# WP5 Dutch Case studies (H-vision project)

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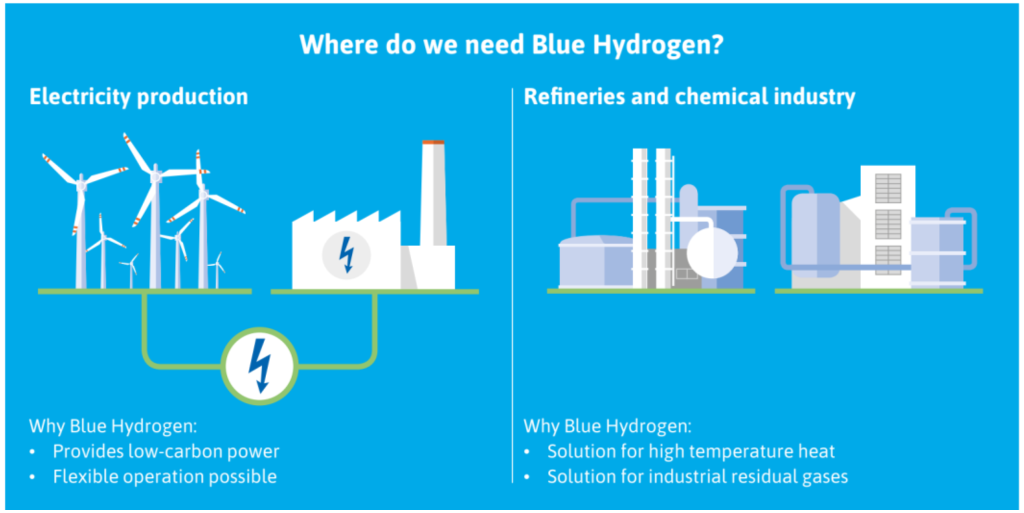
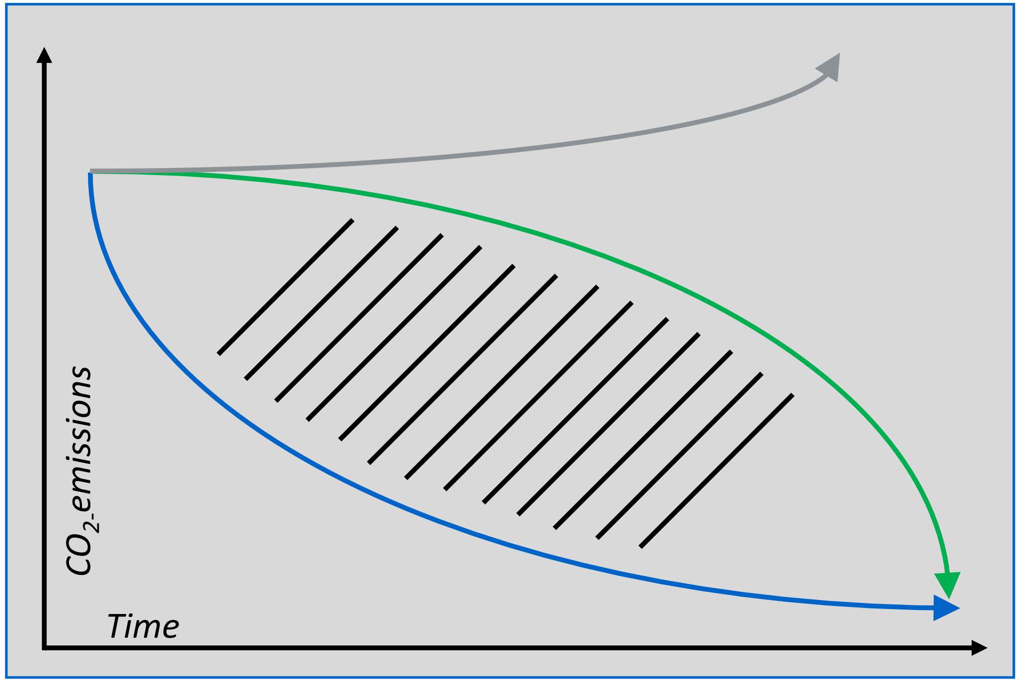
# Context & significance

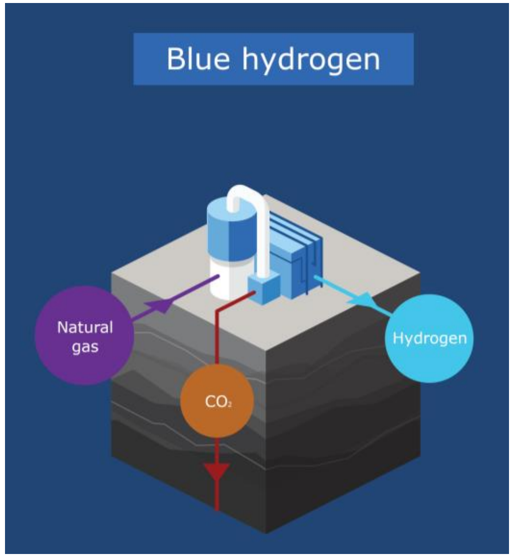
- Decarbonize port industry rapidly using pre-combustion blue $H_2$ for high temperature processes & electricity generation
- Pave the road for the Green Hydrogen Economy
  - Develop market for hydrogen
  - Make user innovation with hydrogen possible

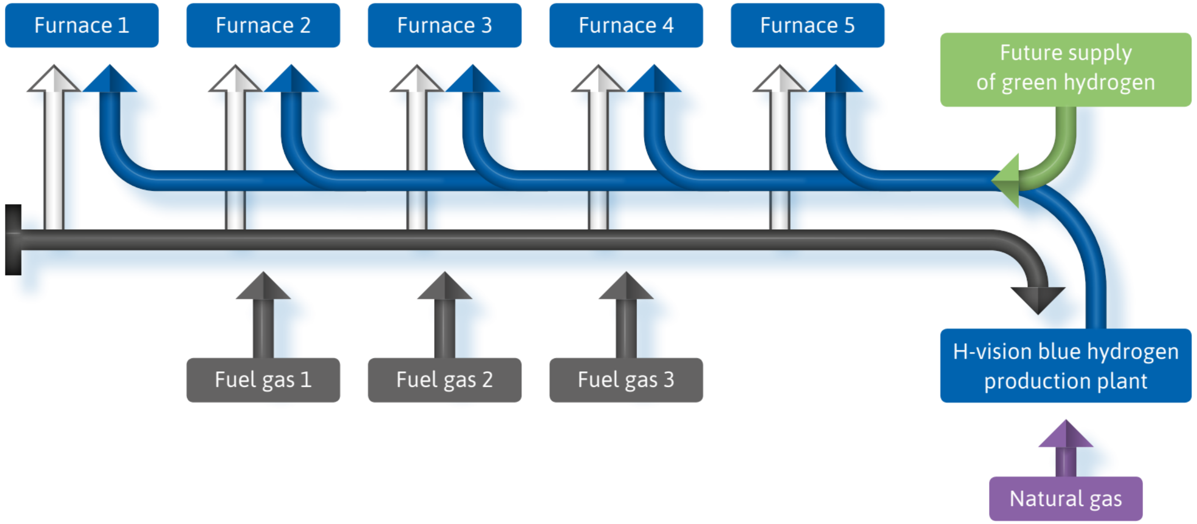


# The Dutch Case study (Rotterdam Port)

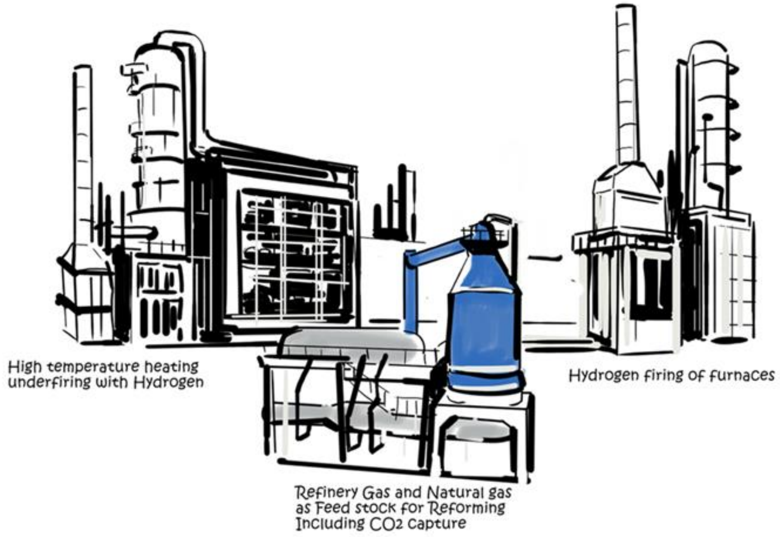
- New combination of existing technologies ($H_2$ from natural gas, CCS, hydrogen burning)
- Use of hydrogen to replace natural gas/coal burning & decarbonize refinery fuel gases
- All core technologies TRL 8-10
- No similar projects on this scale have been built (several studies such as H2M, HyNet, H21)



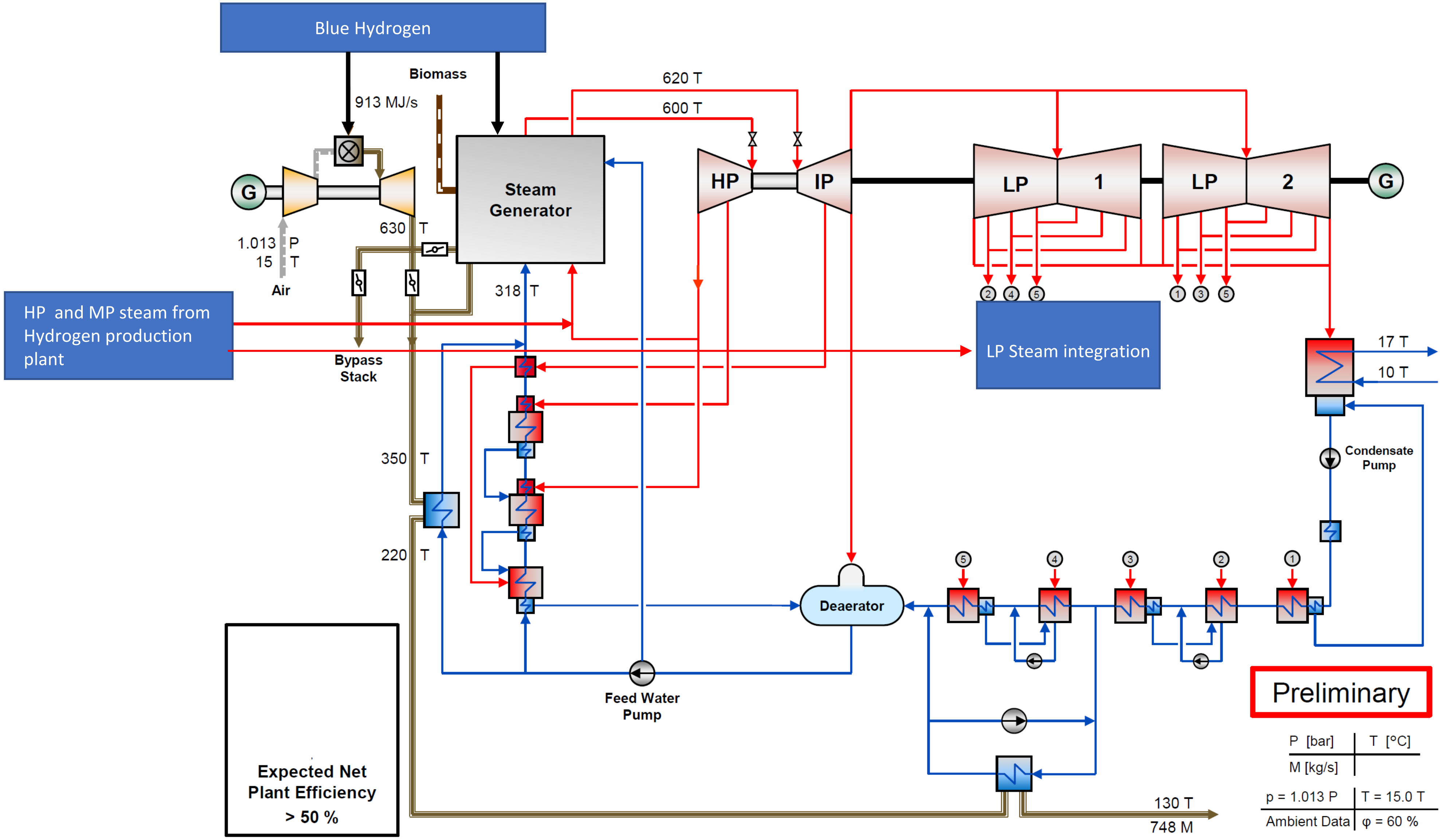



# Starting points, conceptual design:

- ✓ Hydrogen production unit based on ATR (+ GHR) technology
- ✓ Energy feedstock = (treated) refinery fuel gas and natural gas
- ✓ Hydrogen production plant size based on the minimum case of the H-Vision solution space, (in which scope and all value drivers are covered)
- ✓ The quality of hydrogen used by refineries for combustion applications can be lower than current feedstock standards. The optimal depends on project objectives and overall cost of $CO_2$ avoided.
- ✓ Power plants will mainly use hydrogen for flexible power generation, as defined in the minimum case
  - ✓ Additional potential for steam integration between the new $H_2$ production plant and existing power plants
- ✓ Possibility to transport captured $CO_2$ via Porthos pipeline



# H-Vision the solution space

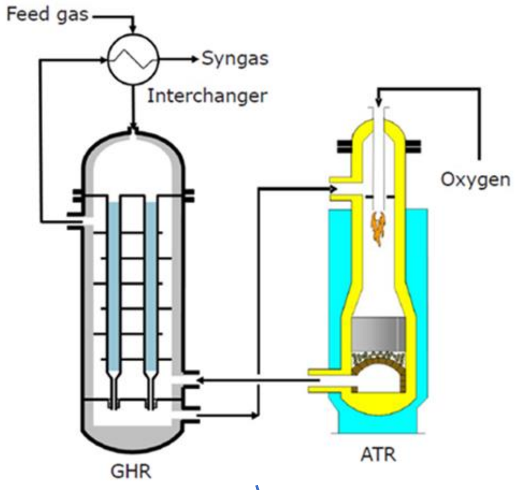


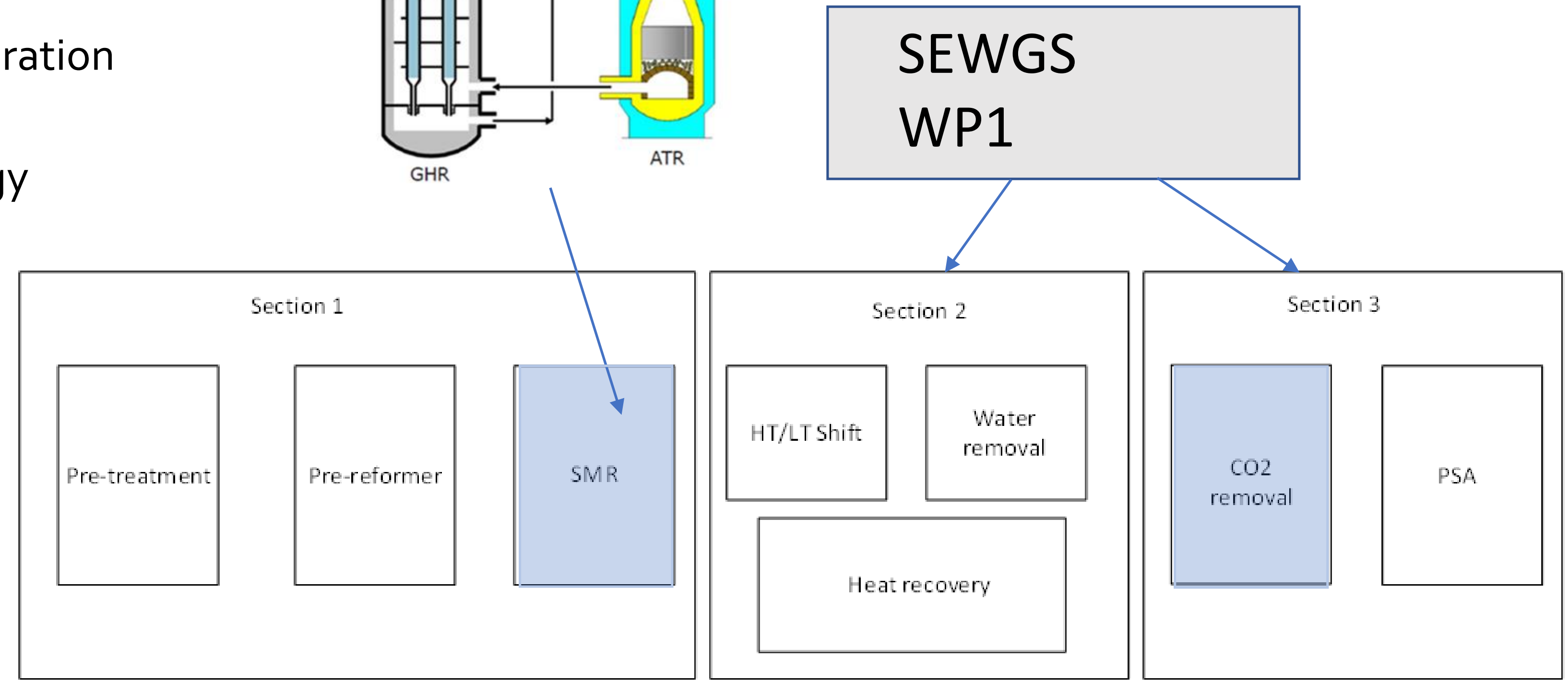

Integration of a Hydrogen Gas Turbine in the Boiler, BFW preheater cycle and IP steam cycle, picture from MHPS.

# Blue Hydrogen critical design parameters

The most critical design parameters to influence the process against these objects are:

- Methane slip
- Steam-to-carbon ratio (SMR vs. ATR)
- Catalysts
- Gas Heated Reformer
- Shift converter configuration
- Hydrogen purification
- $CO_2$ capture technology



# Coal fired PP revamp – two options selected

| Options for Maasvlakte coal units | Biomass | H2 fired preheaters | Steam from H2 plant | H2 Integrated GT | Total H2 demand |
|---|---|---|---|---|---|
| 1. Biomass + steam integration with H-Vision plant + $H_2$ fired preheaters for BFW | ~40% | 10%-15% | Max available from H2 production | | 190-285 MW per boiler |
| 2. Biomass + steam integration + 2 gas turbines (topping cycle & heat integration) + $H_2$ firing? | ~40% | 10%-15% extra still possible? | Max available from H2 production | 2 x 140 MWe GTs (41% eff.) | 683 MW (GTs) + 190-285 MW per boiler |

# Case design parameters

| Key parameters of $H_2$ production via HP ATR | | |
|---|---|---|
| ATR+GHR total plant capacity ($H_2$ output) | 700,000 | $Nm^3/h$ $H_2$ |
| $H_2$ purity in the outlet stream | 95.5 | % |
| ATR+GHR total plant capacity (fuel output) | 2,400 | MW thermal (LHV) |
| Overall thermal efficiency | 78 | % on LHV basis |
| | ~82 | % on HHV basis |
| Total feedstock (input of NG + RFG) required | 3,130 | MW thermal (LHV) |
| Excess steam production (available for export, with 20°C superheating) | 305 | t/h HP steam (100 bar) |
| | 100 | t/h MP steam (30 bar) |
| Electricity import | 128 | MW el |
| Direct $CO_2$ emissions at the H-Vision plant | 6 | t/h $CO_2$ |
| $CO_2$ captured at the H-Vision plant | 498 | t/h $CO_2$ |
| $CO_2$ capture & export factor | 0.208 | t $CO_2$ / MWh |
| $CO_2$ purity in the export stream | 99 | % |
| Overall capture rate (including residual carbon) | 88 | % |
| Overall $CO_2$ emissions factor | 0.028 | t $CO_2$ / MWh |
| Total plant cost | 910 | M€ |
| Fixed OPEX (2.5% of CAPEX annually) | 22.8 | M€ |

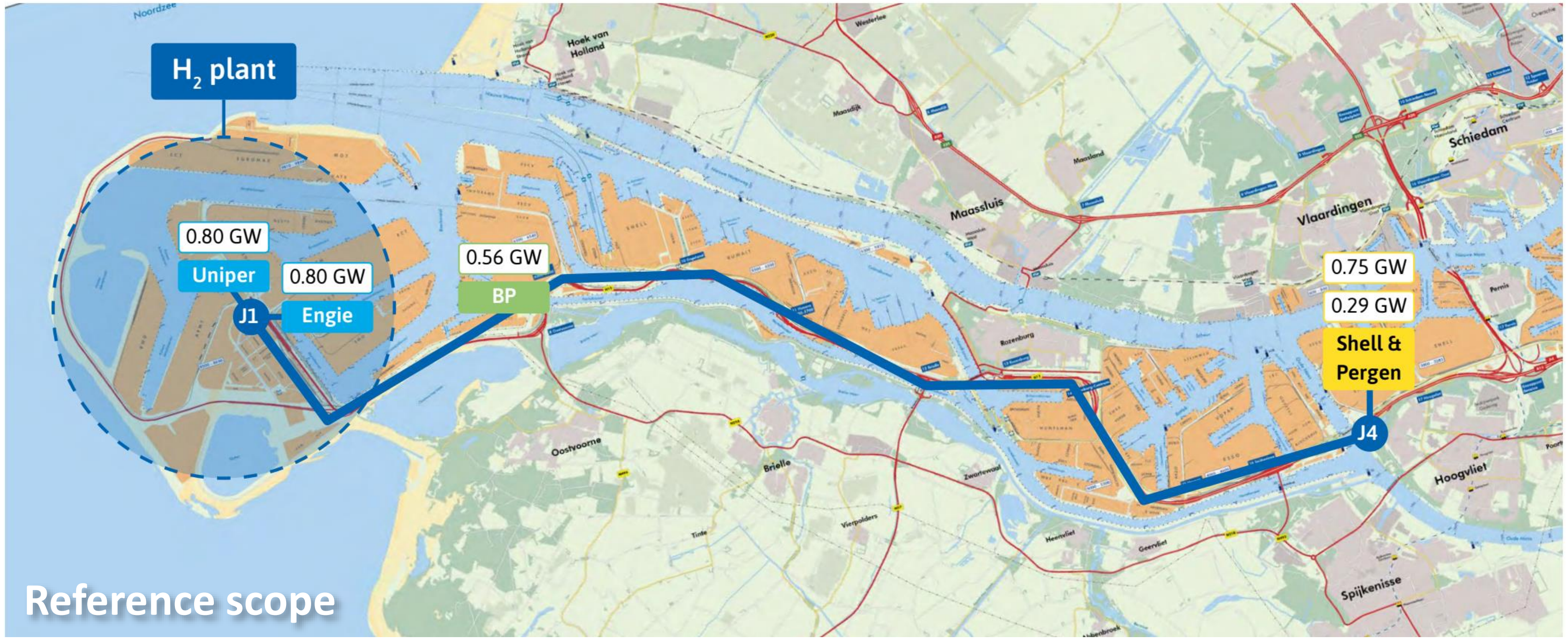
**Overview of variable factors & example calculation for the reference case**

| Type | Factor | Unit | Reference case |
|---|---|---|---|
| NG/RFG feedstock | 1.282 | MWh feed/ MWh $H_2$ | 2573.6 MW* |
| Electricity (+5-10% for the NG and RFG compressors) | 0.053 | MWh el/ MWh $H_2$ | 155.7+17.3 MW el** |
| $CO_2$ export (captured $CO_2$) | 0.208 | t $CO_2$/ MWh $H_2$ | 608.3 t/h $CO_2$ |
| $CO_2$ emissions | 0.028 | t $CO_2$/ MWh $H_2$ | 83 t/h $CO_2$ |

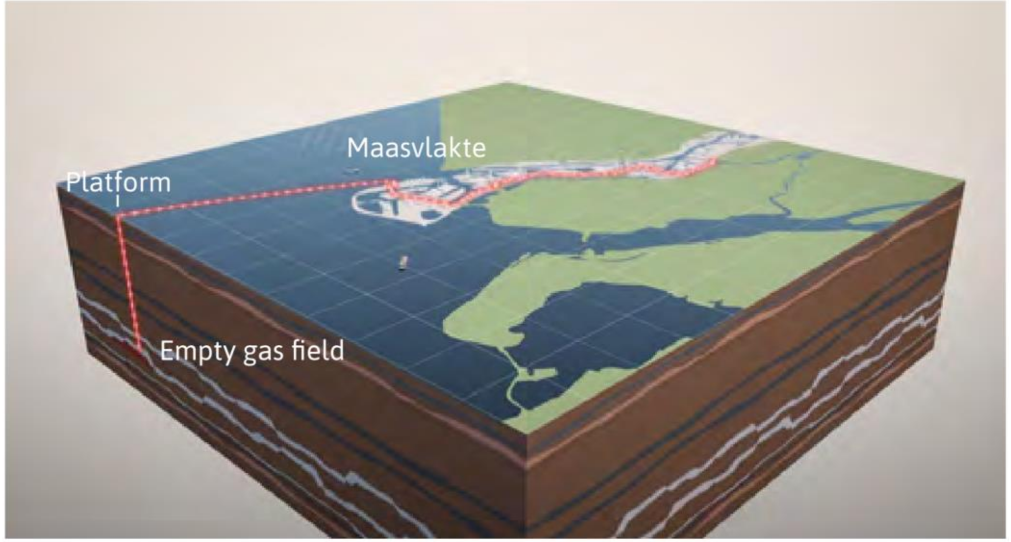
* RFG feedstock is subtracted from the total required, since this is not an additional cost
** Some of the required power will be generated using steam exported from the H-Vision plant, and could be therefore supplied at a lower-than-market cost

# Dutch case industrial platform:

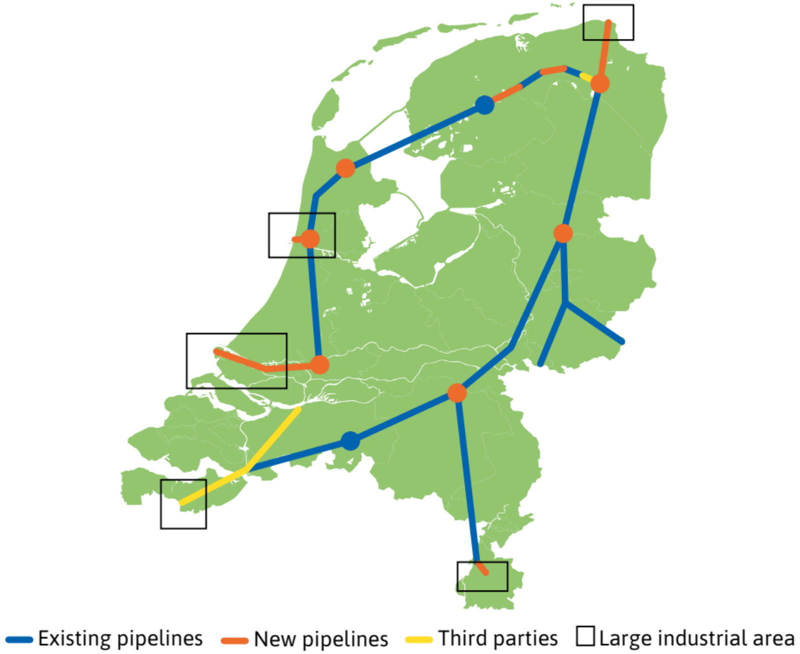
# H-vision – Participants & location



# Dependencies for the Dutch  Case study




Porthos (CCS)

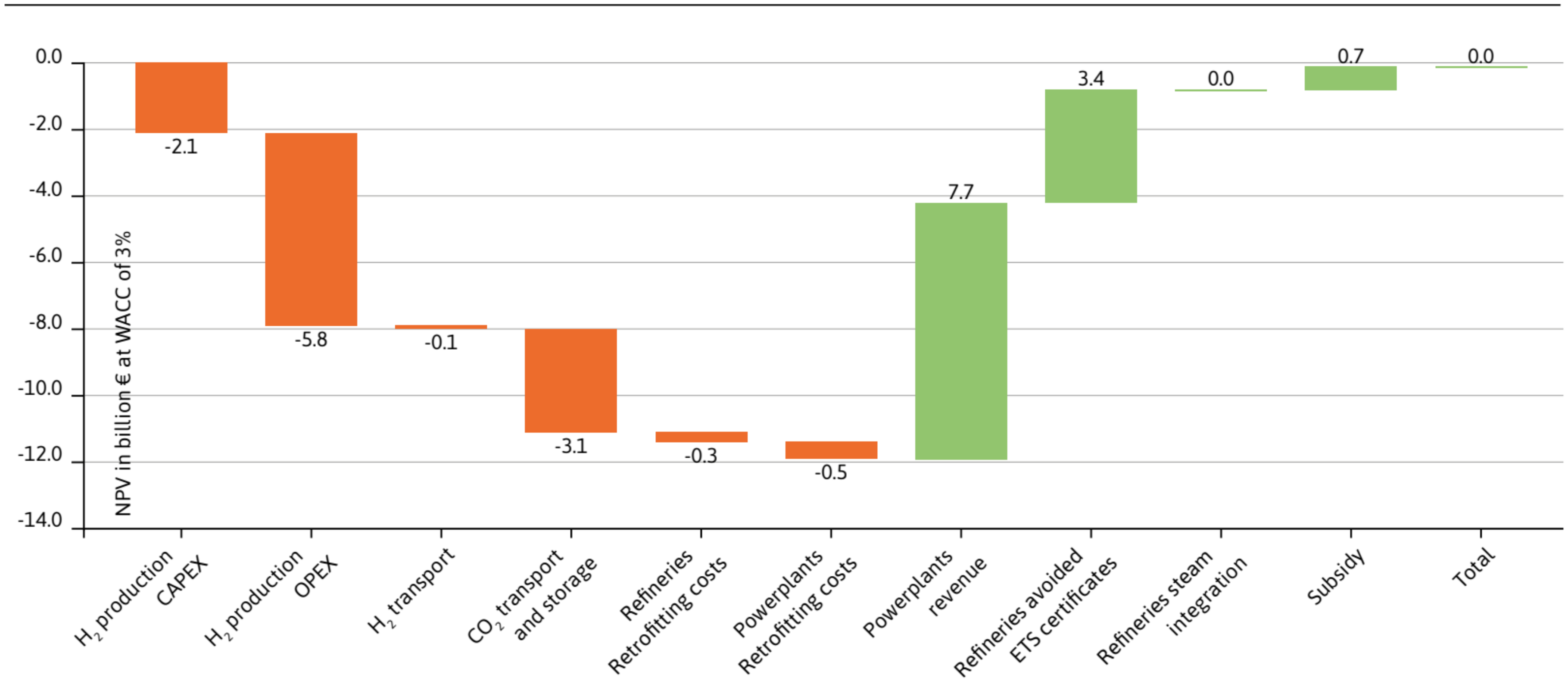



Hydrogen backbone (only for maximum scope)

**Other dependencies**

- Financial support to close gap
- $CO_2$ price
- Regulation regarding CCS & $CO_2$ transport (international)

# Investments & revenues




**2**

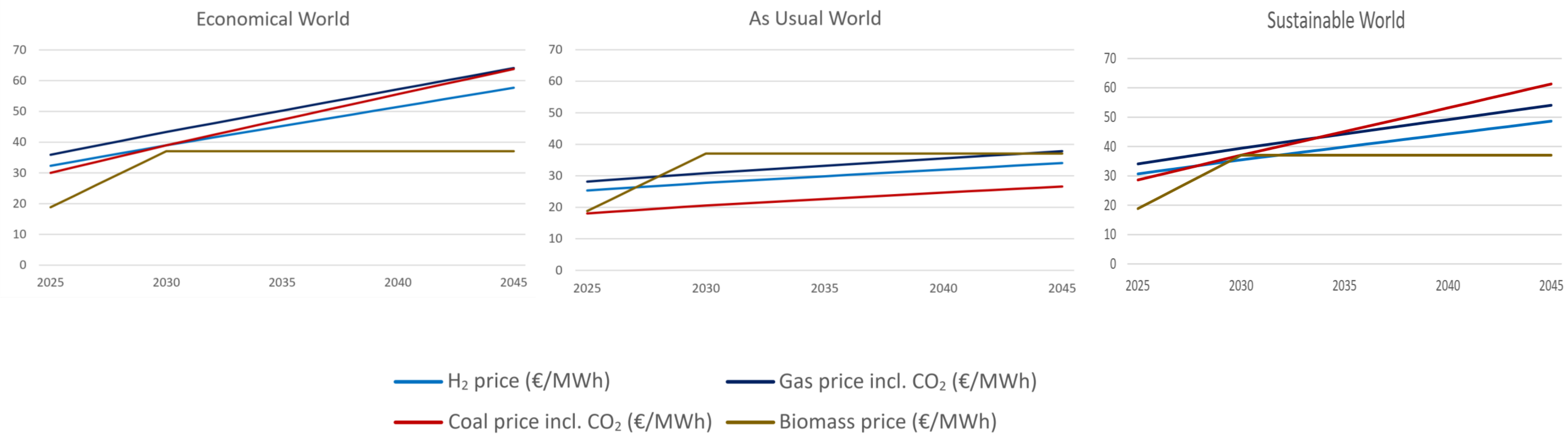
**Billion Euro investment**

**€ 110/ton**

**Avoidance costs for reference – as usual case**

# Scenarios & range

| | | | Minimum scope | Reference scope | Maximum scope |
|---|---|---|---|---|---|
| | $CO_2$ abatement | Mt | 27 | 79 | 130 |
| As Usual | NPV (WACC 3%) | Billion € | -1.8 | -2.8 | |
| | Avoidance costs | €/t $CO_2$ | 146 | 111 | |
| Economical | NPV (WACC 3%) | Billion € | -1.3 | -0.7 | -2.1 |
| | Avoidance costs | €/t $CO_2$ | 190 | **146** | 151 |
| Sustainable | NPV (WACC 3%) | Billion € | | 2.5 | 3.1 |
| | Avoidance costs | €/t $CO_2$ | | 86 | 91 |

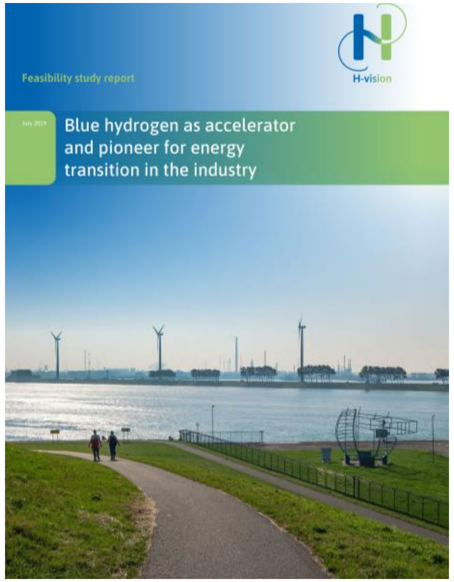


# Stage gate of H-vision project

We are here

| IDENTIFY | ASSESS | SELECT | DEFINE | EXECUTE | OPERATE |
|---|---|---|---|---|---|
| Do we understand what we are starting? | Have we looked wide enough? | Have we selected the optimum solution? | Is everything in place to ensure success? | Are we ready to operate? | What have we learned? |
| DG1 2018 | DG2 2019 | DG3 2020 | DG4 FID 2022 | 2025 | 1st Hydrogen 2026 |

Feasibility study ↑ July 2nd 2019

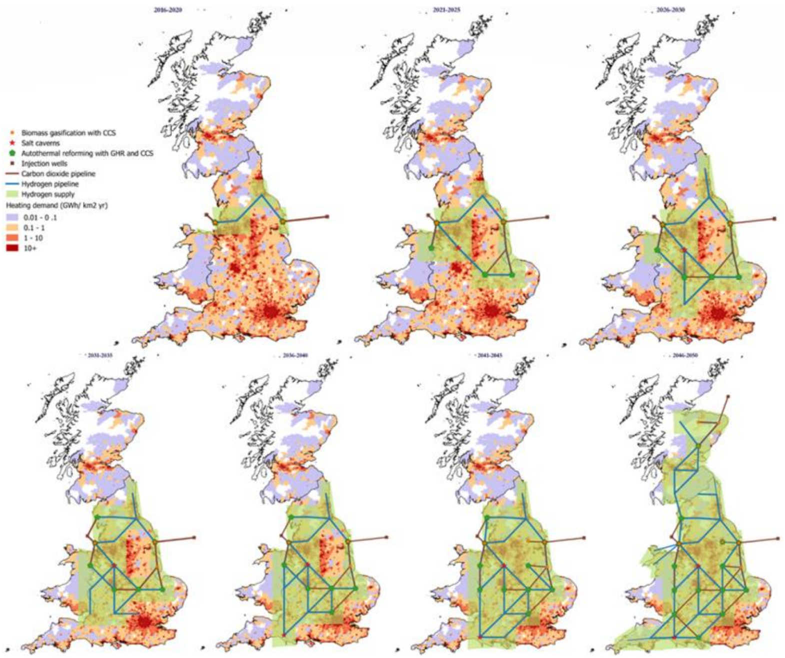


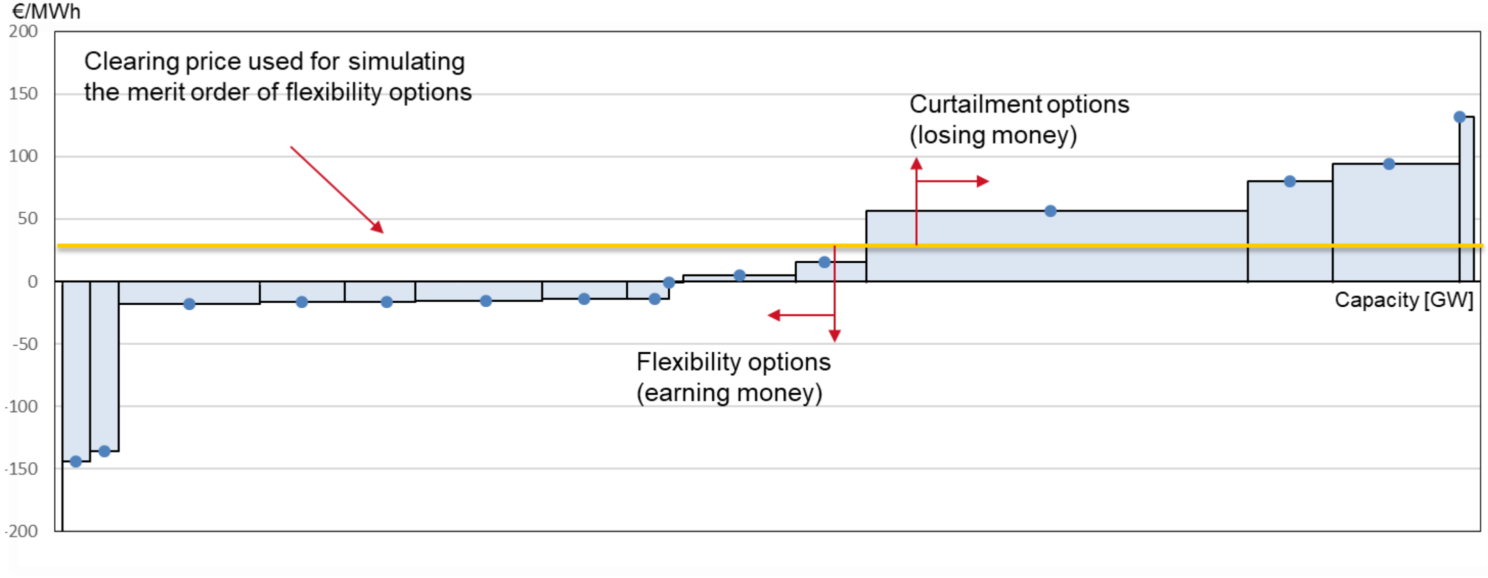

**Next steps & future**

- Working towards SELECT phase
- Kickstart hydrogen economy & innovation in Rotterdam → Europe
- Project economics look good compared to other $CO_2$ reduction solutions
- Financial & policy support needed

# Elegancy Next steps

- Final study on future power market mechanism and further development of TNO Eye-tool: Market simulator that includes (renewable) power, Demand Side Response and Hydrogen market.
- Firm up the Spatial model from (Imperial College) for the Dutch case study in the Rotterdam Region.
- ROADMAP for the introduction of a low carbon industry in the Rotterdam Region.





# Questions?