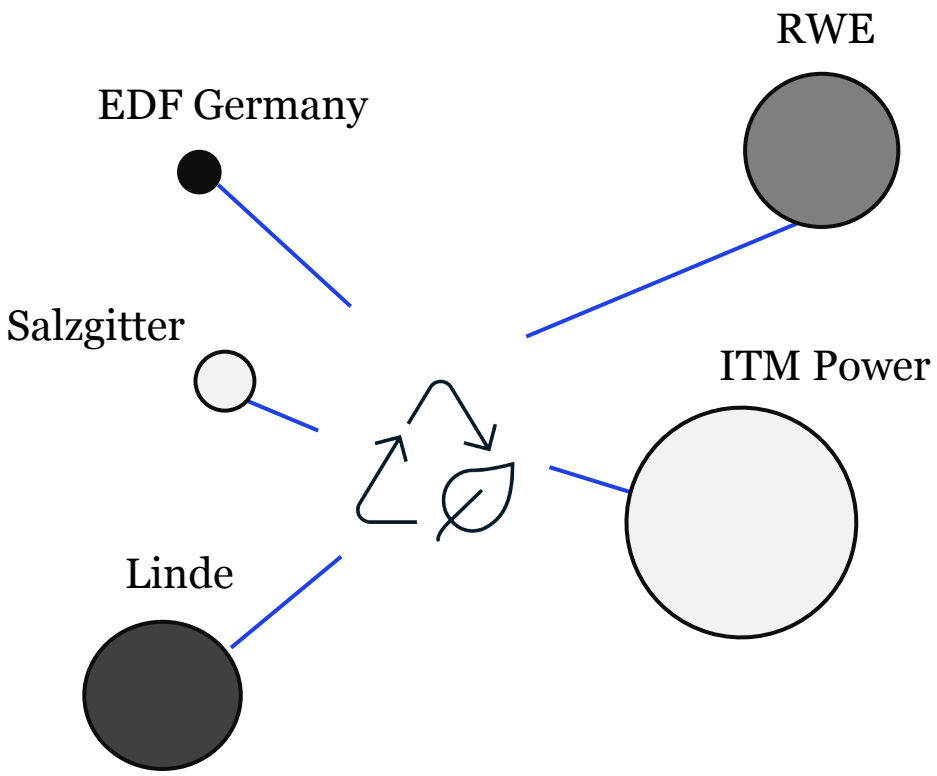



**Ultimate Selection Based on Criteria**

| Company | Technology | ESG | Industry | Financial Health | Execution |
|---|---|---|---|---|---|
| ITM POWER Energy Storage \| Clean Fuel | ✓ | ✓ | ✓ | ✓ | ✓ |
| Linde | ✓ | ✓ | ✓ | ✓ | ✓ |
| RWE | ✓ | ✓ | ✓ | ✓ | ✓ |
| SALZGITTER AG Stahl und Technologie | ✓ | ✓ | ✓ | ✓ | ✓ |
| EDF | ✓ | ✓ | ✓ | ✓ | ✓ |

# Potential H2 End User and Investors

## Potential End User

BASF

We create chemistry

## Potential Investors

European Investment Bank

KFW

Bank aus Verantwortung

Morgan Stanley

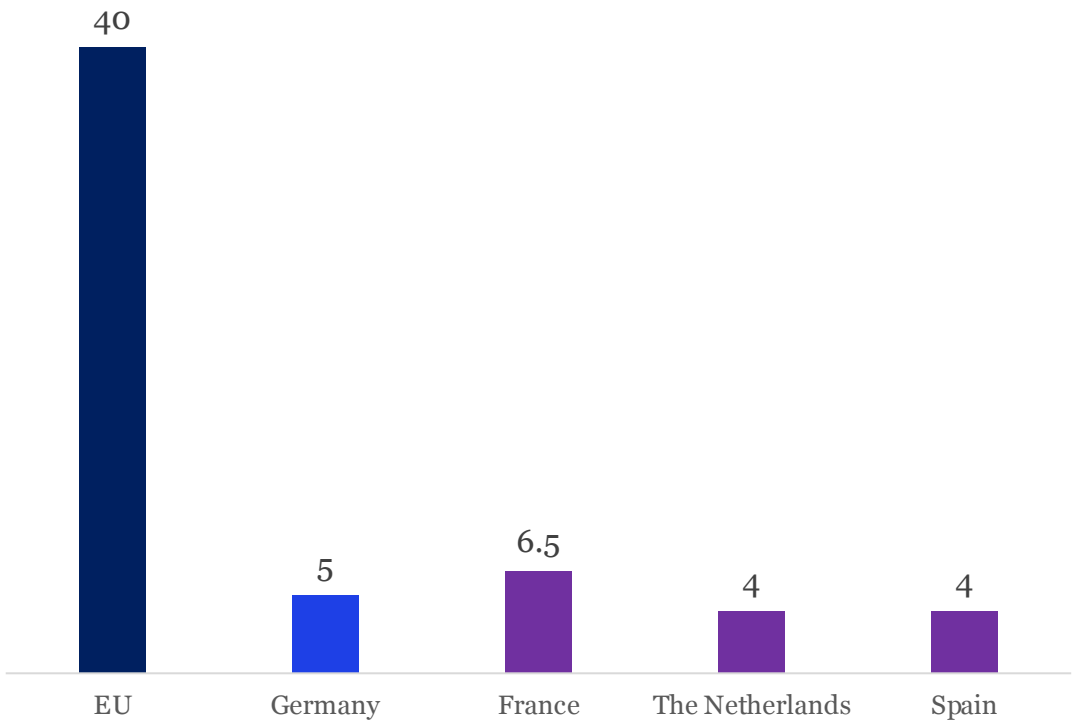
J.P.Morgan

BVK

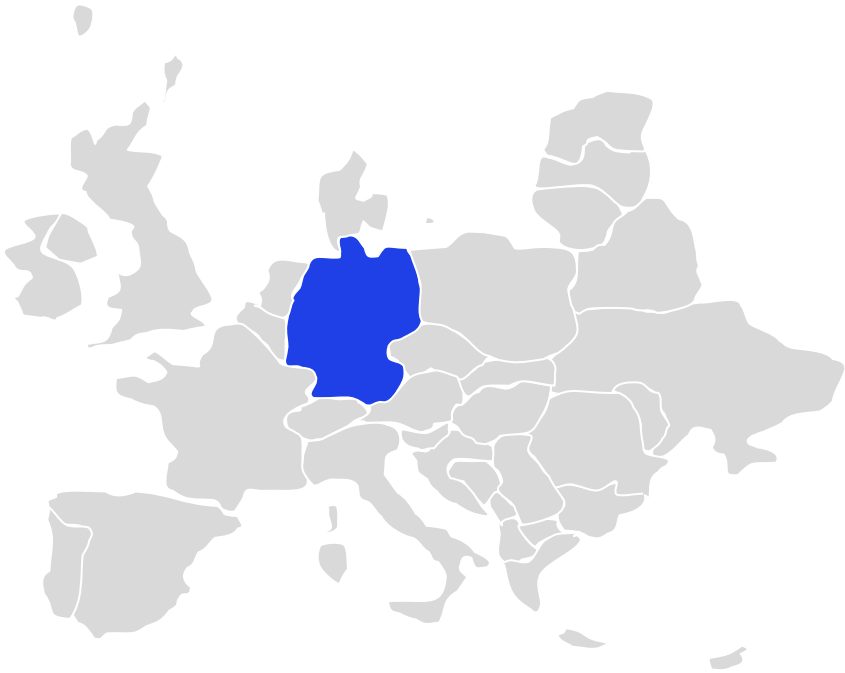
UBS

# Scalability

**EU headline targets for electrolyser capacity by 2030, GW**



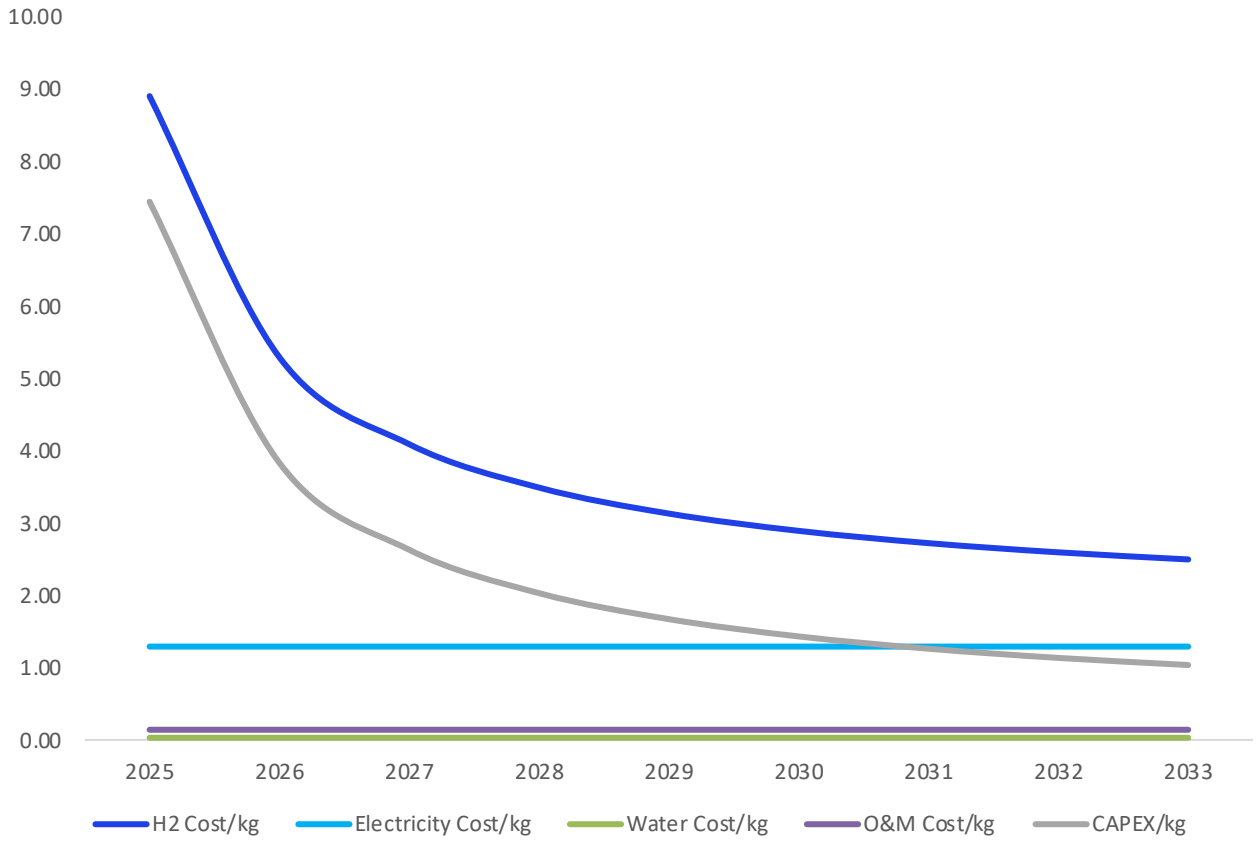

Target Country: Germany



# Financial Projections & Key Assumptions

| | | |
|---|---|---|
| Start of Construction | Date | 01.Jan.24 |
| Construction Period | Months | 12 |
| Commercial Operation | Date | 01.Jan.25 |
| Period for Analysis | Years | 9 |
| End of Operating Life | Date | 01.Jan.34 |
| Electrolyzer (PEM) Capaicty | kg/Hour | 465.12 |
| Electricity Efficiency | kWh/kg | 43.00 |
| kWh per Hour Required- kW Capacity | kWh | 20 000 |
| Water Efficiency | L/kg | 15.00 |
| Maximum Availability | % | 98.00% |
| Maximum Annual Production | kg/Year | 3 992 930 |

**Levelized cost of hydrogen (LCOH) projections, €/kg**



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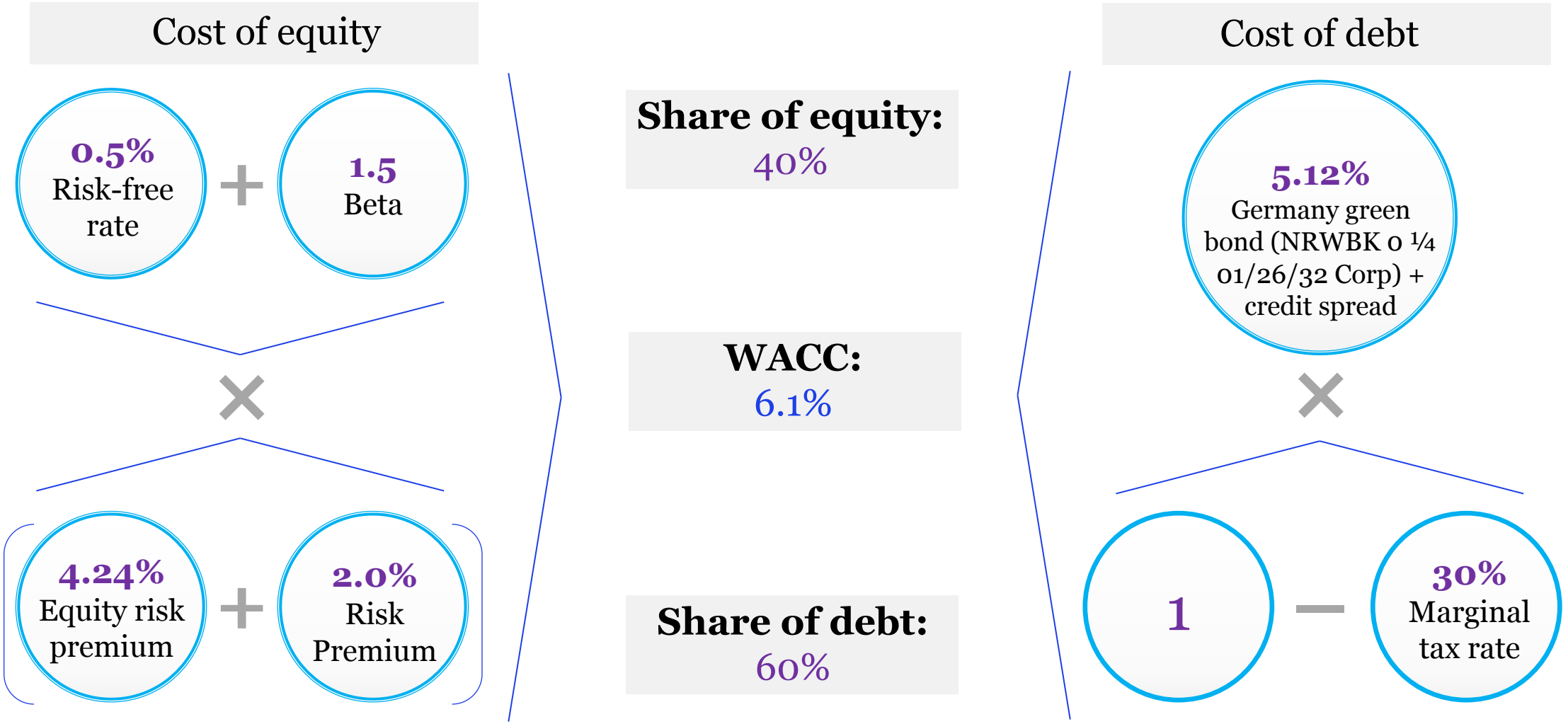
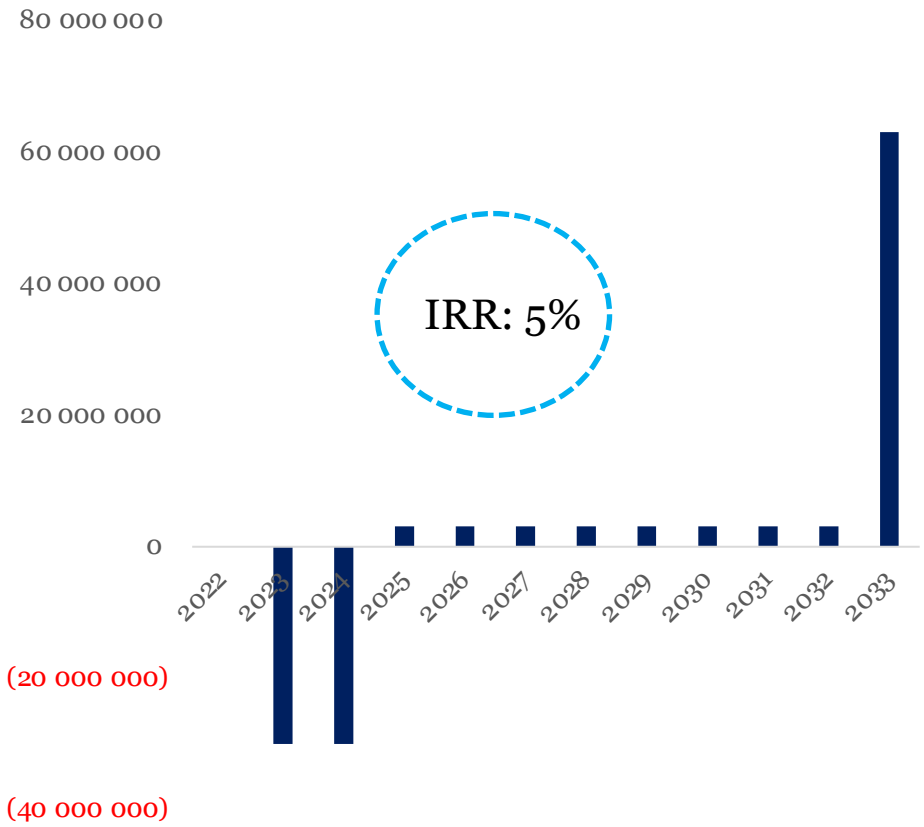


# Financial Projections & Key Assumptions

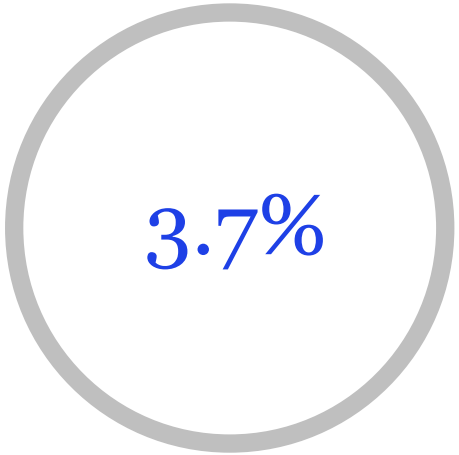
### Debt Investors' Projected Cash Flows, €




### Equity Investors' Projected Cash Flows, €

# Environmental Impact and Metrics

green energy
produced annually




electrolyser capacity target
contribution (Germany's
2030 target of 5 GW)

tons of carbon dioxide
exhaust emissions saved

# Environmental Impact and Metrics

7.1: by 2030, ensure universal access to affordable, reliable and modern energy services

7.2: by 2030, increase substantially the share of renewable energy in the global energy mix

9.4: by 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes

13.2: integrate climate change measures into national policies, strategies and planning

# Risk Management

Strategic risks

- S1 **Liquidity risk**
- S2 **Risk of delayed completion**
- S3 **New technology risk**

Operational risks

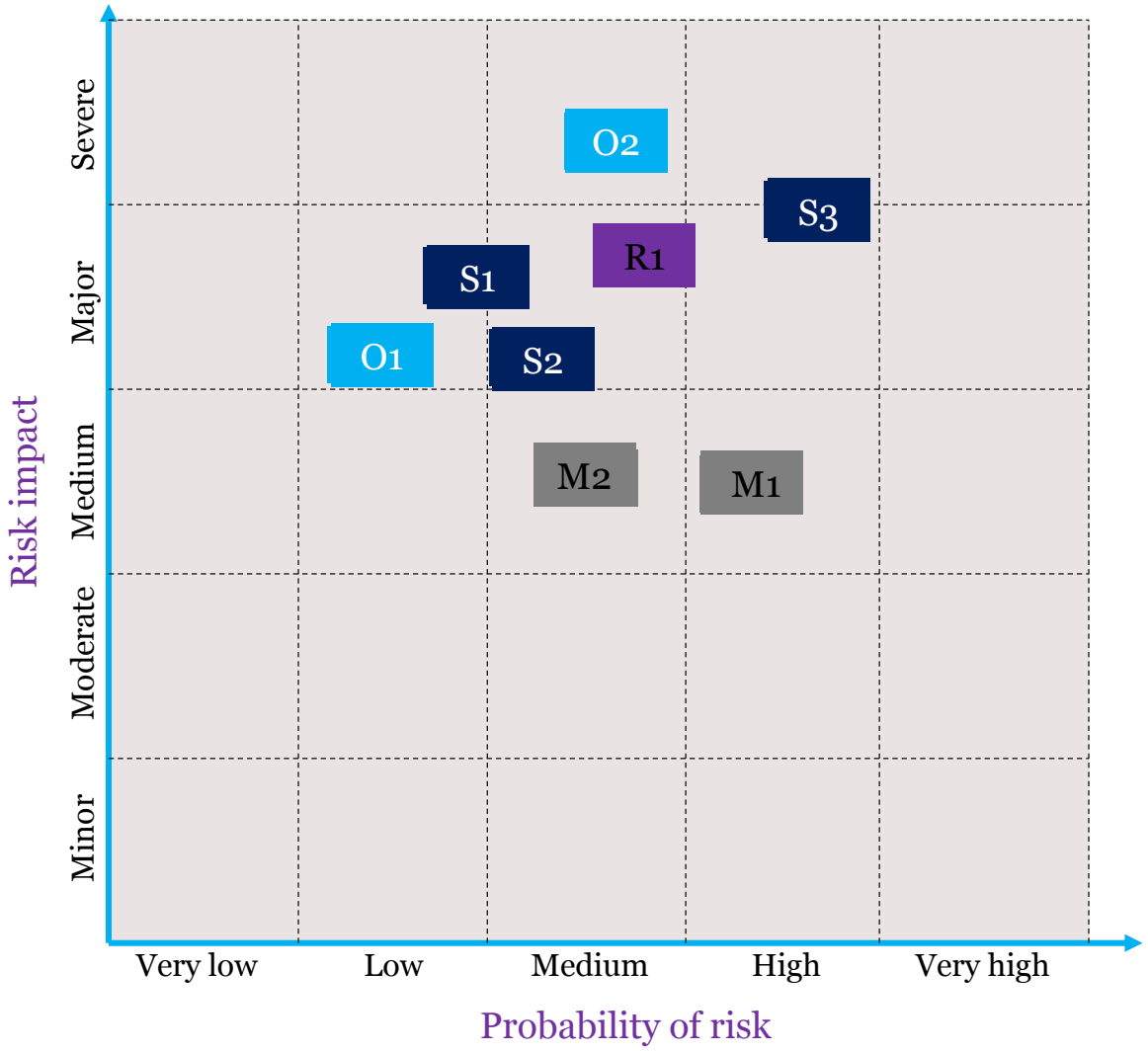
- O1 **Production disruption risk**
- O2 **Failure of electricity and water supply**

Market risks

- M1 **Commodity prices risk**
- M2 **Interest rate risk**

Regulatory risks

- R1 **Change-in-law risk**



# Risk Management

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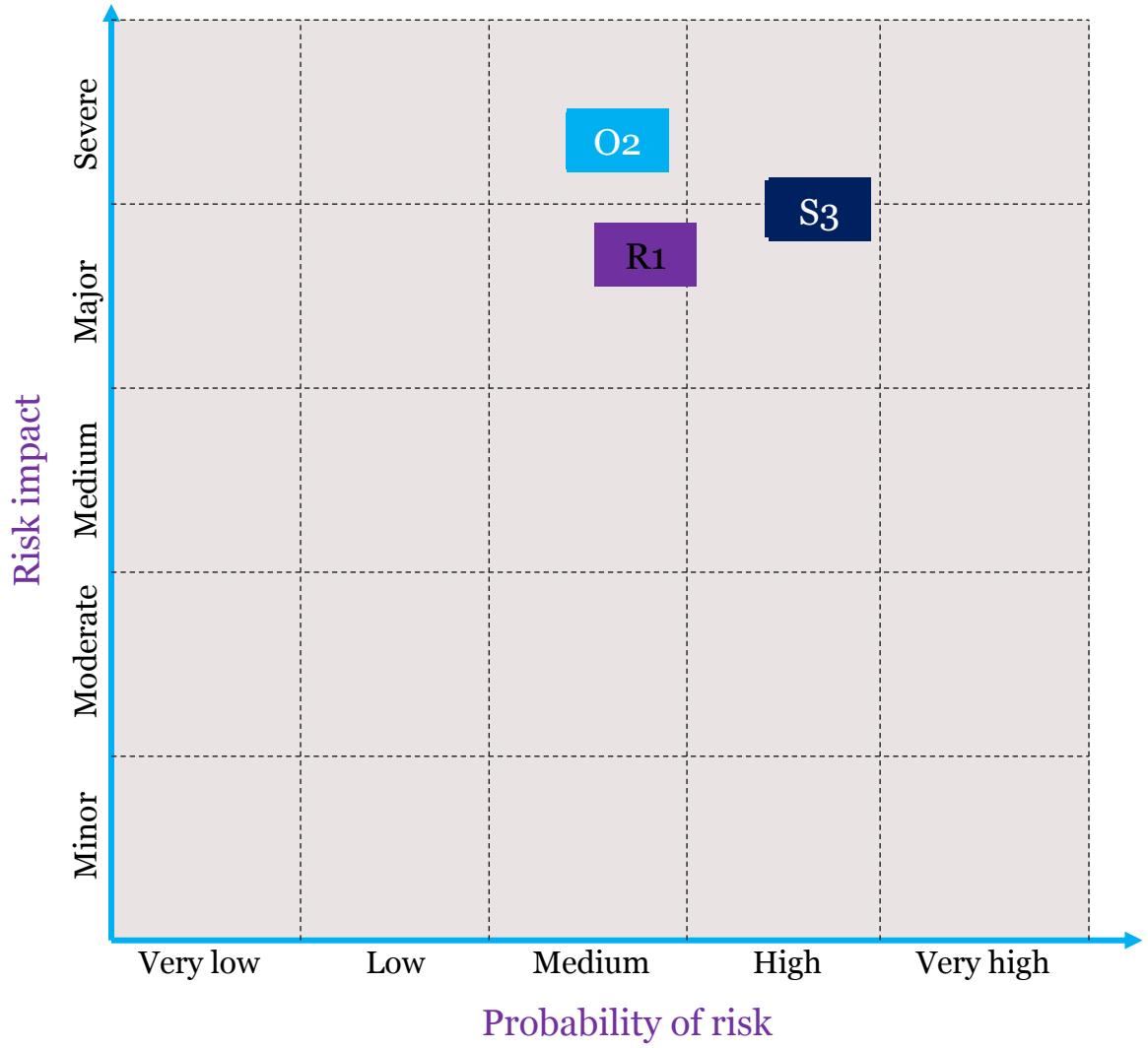


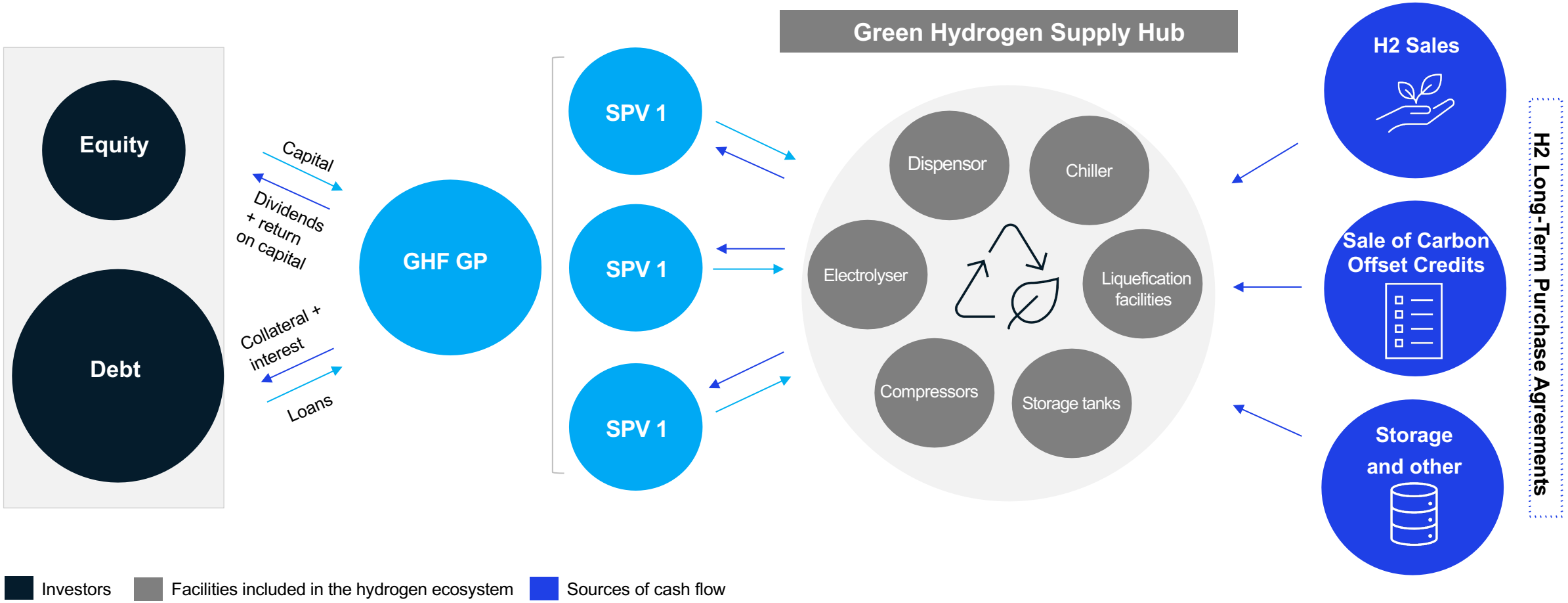
# Green Hydrogen Fund (GHF)

## Kozminski University

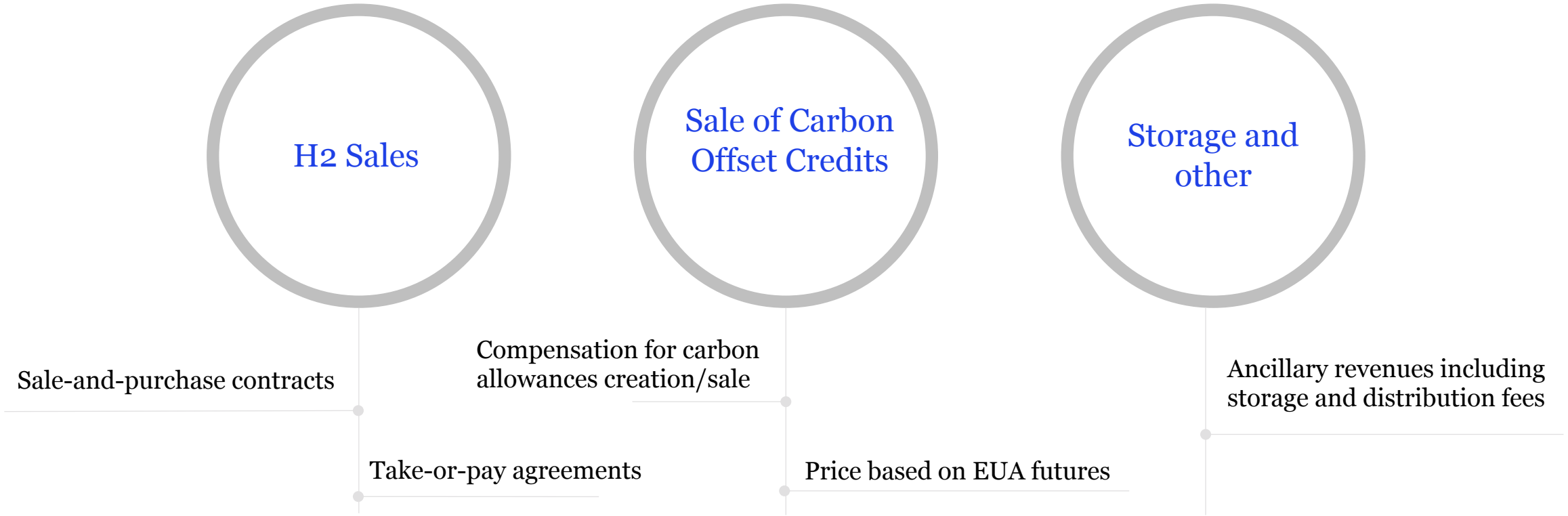
# Q&A

# Appendices

# Appendix 1. Financial Vehicle Diagram

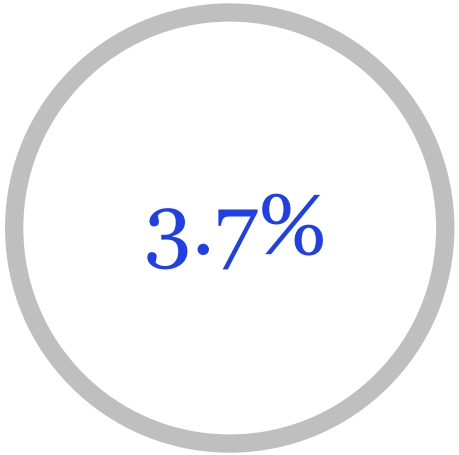


# Appendix 2. Revenue Streams



# Appendix 3. Environmental Impact and Metrics

green energy produced annually




electrolyser capacity target contribution (Germany's 2030 target of 5 GW)

tons of carbon dioxide exhaust emissions saved

# Appendix 4. Inputs & Electrolyzer Assumptions

| **Start of Construction** | Date | 01.Jan.24 |
|---|---|---|
| Construction Period | Months | 12 |
| Commercial Operation | Date | 01.Jan.25 |
| Period for Analysis | Years | 9 |
| End of Operating Life | Date | 01.Jan.34 |
| | | |
| Year of Operation | Date | 01.Jan.25 |
| Electrolyzer Capaicty | kg/Hour | 465.12 |
| Electricity Efficiency | kWh/kg | 43.00 |
| kWh per Hour Required- kW Capacity | kWh | 20 000 |
| Water Efficiency | L/kg | 15.00 |
| Maximum Availability | % | 98.00% |
| Maximum Annual Production | kg/Year | 3 992 930 |
| Lifetime of Electrolyzer | Hours | 100 000 |
| Lifetime of Electrolyzer | Years | 20 |
| Capital Cost per kg | €/kg-hr | 43 000 |
| Capital Cost of Electrolyzer | € | 20 000 000 |
| Capital Cost per kW | €/kW | 1 000 |
| Cost of Electricity | €/kWH | 0.0 |
| Cost of Water | €/kLitre | 1.91 |
| Maintenance Overhaul Years | Years | 9.00 |
| Cost of Major Overhaul as Percent of Cost | % | 40.00% |
| Cost of Major Overhaul | € | 8 000 000 |
| Other Overhead Costs | % of Capital Cost | 2.00% |

| PEM Large | | |
|---|---|---|
| **Production and Efficiency** | | |
| Production capacity | kg/h | 465.12 |
| Production capacity | kg/day | 11 163 |
| Water consumption | L/kg | 15 |
| Nominal power | MW | 20 |
| Nominal Power | kWh | 20 000 |
| Efficiency | kWh/kg | 43.00 |
| Efficiency | kg/kWh | 0.023 |
| Availability | %/year | 98% |
| Minimum power | % Pnom | 5% |
| Peak power - for 10 min | % Pnom | 160% |
| Pressure output | Bar | 30 |
| **Lifetime and Capex** | | |
| Lifetime - System | Years | 20 |
| Degradation - system | %/1000 h | 0.25% |
| Lifetime - Stack @ full charge | Hours | 40 000 |
| Replacement Year | Year | 9 |
| Replacement Percent | | 40% |
| CAPEX - total system equipment | €/kW | 1 000 |
| CAPEX - total system equipment | € | 20 000 000 |
| CAPEX - total system equipment | €/kg-hr | 43 000 |
| **O&M Cost** | | |
| O&M percent | % of Capital | 2.00% |
| **Total Electrolyzer Cost** | | |
| CAPEX+OPEX | € | 20 400 000 |

Source: IEA, IRENA (2022)

# Appendix 5. Assumptions (Costs)

| | | | |
|---|---|---|---|
| CAPEX - Electrolysis | € | 20000000 | |
| CAPEX - Storage and other supporting facilities | | | |
| Storage | € | 2 000 000 | 10%of CAPEX |
| Compression | € | 6 000 000 | 30%of CAPEX |
| Total CAPEX | € | 28 000 000 | |
| Total OPEX | € | 560 000 | |
| Price of electricity | €/kWh | 0.03 | |
| Feedstock - electricity | €/a | 5 150 880 | |
| Price of water | €/kLitre | 1.91 | |
| Feedstock - water | €/a | 116 732 | |
| Residual value after 9 years of operation | 16 800 000 | | |
| WACC | 6.09% | | |
| Share of debt | 0.6 | | |
| Share of equity | 0.4 | | |
| Cost of debt | 5.12% | Germany green bond (NRWBK 0 ¼ 01/26/32 Corp) + 4% credit spread | |
| Cost of equity | 9.86% | Damodaran Equity Risk Premium for Germany+3% risk premium | |
| Marginal tax rate | 30% | KPMG survey of corporate tax rates by country. | |

Source: Team Estimates

# Appendix 6. Assumptions (Costs cont.)

| Year | Sum | CAPEX | OPEX | Feedstock - electricity | Feedstock - water | Hydrogen (kg) | LCOH(t) |
|---|---|---|---|---|---|---|---|
| 2022 | | - | - | - | | | |
| 2023 | | - | - | - | | | |
| 0 | | | - | - | | | |
| 1 | | 28 000 000 | 527 832 | 4 854 997 | 110 027 | 3 763 564 | 8.90 |
| 2 | | 28 000 000.00 | 1 025 343 | 9 431 108 | 213 733 | 7 310 936 | 5.29 |
| 3 | | 28 000 000.00 | 1 494 276 | 13 744 352 | 311 482 | 10 654 536 | 4.09 |
| 4 | | 28 000 000.00 | 1 936 272 | 17 809 830 | 403 616 | 13 806 069 | 3.49 |
| 5 | | 28 000 000.00 | 2 352 878 | 21 641 773 | 490 458 | 16 776 568 | 3.13 |
| 6 | | 28 000 000.00 | 2 745 553 | 25 253 598 | 572 311 | 19 576 433 | 2.89 |
| 7 | | 28 000 000.00 | 3 115 672 | 28 657 948 | 649 462 | 22 215 464 | 2.72 |
| 8 | | 28 000 000.00 | 3 464 529 | 31 866 741 | 722 182 | 24 702 900 | 2.59 |
| 9 | | 28 000 000.00 | 3 793 348 | 34 891 211 | 790 724 | 27 047 451 | 2.49 |

$$\text{LCOH} = \text{P}_{\text{Hydrogen}} = \frac{\sum_{t=1}^{n} \frac{CAPEX_t + OPEX_t + Feedstock_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{Hydrogen_t}{(1+r)^t}}$$

Levelized Cost of Hydrogen

CAPEXt =Investment expenditures in the year t;
OPEXt =Operations and maintenance expenditures in the year t;
Feedstockt =Electricity & water consumption =Feedstock expenditures in the year t;
Hydrogent =Hydrogen generation in the year t;
rt (Depreciation) =discount rate; and
n =lifetime of plant

1 Kg of Hydrogen = 33.3 kWh

Source: Team Estimates

# Appendix 7. Income Statement

| Year | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|
| Year No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Revenues | 38 205 634 | 36 576 519 | 35 028 859 | 33 558 582 | 32 161 819 | 30 834 894 | 29 574 316 | 28 376 766 | 27 239 094 |
| Feedstock - electricity | 10 301 760 | 10 301 760 | 10 301 760 | 10 301 760 | 10 301 760 | 10 301 760 | 10 301 760 | 10 301 760 | 10 301 760 |
| Feedstock - water | 233 464 | 233 464 | 233 464 | 233 464 | 233 464 | 233 464 | 233 464 | 233 464 | 233 464 |
| O&M | 1 120 000 | 1 120 000 | 1 120 000 | 1 120 000 | 1 120 000 | 1 120 000 | 1 120 000 | 1 120 000 | 1 120 000 |
| EBITDA | 26 550 410 | 24 921 294 | 23 373 635 | 21 903 358 | 20 506 595 | 19 179 670 | 17 919 092 | 16 721 542 | 15 583 870 |
| D&A | 2 488 889 | 2 488 889 | 2 488 889 | 2 488 889 | 2 488 889 | 2 488 889 | 2 488 889 | 2 488 889 | 2 488 889 |
| EBIT | 24 061 521 | 22 432 406 | 20 884 746 | 19 414 469 | 18 017 706 | 16 690 781 | 15 430 203 | 14 232 653 | 13 094 981 |
| Interest Expense | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 |
| Net Income before Taxes | 20 989 521 | 19 360 406 | 17 812 746 | 16 342 469 | 14 945 706 | 13 618 781 | 12 358 203 | 11 160 653 | 10 022 981 |
| Income Tax Expense (Benefit) | 6 296 856 | 5 808 122 | 5 343 824 | 4 902 741 | 4 483 712 | 4 085 634 | 3 707 461 | 3 348 196 | 3 006 894 |
| Net Income | 14 692 665 | 13 552 284 | 12 468 922 | 11 439 728 | 10 461 994 | 9 533 147 | 8 650 742 | 7 812 457 | 7 016 087 |
| Equity Cash Dividend | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 |
| Net Income After Equity Dividends and Interest | 9 892 665 | 8 752 284 | 7 668 922 | 6 639 728 | 5 661 994 | 4 733 147 | 3 850 742 | 3 012 457 | 2 216 087 |
| Management & incentive fees | 2 778 533 | 2 550 457 | 2 333 784 | 2 127 946 | 2 000 000 | 2 000 000 | 2 000 000 | 2 000 000 | 2 000 000 |

Source: Team Estimates

# Appendix 8. Cash Flows

| Allocation of Exit Proceeds | |
|---|---|
| EBITDA Multiple (Exit Year) | 6.0x |
| EBITDA (Exit Year) | 15 583 870 |
| **Exit Year Enterprise Value** | **93 503 220** |
| Less: Debt | 60 000 000 |
| **Equity Value - Allocable Proceeds** | 33 503 220 |

| Cash Flows & IRR | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -3 | -2 | -1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **Debt** | | | | | | | | | | | | |
| Initial Investment | 0 | -30 000 000 | -30 000 000 | | | | | | | | | |
| Cash Interest | | 0 | 0 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 |
| Principal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 60 000 000 |
| Participation on Exit | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 0 | -30 000 000 | -30 000 000 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 | 3 072 000 | 63 072 000 |

| IRR | 4.79% |
|---|---|

| | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Equity** | -3 | -2 | -1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Initial Investment | 0 | -20 000 000 | -20 000 000 | | | | | | | | | |
| Cash Dividend | | 0 | 0 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 |
| Participation on Exit | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33 503 220 |
| | 0 | -20 000 000 | -20 000 000 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 | 4 800 000 | 38 303 220 |

| IRR | 9.94% |
|---|---|

Source: Team Estimates

# Appendix 9. Loan Repayment Schedule

| Analysis Year | Loan Year | Principal Owed | Annual Payment | Interest | Principal Payment |
|---|---|---|---|---|---|
| 2022 | 0 | $30 000 000 | $0 | $0 | $0 |
| 2023 | 0 | $60 000 000 | $0 | $0 | $0 |
| 2024 | 0 | $60 000 000 | $0 | $0 | $0 |
| 2025 | 1 | $60 000 000 | $3 072 000 | $3 072 000 | $0 |
| 2026 | 2 | $60 000 000 | $3 072 000 | $3 072 000 | $0 |
| 2027 | 3 | $60 000 000 | $3 072 000 | $3 072 000 | $0 |
| 2028 | 4 | $60 000 000 | $3 072 000 | $3 072 000 | $0 |
| 2029 | 5 | $60 000 000 | $3 072 000 | $3 072 000 | $0 |
| 2030 | 6 | $60 000 000 | $3 072 000 | $3 072 000 | $0 |
| 2031 | 7 | $60 000 000 | $3 072 000 | $3 072 000 | $0 |
| 2032 | 8 | $60 000 000 | $3 072 000 | $3 072 000 | $0 |
| 2033 | 9 | $0 | $63 072 000 | $3 072 000 | $60 000 000 |

Source: Team Estimates

# Appendix 10. FCFF (Electrolyzer)

| Period (years) | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|
| Revenues | 19 102 817 | 18 288 259 | 17 514 429 | 16 779 291 | 16 080 910 | 15 417 447 | 14 787 158 | 14 188 383 | 13 619 547 |

| FCFF | | | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Revenues | | | 19 102 817 | 18 288 259 | 17 514 429 | 16 779 291 | 16 080 910 | 15 417 447 | 14 787 158 | 14 188 383 | 13 619 547 |
| Feedstock - electricity | | | 5 150 880 | 5 150 880 | 5 150 880 | 5 150 880 | 5 150 880 | 5 150 880 | 5 150 880 | 5 150 880 | 5 150 880 |
| Feedstock - water | | | 116 732 | 116 732 | 116 732 | 116 732 | 116 732 | 116 732 | 116 732 | 116 732 | 116 732 |
| Operational costs excluding depret. | | | 560 000 | 560 000 | 560 000 | 560 000 | 560 000 | 560 000 | 560 000 | 560 000 | 560 000 |
| EBITDA | | | 13 275 205 | 12 460 647 | 11 686 817 | 10 951 679 | 10 253 298 | 9 589 835 | 8 959 546 | 8 360 771 | 7 791 935 |
| Depreciation | | | 1 244 444 | 1 244 444 | 1 244 444 | 1 244 444 | 1 244 444 | 1 244 444 | 1 244 444 | 1 244 444 | 1 244 444 |
| EBIT | | | 12 030 761 | 11 216 203 | 10 442 373 | 9 707 235 | 9 008 853 | 8 345 391 | 7 715 101 | 7 116 327 | 6 547 491 |
| Tax * | | | 3 609 228 | 3 364 861 | 3 132 712 | 2 912 170 | 2 702 656 | 2 503 617 | 2 314 530 | 2 134 898 | 1 964 247 |
| NOPAT | | | 8 421 532 | 7 851 342 | 7 309 661 | 6 795 064 | 6 306 197 | 5 841 773 | 5 400 571 | 4 981 429 | 4 583 243 |
| Depreciation | | | 1 244 444 | 1 244 444 | 1 244 444 | 1 244 444 | 1 244 444 | 1 244 444 | 1 244 444 | 1 244 444 | 1 244 444 |
| Investements in Fixed Assets | | 28 000 000 | | | | | | | | | |
| FCFF | - | 28 000 000 | 9 665 977 | 9 095 786 | 8 554 105 | 8 039 509 | 7 550 642 | 7 086 218 | 6 645 015 | 6 225 873 | 5 827 688 |
| Residual Value | | | | | | | | | | | 16 800 000 |
| FCFF + RV | - | 28 000 000 | 9 665 977 | 9 095 786 | 8 554 105 | 8 039 509 | 7 550 642 | 7 086 218 | 6 645 015 | 6 225 873 | 22 627 688 |
| IRR | | 28.62% | | | | | | | | | |
| D FCF | - | 28 000 000 | 9 110 732 | 8 573 295 | 7 599 582 | 6 732 124 | 5 959 557 | 5 271 718 | 4 659 521 | 4 114 841 | 14 096 149 |
| NPV | | 38 117 520 | | | | | | | | | |

Source: Team Estimates

# Appendix 11. Revenues Projections

| 0 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|
| Revenue (H2 sales) | 15 971 721 | 15 173 135 | 14 414 478 | 13 693 754 | 13 009 067 | 12 358 613 | 11 740 683 | 11 153 648 | 10 595 966 |
| Revenue (EUA sales) | 2 811 661.75 | 2 811 661.75 | 2 811 661.75 | 2 811 661.75 | 2 811 661.75 | 2 811 661.75 | 2 811 661.75 | 2 811 661.75 | 2 811 661.75 |
| Revenue (Storage) | 319 434 | 303 463 | 288 290 | 273 875 | 260 181 | 247 172 | 234 814 | 223 073 | 211 919 |
| Price of gray hydrogen | 2 | 2.1 | 2.205 | 2.31525 | 2.4310125 | 2.552563125 | 2.680191281 | 2.814200845 | 2.954910888 |
| Price of green hydrogen assumption | 4.00 | 3.80 | 3.61 | 3.43 | 3.26 | 3.10 | 2.94 | 2.79 | 2.65 |
| Annual production (kg) | 3 992 930 | 3992930 | 3992930 | 3992930 | 3992930 | 3992930 | 3992930 | 3992930 | 3992930 |
| Price per 1 EU Allowance (EUA) | 78.24 | 78.24 | 78.24 | 78.24 | 78.24 | 78.24 | 78.24 | 78.24 | 78.24 |

| | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|
| Price/kg | 4.00 | 3.80 | 3.61 | 3.43 | 3.26 | 3.10 | 2.94 | 2.79 | 2.65 |
| H2 Cost/kg | 8.90 | 5.29 | 4.09 | 3.49 | 3.13 | 2.89 | 2.72 | 2.59 | 2.49 |
| Electricity Cost/kg | 1.29 | 1.29 | 1.29 | 1.29 | 1.29 | 1.29 | 1.29 | 1.29 | 1.29 |
| Water Cost/kg | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| O&M Cost/kg | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 |
| CAPEX/kg | 7.44 | 3.83 | 2.63 | 2.03 | 1.67 | 1.43 | 1.26 | 1.13 | 1.04 |

Source: Team Estimates

# Appendix 12. Sensitivity Analysis

Sensitivity analysis
change of sales

| 28.62% | |
|---|---|
| **15%** | **36.0%** |
| 10% | 33.6% |
| 5% | 31.1% |
| 0% | 28.62% |
| -5% | 26.1% |
| -10% | 23.6% |
| -15% | 21.1% |

Sensitivity analysis
electricity costs

| 28.62% | |
|---|---|
| **15%** | **26.4%** |
| 10% | 27.1% |
| 5% | 27.9% |
| 0% | 28.6% |
| -5% | 29.4% |
| -10% | 30.1% |
| -15% | 30.8% |

Sensitivity analysis
price

| 28.62% | |
|---|---|
| **15%** | **43.0%** |
| **10%** | 38.2% |
| **5%** | 33.4% |
| **0%** | 28.6% |
| **-5%** | 23.9% |
| **-10%** | 19.2% |
| **-15%** | 14.8% |

| | | Price | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 28.62% | -15% | -10% | -5% | 0% | 5% | 10% | 15% |
| Volume | 15% | 42.2% | 42.5% | 42.7% | 43.0% | 43.3% | 43.6% | 43.8% |
| | 10% | 37.3% | 37.6% | 37.9% | 38.2% | 38.5% | 38.9% | 39.2% |
| | 5% | 32.4% | 32.7% | 33.1% | 33.4% | 33.8% | 34.1% | 34.5% |
| | 0% | 27.4% | 27.8% | 28.2% | 28.6% | 29.0% | 29.4% | 29.8% |
| | -5% | 22.5% | 22.9% | 23.4% | 23.9% | 24.3% | 24.8% | 25.2% |
| | -10% | 17.6% | 18.1% | 18.7% | 19.2% | 19.7% | 20.2% | 20.8% |
| | -15% | 12.9% | 13.6% | 14.2% | 14.8% | 15.4% | 16.0% | 16.5% |

Source: Team Estimates

# Appendix 13. Selected Examples of Announced Policies to Stimulate Hydrogen Demand

| Government | Policy type | Description | Status |
|---|---|---|---|
| **China** | Financial rewards | The FCEV pilot programme rewards clusters of cities that deploy more than 1 000 FCEVs that meet certain technical standards, achieve a maximum delivered hydrogen price of CNY 35/kg (~USD 5/kg) and establish at least 15 operational HRSs. | In force |
| **Germany** | Auctions | The government's H2 Global programme will tender ten-year purchase agreements on hydrogen-based products, providing investor certainty on project bankability. | In force |
| **Norway** | Public procurement requirement | The government has announced that the country's largest ferry connection will be hydrogen-fuelled. | In force |
| **Switzerland** | Tax | The country adopted the LSVA road tax, which levies trucks weighing more than 3.5 tonnes but waives fees for ZEVs. | In force |
| **European Union** | Quota | As part of Fit for 55, the European Commission has proposed a Renewable Energy Directive modification to mandate 50% renewable hydrogen consumption in industry by 2030. | Proposed |
| **European Union** | Quota | In the ReFuel Aviation Initiative, the European Commission proposed a rising quota for synthetic aviation fuels (from a 0.7% share in 2030 to 28% in 2050). | Proposed |
| **India** | Quota | The government announced that, from 2023/24, 10% of refinery hydrogen demand (increasing to 25% in the following five years) and 5% of hydrogen demand for fertiliser production (increasing to 20% in the following five years) should be met with renewable hydrogen. | Proposed |

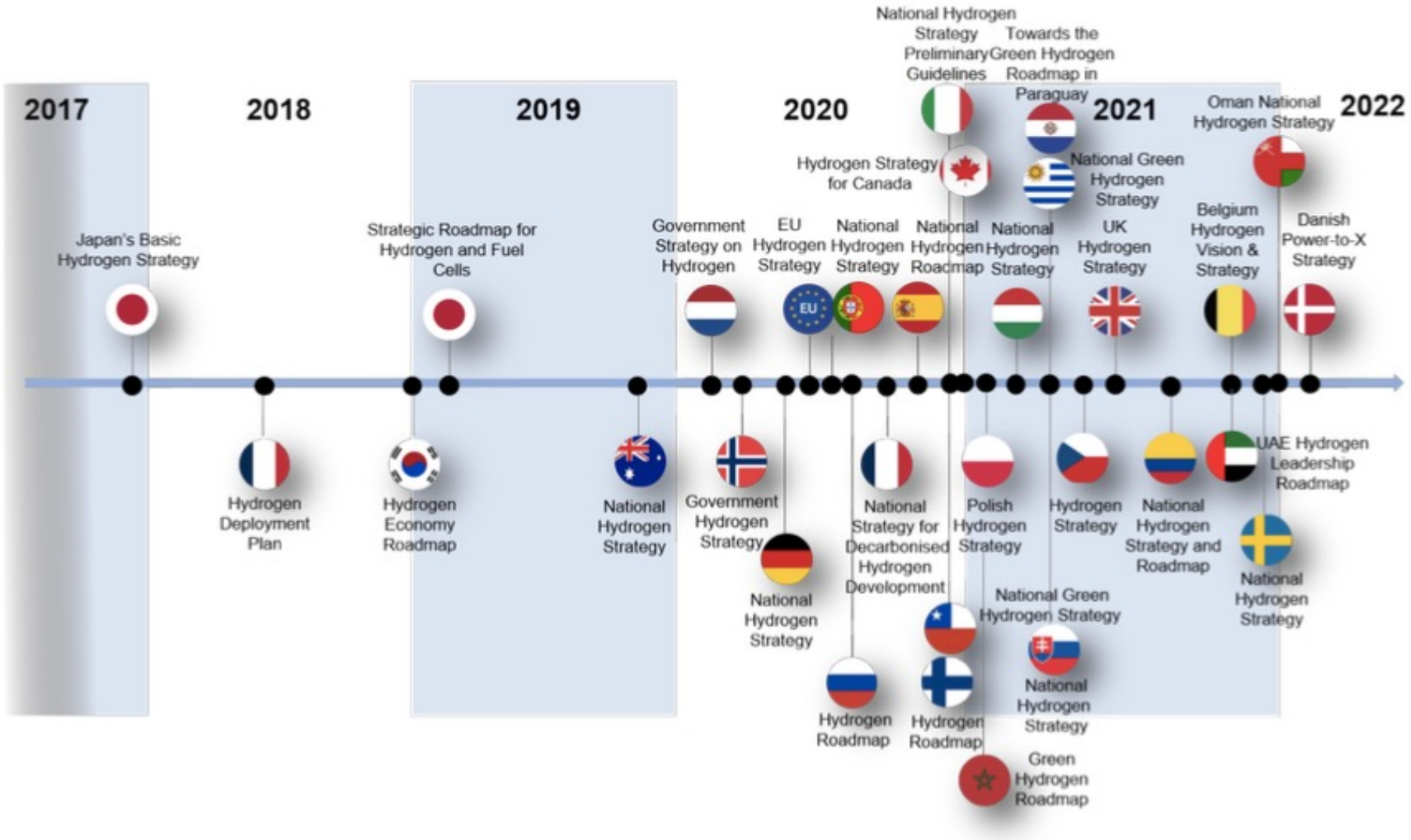
Source: IEA (2022)

# Appendix 14. IEA hydrogen project database

| Project name | Country | Start | End | Technology | H - *Power* | H - *Grids* | H - *Mobility* | H - *Industry* | H - *CHP* | H - *Chemicals* | M - *Grids* | M - *Mobility* | L - *Mobility* | MWel | nm³ $H_2$/hour | Tonne $CO_2$ captures/yr | **IEA estimated normalized capacity [nm³ $H_2$/hour]** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DVGW-EBI KIT - Demo-SNG | Germany | 2011 | 2015 | PEM | | | | | | | 1 | | | | | | |
| Cotbus | Germany | 2012 | | PEM | | 1 | | | | | | | | 0.145 | 20 | | 20.00 |
| Ekolyser (R&D) | Germany | 2012 | 2015 | PEM | | | | | | | | | | | | | |
| LastEISys (R&D) | Germany | 2012 | 2015 | PEM | | | | | | | | | | | | | |
| EON PtG plant Hamburg-Reitbrook | Germany | 2013 | 2015 | PEM | | 1 | | | | | | | | 1.5 | 265 | | 265.00 |
| Thüga PtG plant Frankfurt/Main | Germany | 2013 | 2016 | PEM | 1 | 1 | 1 | | | | 1 | | | 0.36 | 60 | | 60.00 |
| BioPower2Gas, Allendorf, Eder | Germany | 2013 | 2016 | PEM | | | | | | | 1 | | | 0.4 | 60 | | 60.00 |
| RWE PtG plant Ibbenbüren | Germany | 2013 | | PEM | 1 | 1 | | | 1 | | | | | 0.15 | 30 | | 30.00 |
| MicrobEnergy GmbH, Schwandorf | Germany | 2013 | | PEM | 1 | | | | 1 | | | | | 0.18 | 30 | | 30.00 |
| MEFCO2 | Germany | 2014 | 2018 | PEM | | | | | | 1 | | | 1 | 1 | 200 | | 200.00 |
| Energiepark Mainz | Germany | 2015 | 2017 | PEM | | 1 | 1 | 1 | | | | | | 6 | 1000 | | 1 000.00 |
| H2ORIZON | Germany | 2015 | 2017 | PEM | 1 | | 1 | | 1 | | | | | 0.9 | 70 | | 70.00 |
| Hamburg - Schnackenburgallee | Germany | 2015 | | PEM | | | 1 | | | | | | | 0.185 | 30 | | 30.00 |
| Emden II Upscaling | Germany | 2015 | 2020 | PEM | 1 | | | | 1 | | 1 | | | | | | |
| Hassfurt | Germany | 2016 | | PEM | 1 | 1 | | | 1 | | | | | 1.25 | | | 260.42 |
| HPEM2GAS (R&D) | Germany | 2016 | 2019 | PEM | | 1 | | | | | | | | 0.18 | | | 37.50 |
| H&R Ölwerke Hamburg-Neuhof | Germany | 2017 | | PEM | | | | 1 | | | | | | 5 | | | 1 041.67 |
| Energy in the Container, Fraunhofer IISB, Erlangen, Leistungszentren Elektroniksysteme (LZE) | Germany | 2017 | | PEM | 1 | | | | | | | | | | | | |
| Wind to gas Brunsbüttel | Germany | 2018 | | PEM | | 1 | | | | | | | | 2.4 | 500 | | 500.00 |
| eFarm | Germany | 2019 | | PEM | | | 1 | | | | | | | 1.125 | | | 234.38 |
| Maximator | Germany | 2019 | | PEM | | | 1 | | | | | | | 0.833 | | | 173.61 |
| REFHYNE | Germany | 2020 | 2022 | PEM | | | | 1 | | | | | | 10 | | | 2 083.33 |
| Salzgitter Clean Hydrogen project | Germany | 2020 | | PEM | | | | 1 | | | | | | 20 | 400 | | 400.00 |

Source: IEA (2022)

# Appendix 15. Clean hydrogen policy interest




Source: Goldman Sachs Global Investment Research (2021)

# Appendix 16. Hydrogen Properties

| Fuel properties | Energy per unit mass (MJ/kg) | Density (kg/m3) | Energy density (MJ/L) | Specific energy - per unit mass (kWh/kg) | Energy density - per unit volume (kWh/L) | Physical conditions |
|---|---|---|---|---|---|---|
| Gasoline | 46.4 | 737.1 | 34.20 | 12.89 | 9.5000 | Ambient, 1 bar, 25 °c |
| Natural gas (ambient) | 53.6 | 0.7 | 0.04 | 14.89 | 0.0101 | Ambient, 1 bar, 25 °C |
| LNG | 53.6 | 414.2 | 22.20 | 14.89 | 6.1667 | Liquefaction temperature: -160 °C |
| Hydrogen (ambient) | 120.1 | 0.09 | 0.01 | 33.36 | 0.0028 | Ambient, 1 bar, 25 °C |
| Liquid hydrogen | 120.1 | 70.8 | 8.49 | 33.36 | 2.3586 | Liquefaction temperature: -253 °C, 1 bar |

Source: Goldman Sachs Global Investment Research (2021)

# Appendix 17. Key addressable markets for clean hydrogen

| | End-use market | % of global CO2 emissions (direct, 2019) | Key competing de-carbonization technologies: Bioenergy | Key competing de-carbonization technologies: Electrification (renewable power & storage ) | Key competing de-carbonization technologies: Carbon Capture | Potential role for hydrogen: Hydrogen stage of development |
|---|---|---|---|---|---|---|
| | Refining | 1.3 GtCO2, c. 3% | ● | ◑ | ◑ | ● |
| | Primary chemicals | 0.9 GtCO2, c. 3% | ◑ | ◑ | ◕ | ◕ |
| | Iron & Steel | 2.6 GtCO2, c. 7% | ○ | ◑ | ◑ | ◑ |
| | Road transport Light-duty vehicles *(LDVs)* | 3.9 GtCO2, c. 10% | ● | ● | ○ | ◕ |
| | Road transport Heavy-duty vehicles *(HDVs, incl. trucks and buses)* | 2.3 GtCO2, c. 6% | ● | ◕ | ○ | ◕ |
| | Rail | 0.2 GtCO2, <1% | ◕ | ● | ○ | ◕ |
| | Shipping | 0.9 GtCO2, c.2% | ◕ | ◕ | ○ | ◕ |
| | Aviation | 1.0 GtCO2, c.3% | ◕ | ◕ | ○ | ◕ |
| | Power generation | 13.8 GtCO2, c.36% | ● | ● | ◕ | ◑ |

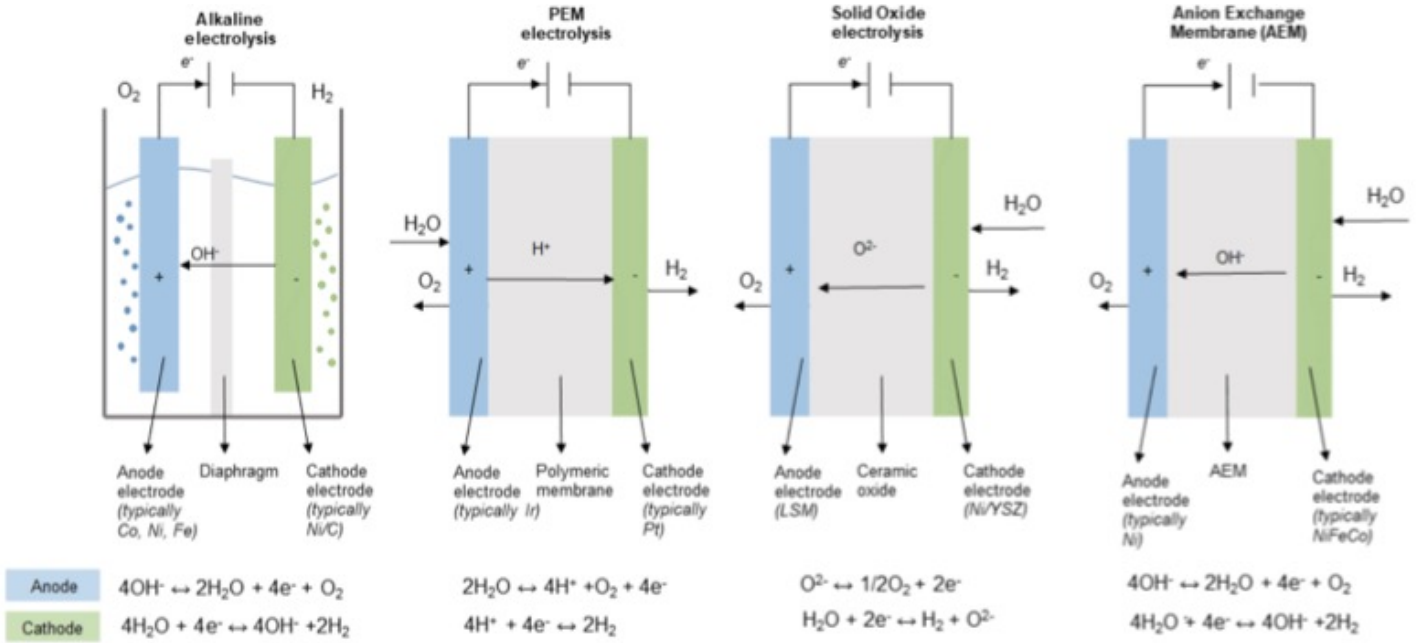
Source: Goldman Sachs Global Investment Research (2021)

# Appendix 18. Key hydrogen shades

| Hydrogen colour | | Hydrogen production process technology | | | Direct carbon intensity | Efficiency | | Scalability | Conditions | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Process | Feedstock | Process description | kgCO2e/kg H2 | kWh/kg H2 | % LHV | Typical plant size | Temperature °C | Water |
| Thermochemical | Brown | Gasification | Coal, Biomass, Oil, Solid waste | Coal is heated in a pyrolysis process to 400 degrees, vaporising volatile components of feedstock in H2,CO, CO2, CH4. Then oxygen is added in the combustion chamber and char undergoes gasification releasing gases, tar vapors, solid residues (CO and H2). Water-gas shift reaction converts CO into CO2 and H2 and then purification through methanation or PSA occurs. | 19.5 kgCO2e/kg H2 | 41-47 | 70-80% | 500,000 kgH2 pd | 80-1,800 | 9 L/kg H2 |
| | Turqoise | Pyrolysis | Natural gas | Hydrocarbons undergo heating without air combustion splitting into hydrogen and solid carbon black. There are four types: slow, flash, fast and microwave pyrolysis. | - | 47-66 | 50-70% | 10,000-50,000 kg H2 pd | 200-760 | n.a. |
| | Grey | Steam methane reforming (SMR) | Natural gas | Natural gas (methane) and high-temperature steam are mixed with nickel catalyst to produce hydrogen, CO and a small amount of CO2. Heat is typically provided by burning fuel gas. A water-gas shift reaction occurs where CO and steam are then reacted further to produce CO2 and more hydrogen. In the final step, hydrogen is separated from the tail gas through selective adsorption. | 9-11 kgCO2e/kg H2 | 52 | 64% | 200,000-500,000 kgH2 pd | 750-1,100 | 4.5 L/kg H2 |
| | | Autothermal reforming (ATR) | | ATR combines the endothermic reaction of steam reforming and exothermic reaction of oxidation. Feedstock natural gas, steam, or sometimes CO and dioxygen are mixed before pre-heating. In the combustion zone partial oxidation occurs producing a mixture of CO2 and hydrogen. In the catalytic zone gases leaving the combustion zone reach equilibrium. A water-gas shift reaction happens post ATR reacting CO with steam to produce more hydrogen and CO2. | 9 kgCO2e/kg H2 | 40-42 | 78-82% | up to 1,500,000 kg H2 pd | 980-1,200 | n.a. |
| | Blue | Steam methane reforming (SMR) + CCUS | Natural gas | Similar process to SMR above but with an integrated carbon capture system added. CO2 capture can be done on three streams: on the shifted syngas with MDEA, on the PSA tailgas with MDEA or from the SMR fuel gas using MEA. | 0.9-2.5 kgCO2e/kgH2 | lower end of range | lower end of range | 200,000-500,000 kgH2 pd | 750-1,100 | 4.5 L/kg H2 |
| | | Autothermal reforming (ATR) + CCUS | | Similar process to ATR above. Carbon capture is typically more effective in ATR compared to SMR given the higher concentration of CO2 in the stream. | 0.5-1.35 KgCO2e/kg H2 | lower end of range | lower end of range | up to 1,500,000 kg H2 pd | 980-1,200 | n.a. |
| Electrolysis | Green | Alkaline electrolysis (AE) | Renewable Electricity, Water | For all of these electrolysis routes direct current passes through an ionic substance producing chemical reaction at the electrodes. Electrodes are immersed in electrolyte and separated by a medium where Hydrogen ions move towards the cathode to form H2 and receivers collect this hydrogen and oxygen (other electrode) in gaseous forms | - | 48-64 | 52-69% | Scale-up ongoing | 60-80 | 9-15 L/kg H2 |
| | | Proton-exchange membrane electrolysis (PEM) | | | - | 43-60 | 60-75% | Scale-up ongoing | 50-80 | 9-15 L/kg H2 |
| | | Solid oxide electrolyzer cell (SOEC) | Renewable Electricity, Steam | | - | 40-45 | 74-81% | Research/ Pilot | 650-1,000 | 9-15 L/kg H2 |
| | Pink | Nuclear electrolysis | Nuclear energy, Water | Pink hydrogen is generated through electrolysis powered by nuclear energy. Nuclear-produced hydrogen can also be referred to as purple hydrogen or red hydrogen. | - | n.a. | n.a. | Research/ Pilot | n.a | n.a |

Source: Goldman Sachs Global Investment Research (2021)

# Appendix 19. Currently commercialized electrolysis technologies




| | Alkaline electrolyser | PEM electrolyser | SOEC electrolyser | AEM electrolyser |
|---|---|---|---|---|
| Development status | Commercial | Commercial | Demonstration/Pilot | Research |
| System cost (US$/kW) | 600-1,100 | 800-1,250 | >1,850 | n.a. |
| Electrical efficiency | 52-70% | 55-75% | 74-85% | 40-70% |
| Operating temperature (°C) | 60-80 | 50-85 | 600-1000 | 40-60 |
| Opearing pressure (bar) | 1- 30 | 30 to 80 | c. 1 | <35 |
| Current density (A/cm2) | 0.2-0.6 | 1.0-3.0 | 0.5-1 | n.a. |
| Response time | Start: 1-10 mins<br>Shut: 1-10 mins | Start: 1 sec - 5 mins<br>Shut: few seconds | High (n.a.) | n.a. |
| Load range (% of nominal load) | 10-110% | 20-160% | 20-100% | 5-100% |
| Stack lifetime (hours) | 60,000 - 90,000 | 30,000 - 80,000 | 10,000 - 40,000 | 5,000-9,000 |

Source: Goldman Sachs Global Investment Research (2021)