DELIVERABLE REPORT

D7.1 Recommendations for market deployment support mechanisms

Version 02.06.2014

DISSEMINATION LEVEL: Public (PU)

Acknowledgement:
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Scope & background

The FCH-JU supported PHAEDRUS project is conducting R&D of 70MPa hydrogen refueling stations (HRS).
Emphasis is on R&D of high pressure PEM electrolysis and electrochemical compression technologies.

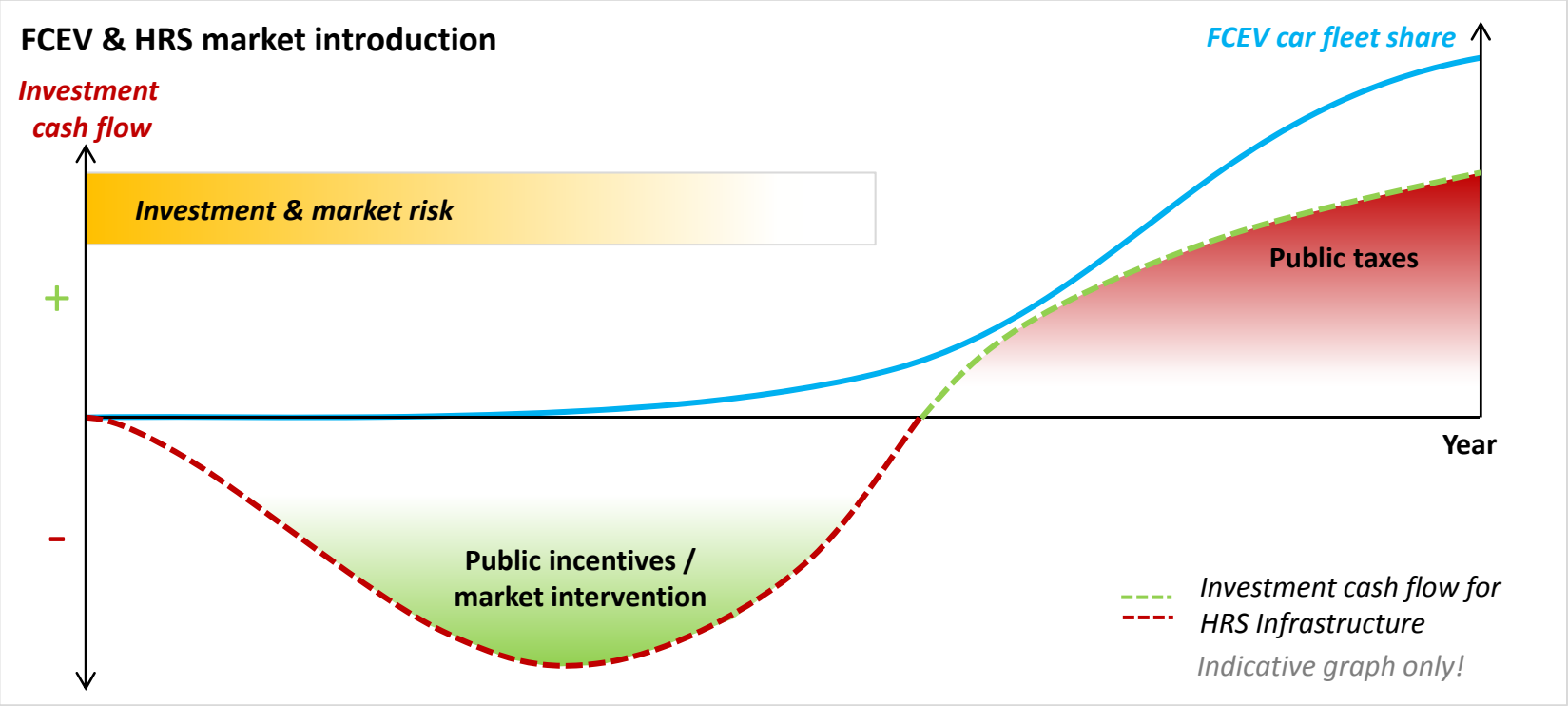
Several support activities in the project are to analyze the market conditions around future HRS's.
This deliverable report is to present recommendations for market deployment support mechanisms.
Focus is on mechanism for HRS's that can bridge the gap between early roll-out & future commercialization.

Perspective of the analysis and recommendations takes into account previous efforts done within the topic.
In particular previous HRS roll-out analyses from the various European H2Mobility initiatives and studies.
Where these past efforts typically focused on HRS network level – this report looks at each individual HRS.
In particular what level of public support is required to enable a feasible & attractive HRS's operation.

This report is available at www.phaedrus-project.eu

Overall challenge: HRS network roll-out (Macro level)

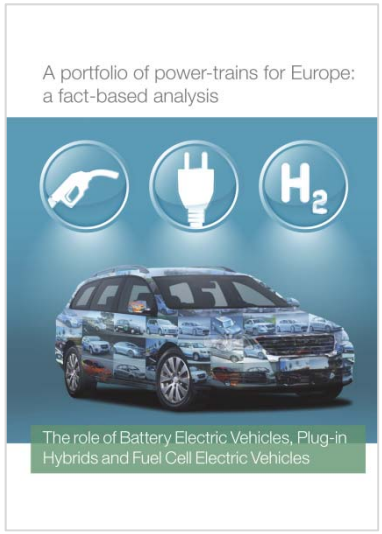
The overall challenge in rolling out a HRS network is well-known and illustrated in the figure below.
During the early years substantial upfront investments with high risks are to be made.
In order to grow FCEV sales HRS capacity build-up grows faster during the early years.
This leads to a low network utilization that again impacts the overall feasibility of the network operation.
Additionally the HRS technology costs during the early years will most likely be above commercial targets.
Public incentives or market intervention may help close the financial gap and reduce risk for investors.



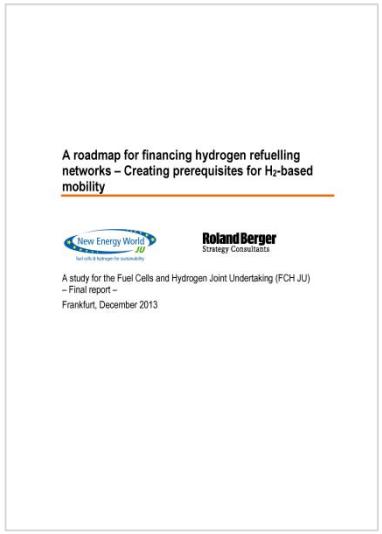
Previous HRS network roll-out analyses (Macro level)

The challenges and economical fundamentals of a HRS network roll-out is supported by numerous studies. In particular the various European H2Mobilities and various FCH-JU supported analyses and projects.

Both the EU Power Train Analysis and UK H2Mobility arrives at a similar network roll-out challenge. Based on this the FCH-JU recently supported a study on how to finance HRS network roll-out (macro). The FCH-JU report in focused on how to leverage the financial risks, on an overall network level (macro).



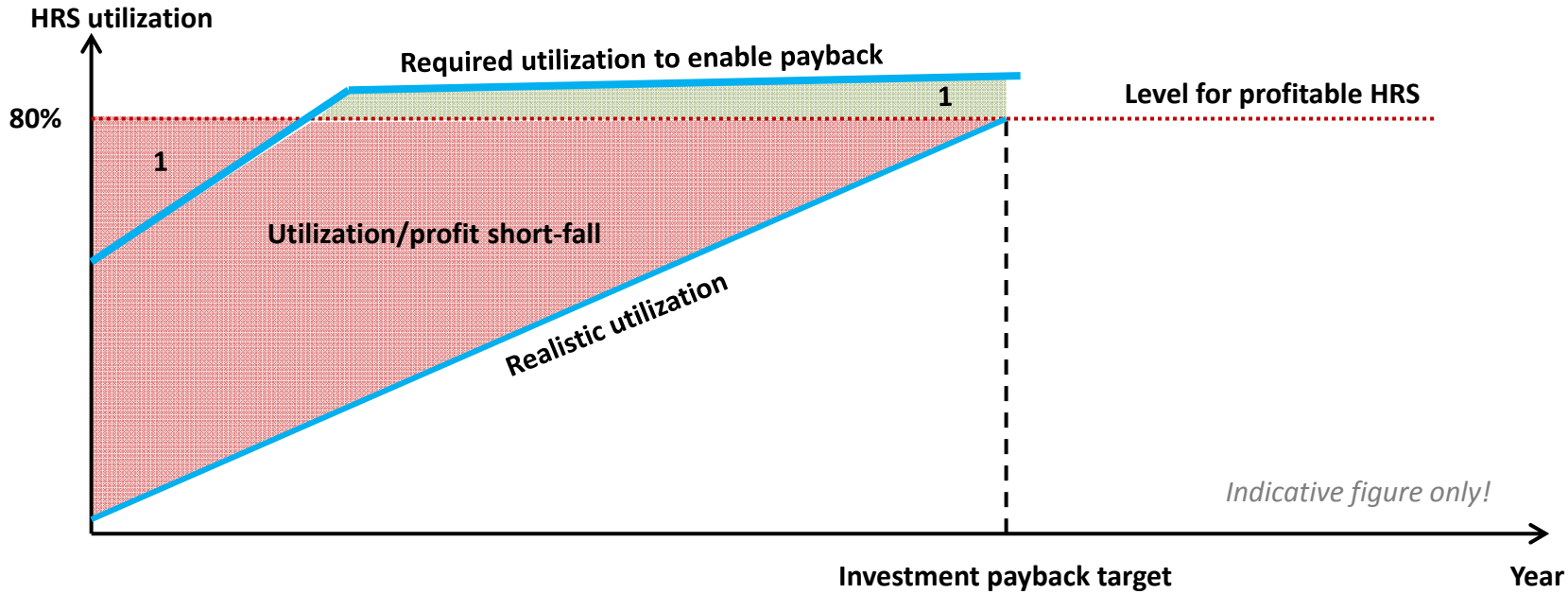
HRS network roll-out analyses



HRS network financing analysis

The utilization challenge for each HRS (Micro level)

The roll-out challenge on overall network level is caused by a fundamental utilization challenge for each HRS.
Most commercial investors require payback + IRR of the investment after a limited number of years.
For the HRS to be capable of this, would require that sufficient utilization (e.g. 80%) is reached from year 1.
However as the FCEV market penetration most likely will be slow, this is very likely not to be possible.
Instead the utilization will grow much slower, resulting in a shortfall of profit thus not reaching payback target.
The "idea" on network level is that better utilized HRS's can cover the short-fall for less utilized HRS's.
However this requires that one or few companies has a large share of the network for several years.
Support incentives, e.g. risk sharing, can then be applied on a network level (macro level).



Applying incentives for individual HRS's (micro level)

The situation as of today is that HRS's typically are build by individual stakeholders.

Thus the operation of and investing in a HRS is to be view and evaluated on individual/micro level.

The HRS operator therefore needs to ensure a feasible operation for each individual HRS.

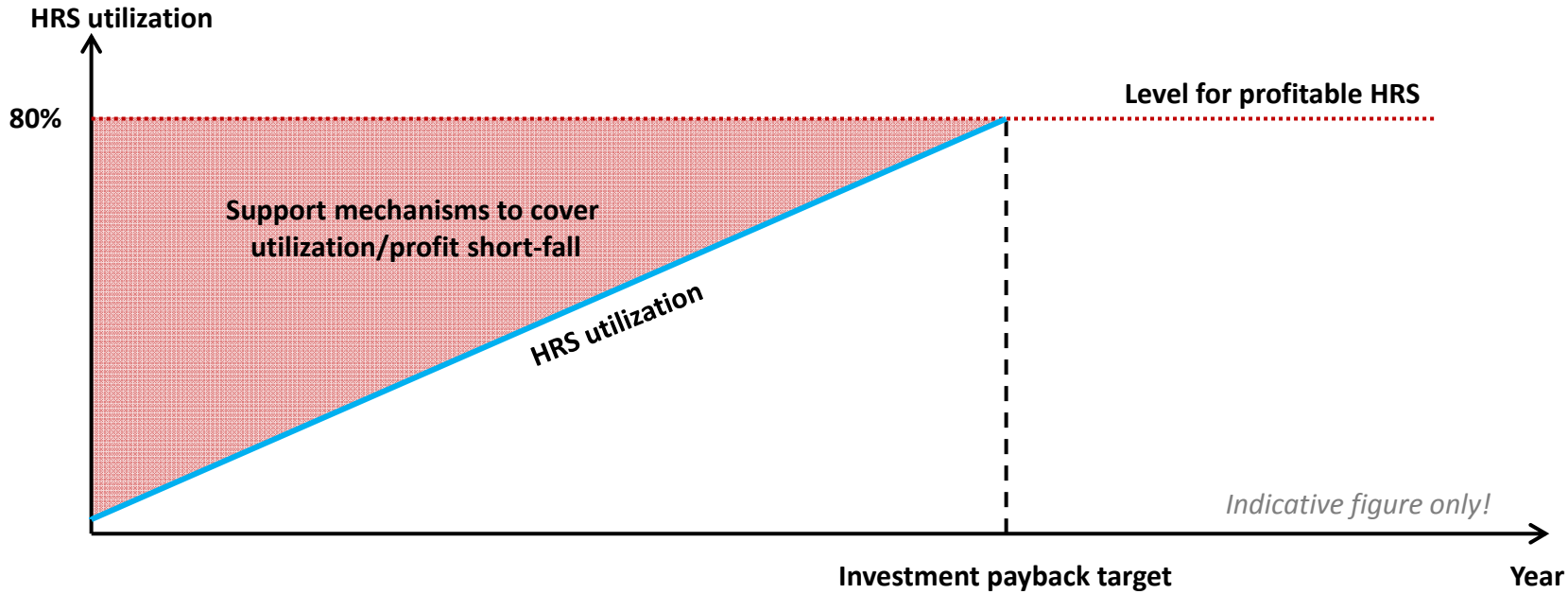
There will be no contributions from other highly utilized HRS's in the network.

Instead other HRS's in the network may on a local basis reduce utilization level (local HRS competition).

To enable a feasible operation either HRS's are build as part of a joint network company (e.g. H2Mobility).

Or public support schemes for each individual HRS's enables reaching of a feasible operation.

Report scope is to calculate the public support needed for achieving feasible operation of individual HRS's.



Calculation model for HRS support need (micro level)

The public support required to reach a commercial attractive HRS operation depends on several variables.

- *HRS CAPEX*
- *Cost of H2 delivered to HRS & annual increase*
- *H2 retail price (at pump) & annual increase*
- *Electricity consumption for dispensing*
- *Electricity cost & annual increase*
- *Year of HRS operation start*
- *Evolvement in HRS utilization*
- *Fixed OPEX cost & annual increase*
- *Payback time target (investor)*
- *IRR target (investor)*

H2 Price	2012	2017	2020	2023
Delivery ↓ Sale →	€ 8,5	€ 9,4	€ 10,8	€ 12,4
€ 13,0	IRR<0 Year20			
€ 11,0		IRR<0 Year20		
€ 9,0			€ 62.748	
€ 7,0				€ 927.259
€ 5,0	€ 474.823	€ 679.620	€ 1.016.426	€ 1.404.098

RUN CALCULATION (CTRL+R)

MAKE SURE TO RUN CALCULATION AFTER ANY CHANGE!

PARAMETERS											
HRS max. capacity	200		kg/day								
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10+	
HRS utilization %	25%	31%	37%	43%	49%	56%	61,7%	68%	74%	80%	%
HRS average kg/day	50	62,22	74,44	86,67	98,89	111,11	123,33	135,56	147,78	160	kg/day
HRS kg sales annual	18.250	22.711	27.172	31.633	36.094	40.556	45.017	49.478	53.939	58.400	kg/year
Public fuel support	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€/kg if this applies
Customer fuel VAT%	0%		Add fuel VAT% if this applies to refueling customer								
H2 Price increase	4,8%		Annual percentage increase for both delivery & sales								
HRS electricity consumption	5,0		kWh/kg consumped for entire HRS - ex. H2 supply (15% LHV)								
Electricity price	€ 0,15		€/kWh including all applicable taxes (EU average 2014)								
Electricity price increase	3,8%		Annual percentage increase (EU average increase 2000-2013)								
Maintenance cost	€ 30.000		€/year								
Maintenance cost increase	3,0%		Annual percentage increase								
Public CAPEX support	0,00%		Percentage of CAPEX								
Payback time	10		No. of years wanted - either: 3, 5, 7, 10, 12 or 15								
IRR %	15,0%		Internal Rate of Return as percentage								

A calculation model has been developed that calculates the public support required to break-even.

The principle is that an investor is to break-even with a certain IRR level after a certain number of years.

The level of public support depends on whether operation is profitable, and if sufficient to cover HRS CAPEX.

Model calculation examples	**2017**	**2020**	**2023**
HRS CAPEX investment	-€ 1.000.000	-€ 800.000	-€ 600.000
HRS profit/loss (coverage of OPEX & IRR)	-€ 743.883	€ 695.577	€ 1.002.956
Result	-€ 1.743.883	-€ 104.423	€ 402.956
Public support to break-even	€ 1.743.883	€ 104.423	€ 0
Public support needed as % of HRS CAPEX	**174%**	**13%**	**0%**

Public support need principles:

Acc. result ≥ HRS CAPEX = no need for public support

Acc. result ≤ HRS CAPEX = 0-100% public support

Acc. result ≤ HRS OPEX+IRR = 100+% public support

HRS assumptions – 200kg/day 70MPa SAE J2601

HRS CAPEX targets for 2017, 2020 and 2023 are derived from the FCH-JU MAWP 2014 (draft)

Fixed OPEX per year is assumed to reach 5% of CAPEX (general level for industrial plants) + 3% annual increase.

Dispensing energy kWh/kg is derived from NREL report – however figure with great uncertainty.

Additionally impact of idling consumption at “under utilization” is not taken into account.

<table>
<tr><th rowspan="2">Parameter</th><th colspan="3">Year</th><th rowspan="2">Source</th></tr>
<tr><th>2017</th><th>2020</th><th>2023</th></tr>
<tr><td>HRS CAPEX
200kg/day 70MPa SAE J2601</td><td>€1.000.000</td><td>€800.000</td><td>€600.000</td><td>FCH-JU MAWP 2014 targets (draft)</td></tr>
<tr><td rowspan="2">Fixed OPEX / year</td><td>€50.000</td><td>€40.000</td><td>€30.000</td><td rowspan="2">Assumed general level for industrial plants</td></tr>
<tr><td colspan="3">5% of CAPEX</td></tr>
<tr><td>Fixed OPEX increase per year</td><td colspan="3">3%</td><td>On level with general EU inflation</td></tr>
<tr><td>Dispensing energy kWh/kg</td><td colspan="3">5,0</td><td>NREL "Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs" May 2014 (85% compressor efficiency, 15% loss of LVH H2 (33,33kWh)</td></tr>
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Variable OPEX assumptions – H2 & electricity

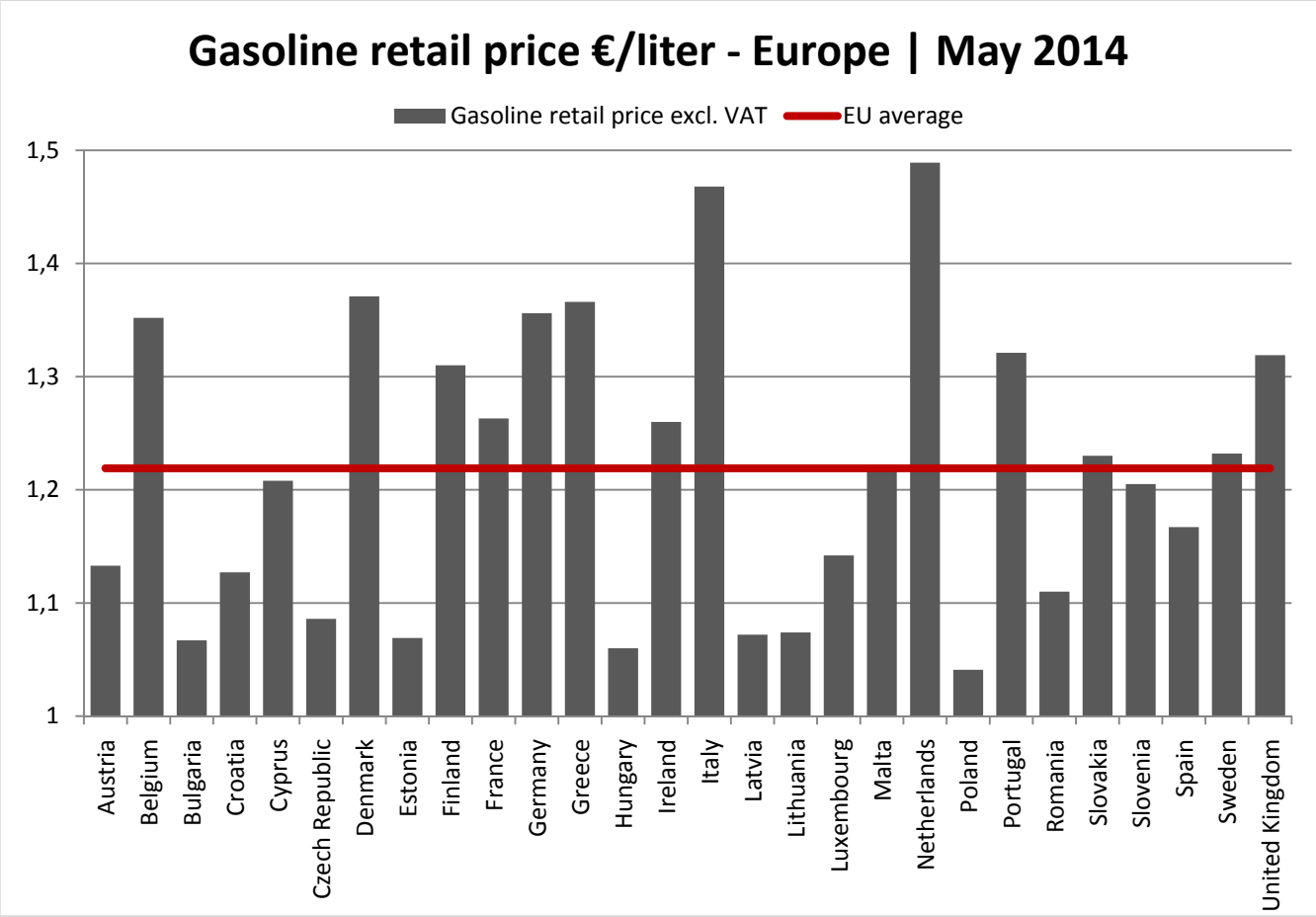
Cost of hydrogen delivered at HRS for 2017, 2020 and 2023 are derived from the FCH-JU MAWP 2014 (draft)
Assumptions for hydrogen retail price, electricity & annual increase are further elaborated on following slides.

Parameter		Year			Source
		2017	2020	2023	
Cost of hydrogen delivered at HRS	Hydro-carbon fuelled	€5/kg			FCH-JU MAWP 2014 targets (draft)
	Hydrogen fuelled	€11/kg	€9/kg	€7/kg	
Hydrogen retail price excl. VAT		€9,4/kg	€10,8/kg	€12,4/kg	Gasoline completive pricing. See next slides
Electricity cost incl. taxes, excl. VAT		€0,116/kWh	€0,130/kWh	€0,146/kWh	EU average - See next slides
Annual price increase hydrogen Both H2 delivery cost and pump price		4,8%			Same annual increase as EU average gasoline pump price for past 14 years (2000-2013). See next slides.
Annual price increase electricity		3,8%			Same annual increase as EU average electricity price for past 14 years (2000-2013). See next slides.

Gasoline retail price excl. VAT in EU countries | May 2014

EU average gasoline retail price excl. VAT of €1,219/liter in May 2014.

Historic statistics & regular updates made by www.energy.eu



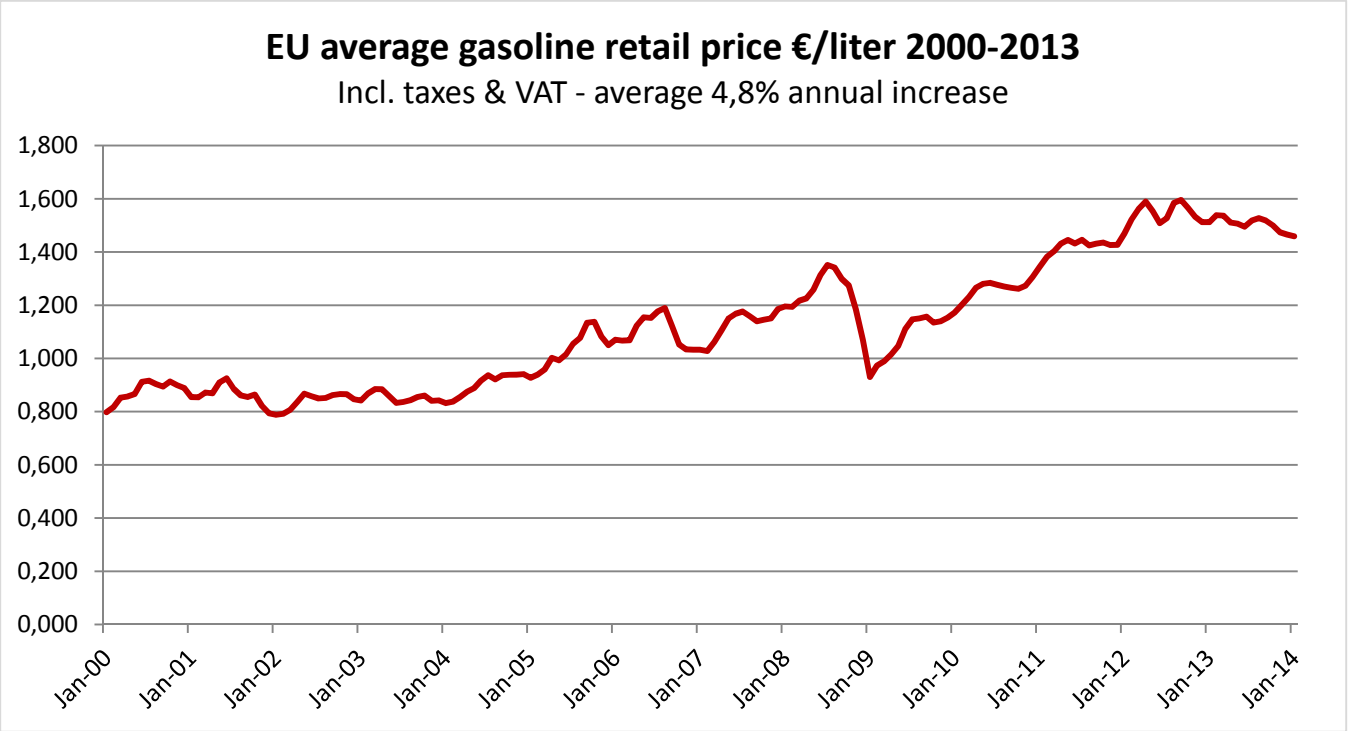
Europe's Energy Portal
Energy prices from past to present

EU average gasoline retail price incl. VAT 2000-2013

The EU average gasoline retail price has increased 4,8% annually during 2000-2013 (14 years).

The increase is for the retail price incl. VAT based on www.energy.eu

Increase for retail price excl. VAT is not available – assumed same annual increase of 4,8%.

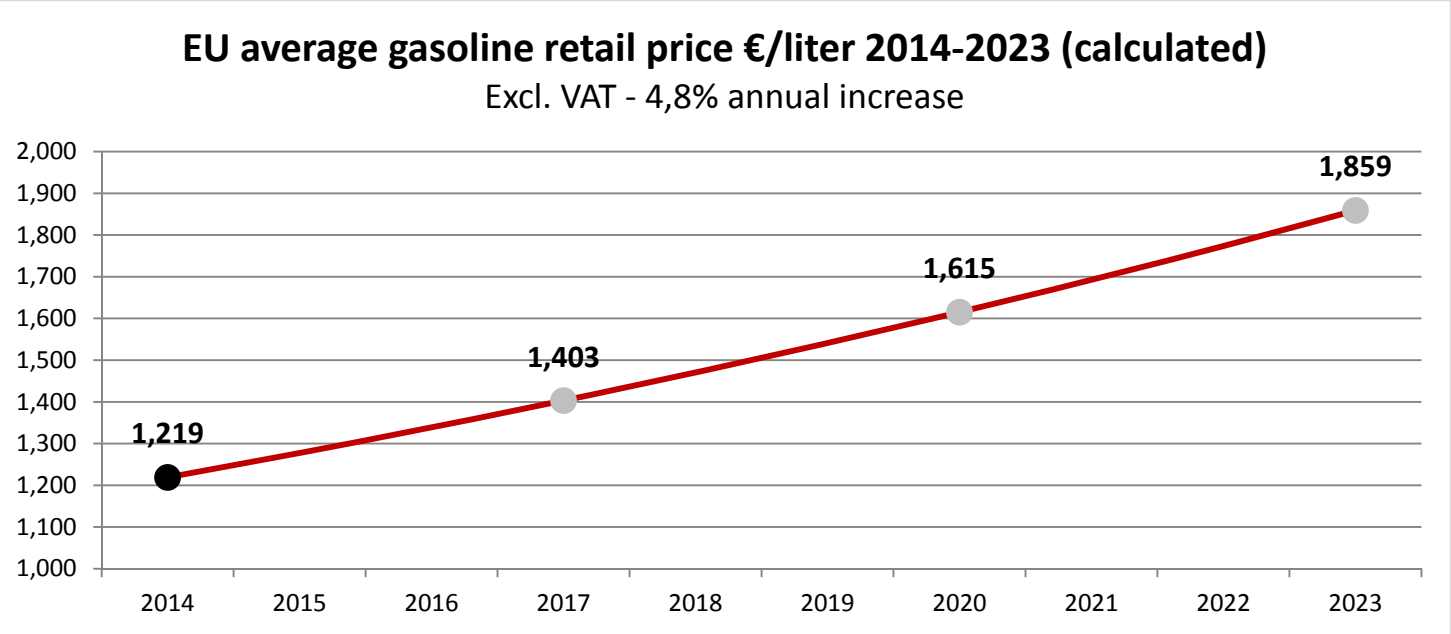


Europe's Energy Portal
Energy prices from past to present

EU average gasoline retail price 2014-2023 (calculated)

Based on a 4,8% annual increase the EU average gasoline retail price onwards 2023 is calculated.

The annual gasoline price is the basis for calculating a competitive hydrogen pump price (fuel cost/km).



Hydrogen price match gasoline – EU average | May 2014

Determining the hydrogen pump price is based on ensuring competitiveness with gasoline (fuel cost/km).
Fuel consumption (NEDC) for gasoline ICE and FCEV is based on assumed average figures as of today.
Assumption is that efficiency improvement for ICE and FCEV will be similar onwards 2023.
Ratio between ICE and FCEV consumption figures is therefore kept constant onwards 2023.

Hydrogen Pricing - EU average | May 2014

Based on EU average gasoline retail price excl. VAT

	Fuel retail price *Excl. VAT*			**Consumption** *km/l or kg/100 km*			**Price/km** *€/km*
GASOLINE	**1,219**	*€/liter*	→	**15**	*km/liter*	→	0,08
							↓
HYDROGEN	**8,13**	*€/kg*	←	**1,00**	*kg H2/100 km*	←	0,08

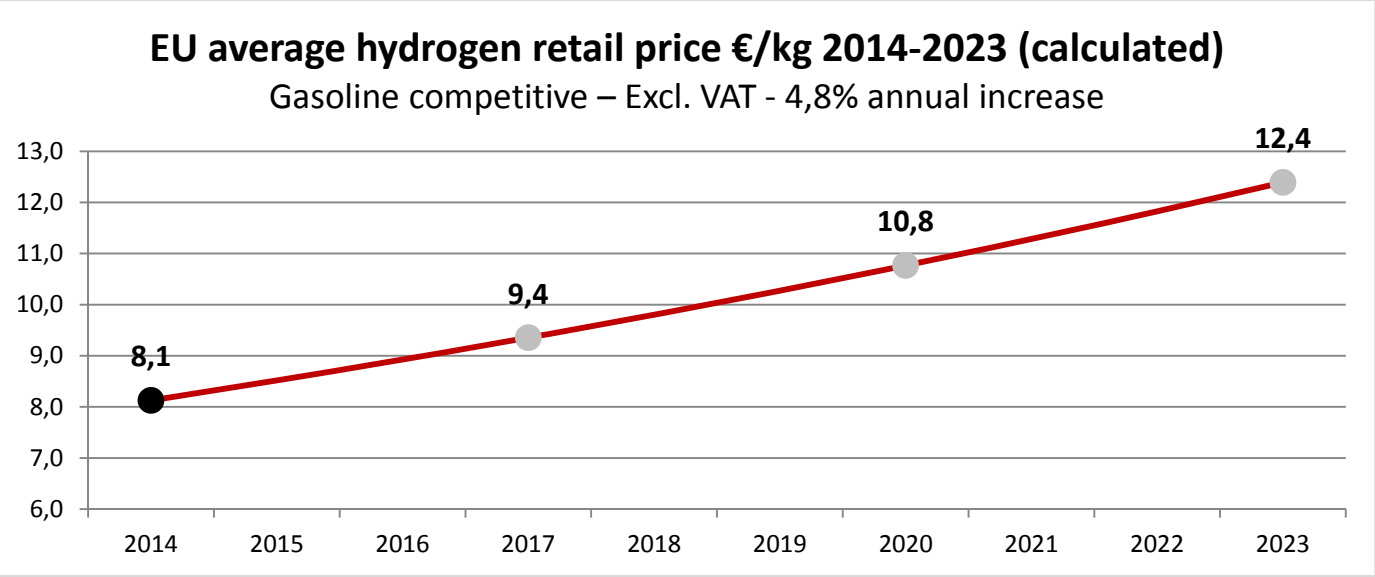
EU average hydrogen retail price 2014-2023 (calculated)

Based on a 4,8% annual increase the EU average hydrogen retail price onwards 2023 is calculated.

The hydrogen retail price is competitive with gasoline on a fuel cost per driven km basis.

For the HRS operation calculations the calculated H2 retail price for the “year of operation start” is used.

Operation calculations are dynamic – thus 4,8% annual increase from “year of operation start” is included.

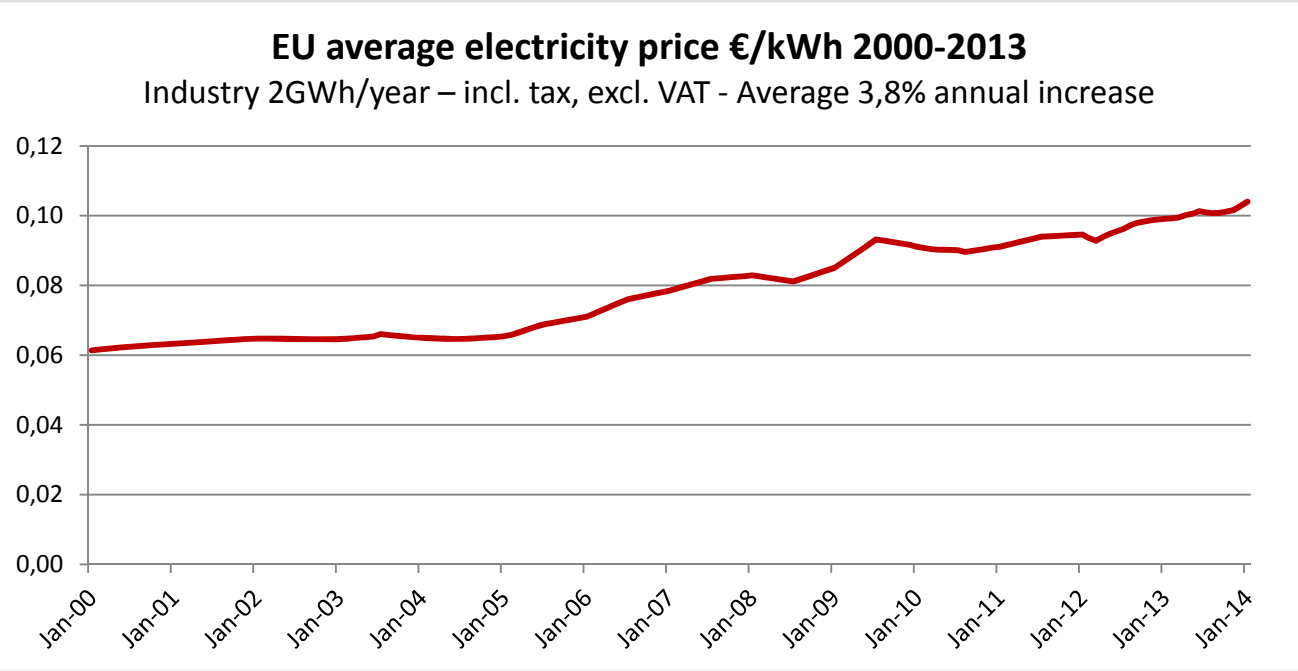


EU average electricity price incl. tax, excl. VAT 2000-2013

The EU average electricity price has increased 3,8% annually during 2000-2013 (14 years).

The increase is for the price incl. tax but excl. VAT based on www.energy.eu

Price is for an Industrial Customer with at least 2GWh consumption per year.



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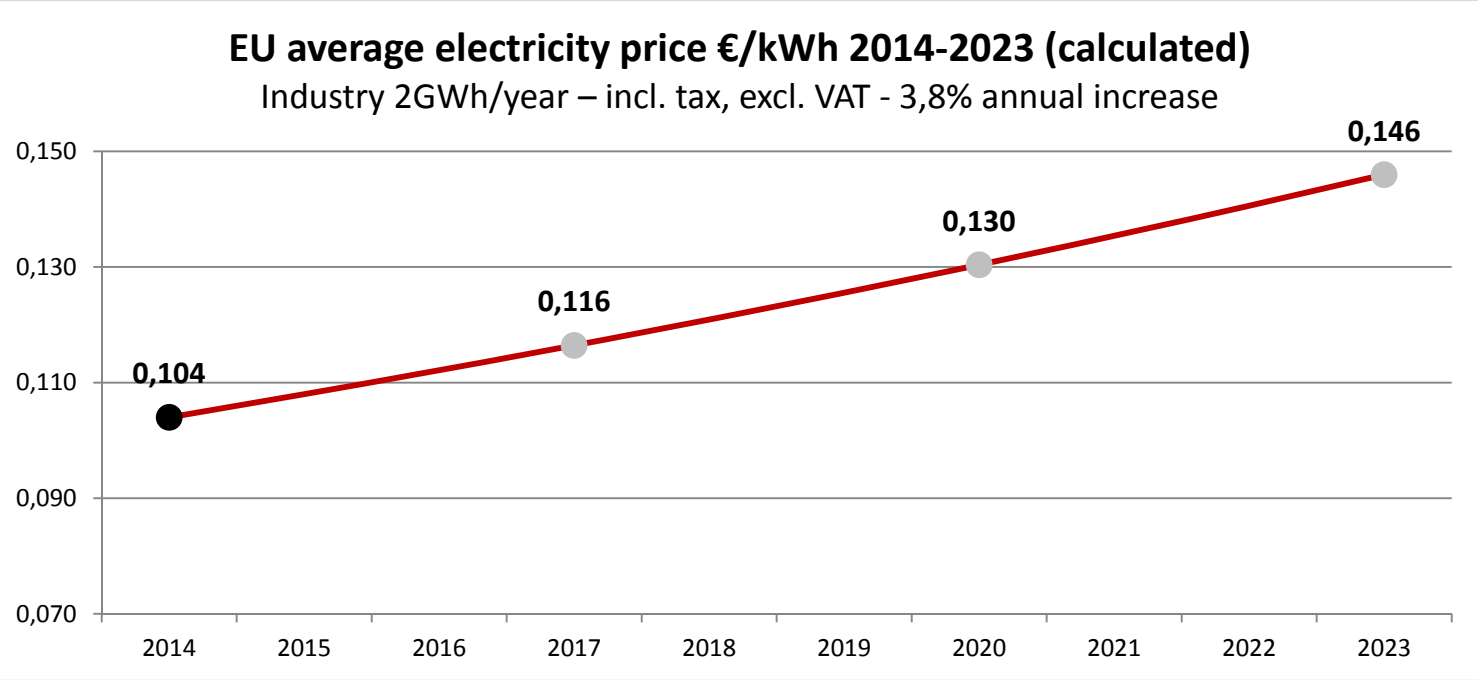
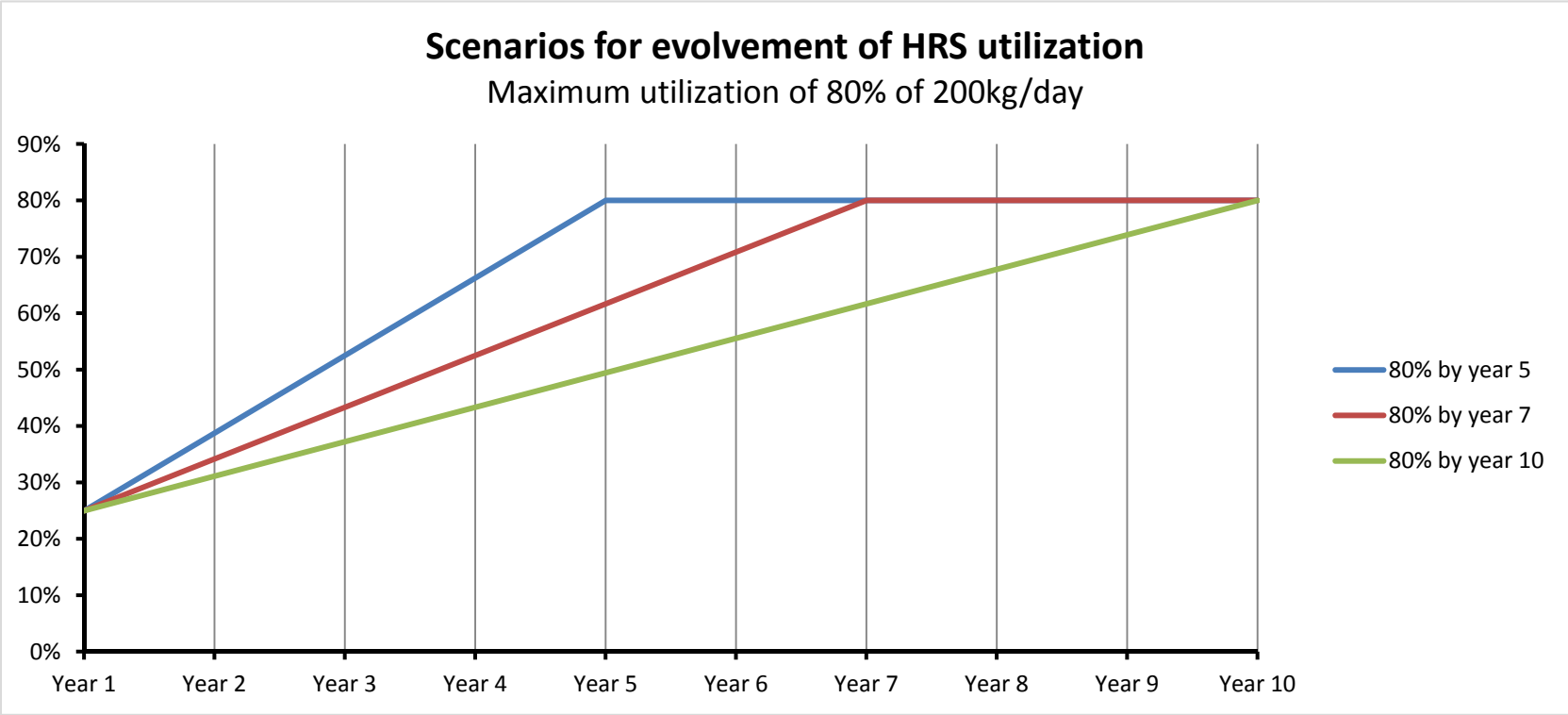


HRS utilization scenarios – years to reach 80% utilization

Evolvement of the annual HRS utilization is a main parameter in affecting the payback case.
Utilization scenarios are very affected by the overall HRS network (impact from other HRS) and FCEV roll-out.
Three scenarios are modeled with either 5, 7 or 10 years to reach 80% utilization (assumed maximum).
Assumed that probability of at least 25% utilization during first year is required to decide on a HRS investment.
A linear annual increase from 25% to 80% during the periods (5, 7 or 10 years) – provides a wide range.



Payback time and IRR targets

Payback time and IRR requirements varies depending on the investor and financing type.
Three scenarios have been formulated in order to provide a wide range for the HRS operation calculations.
The rationale is that IRR requirement increases with the length of payback period (higher risk).
IRR is calculated every year as an “interest” of the accumulated negative CAPEX & OPEX investment cash flow.

Payback period	IRR %
5 year payback	10%
7 year payback	12,5%
10 year payback	15%

Public support required to reach payback & IRR targets

Support as % of HRS CAPEX – after inclusion of operation profit/loss

RESULTS OF CALCULATION MODEL (54 scenarios)

Public HRS support required to reach payback & IRR targets (% of CAPEX)

>70%	<70%	0%

Start of HRS operation →	**2017**			**2020**			**2023**		
Cost of H2 delivered* →	€11/kg			€9/kg			€7/kg		
H2 pump price excl. VAT* →	€9,4/kg			€10,8/kg			€12,4/kg		
HRS CAPEX	€ 1.000.000			€ 800.000			€ 600.000		
80% HRS utilization reached →	Year 5	Year 7	Year 10	Year 5	Year 7	Year 10	Year 5	Year 7	Year 10
5 years payback / 10% IRR	174%	166%	160%	98%	102%	105%	0%	12%	27%
7 years payback / 12,5% IRR	251%	237%	196%	93%	98%	103%	0%	0%	0%
10 year payback / 15% IRR	294%	284%	267%	88%	92%	98%	0%	0%	0%

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80% HRS utilization reached →	Year 5	Year 7	Year 10	Year 5	Year 7	Year 10	Year 5	Year 7	Year 10
5 years payback / 10% IRR	58%	69%	76%	13%	32%	44%	0%	0%	0%
7 years payback / 12,5% IRR	36%	48%	61%	0%	0%	16%	0%	0%	0%
10 year payback / 15% IRR	16%	27%	41%	0%	0%	0%	0%	0%	0%

**Cost of H2 delivered and H2 pump price is increased 4,8% per year from start of operation (same as gasoline past 14 years in EU)*

FCH-JU vs. Californian HRS demonstration support levels

Both the FCH-JU (2.0) and State of California support demonstration of HRS's.

California offers up to 90% CAPEX support and up to $300.000 in OPEX support for 3 years.

The FCH-JU funding rates under HORIZON 2020 may be as high as 70% and may support both CAPEX & OPEX.

As illustrated below both schemes provides sufficient support for several of the calculation scenarios.

For EU actual market deployment of higher number of HRS's may require other national or EU programs.

		California & FCH-JU CAPEX+OPEX	**FCH-JU** CAPEX	
FCH-JU & California HRS demonstration support	>127%	70-140%	<70%	0%

Start of HRS operation →	**2017**			**2020**			**2023**		
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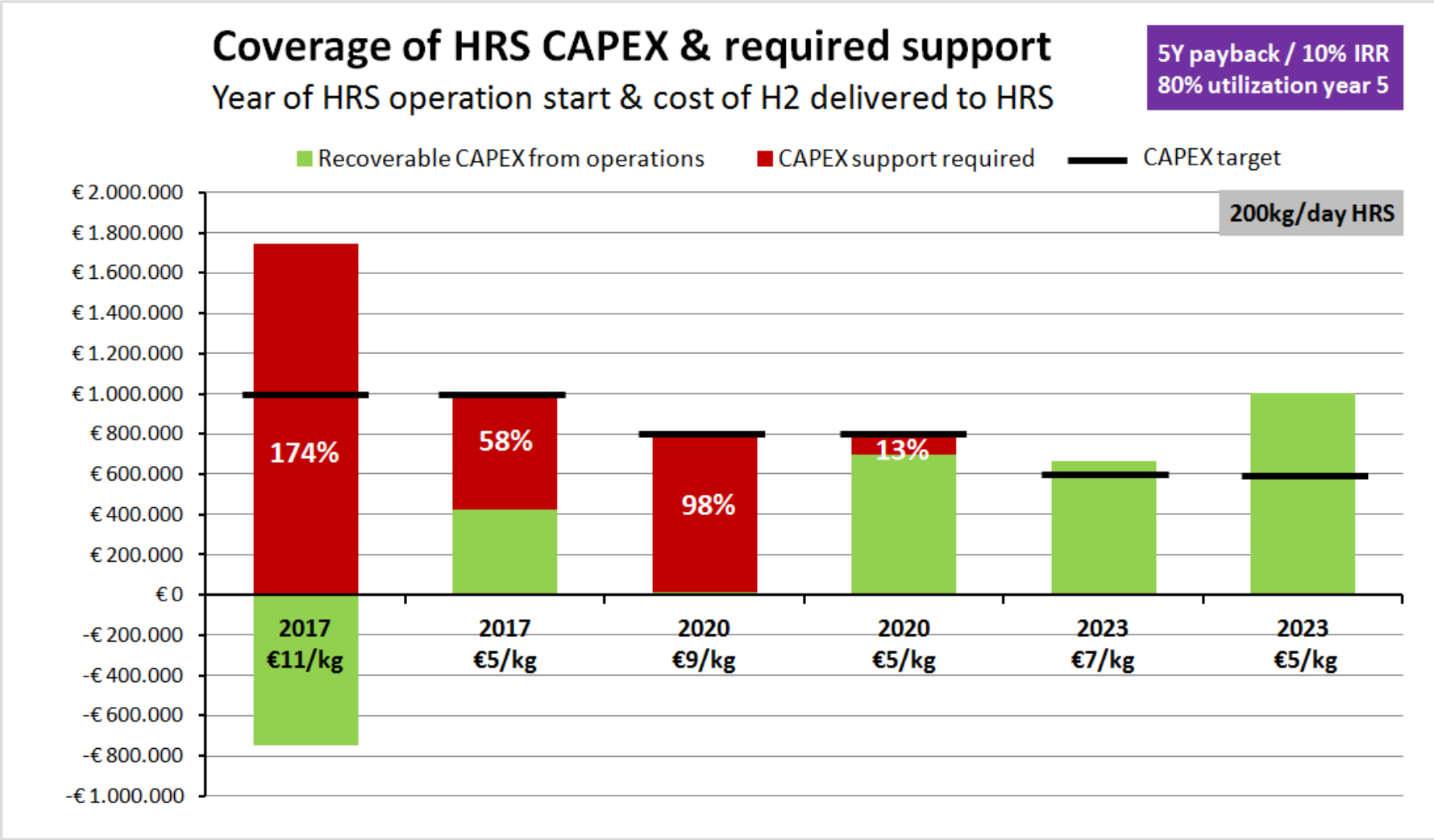
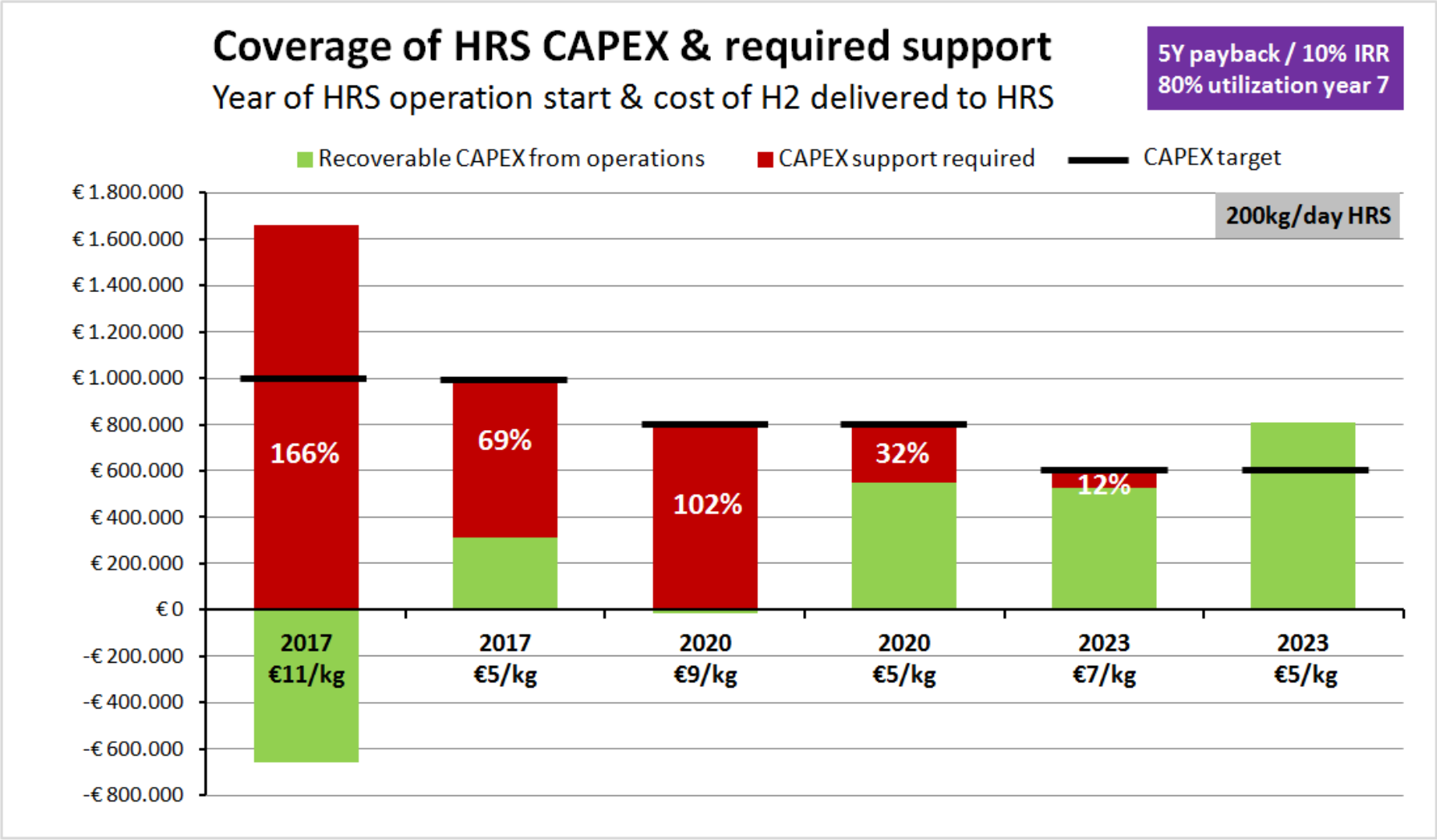
7 years payback / 12,5% IRR	36%	48%	61%	0%	0%	16%	0%	0%	0%
10 year payback / 15% IRR	16%	27%	41%	0%	0%	0%	0%	0%	0%

Detailed results comparison charts

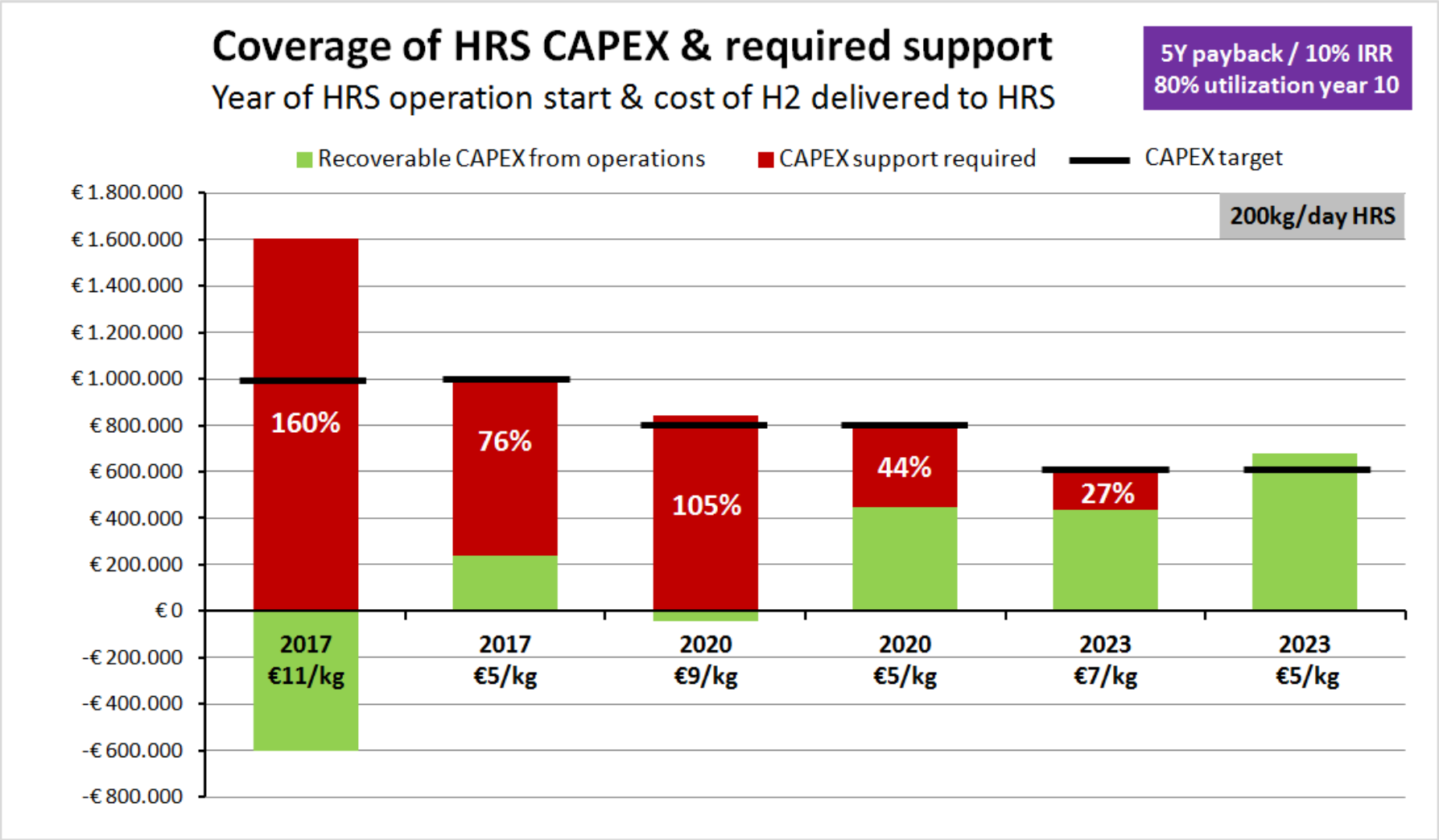
Results: 5Y payback / 10% IRR – 80% utilization by year 5



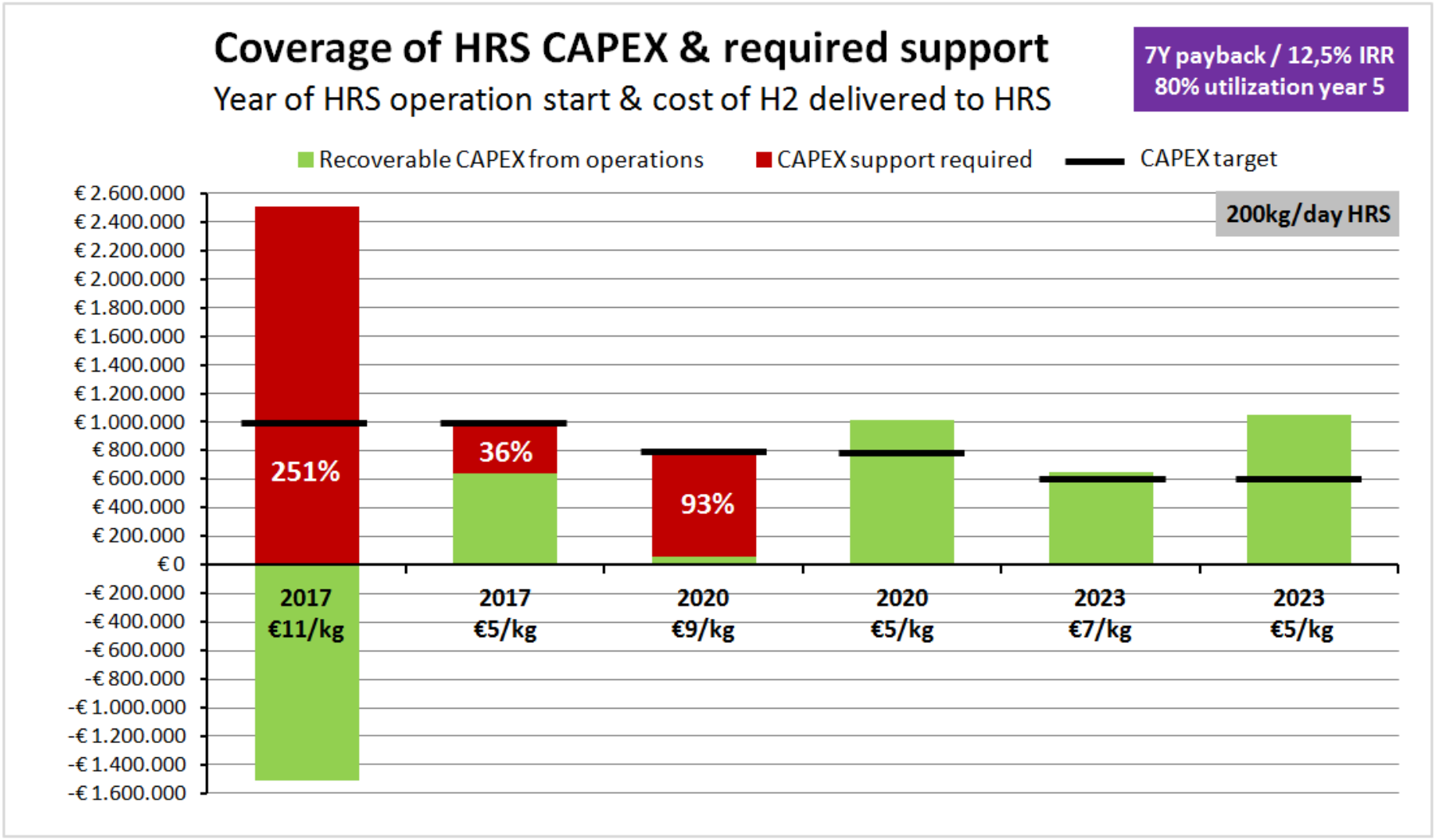
Results: 5Y payback / 10% IRR – 80% utilization by year 7



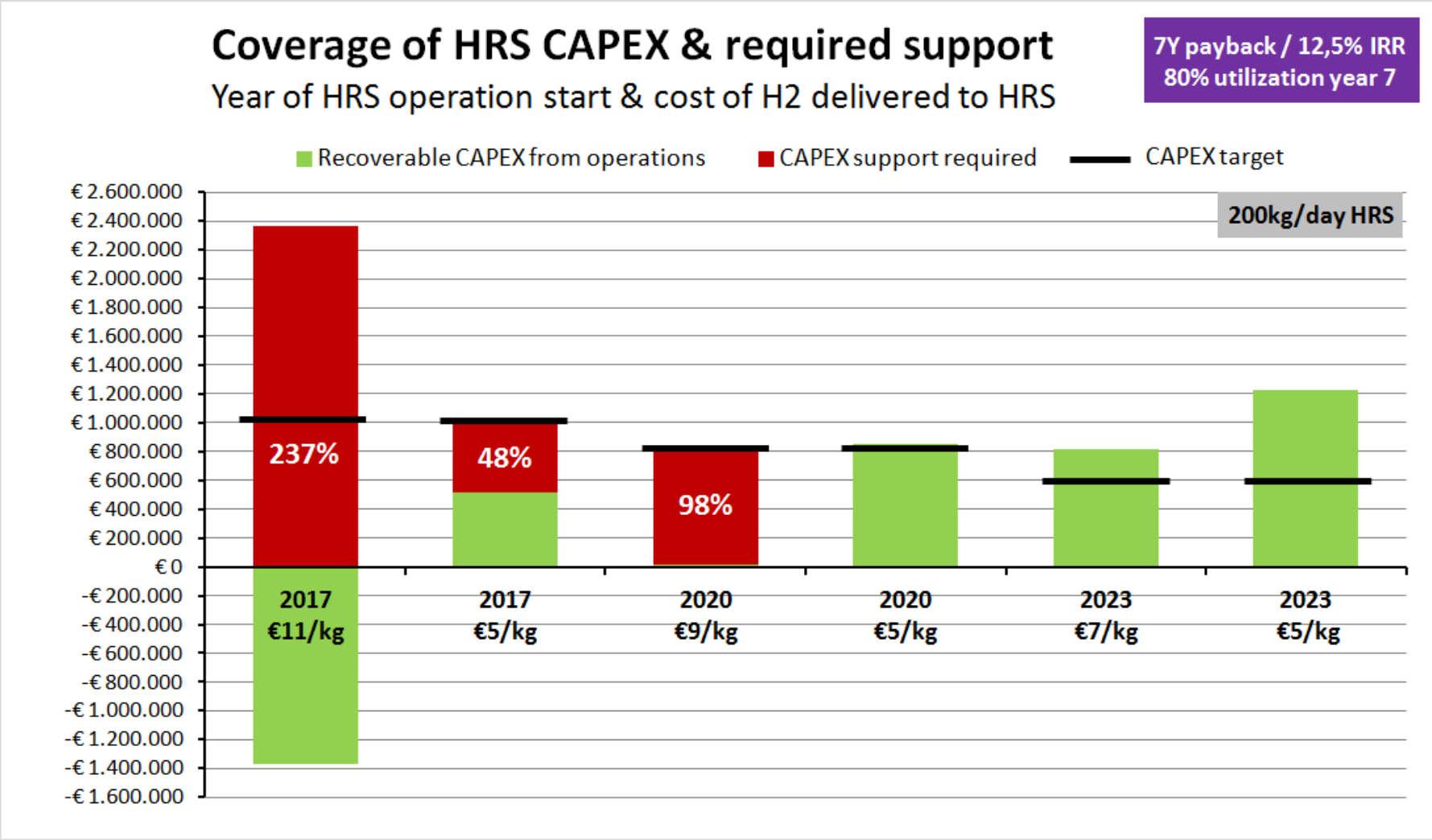
Results: 5Y payback / 10% IRR – 80% utilization by year 10



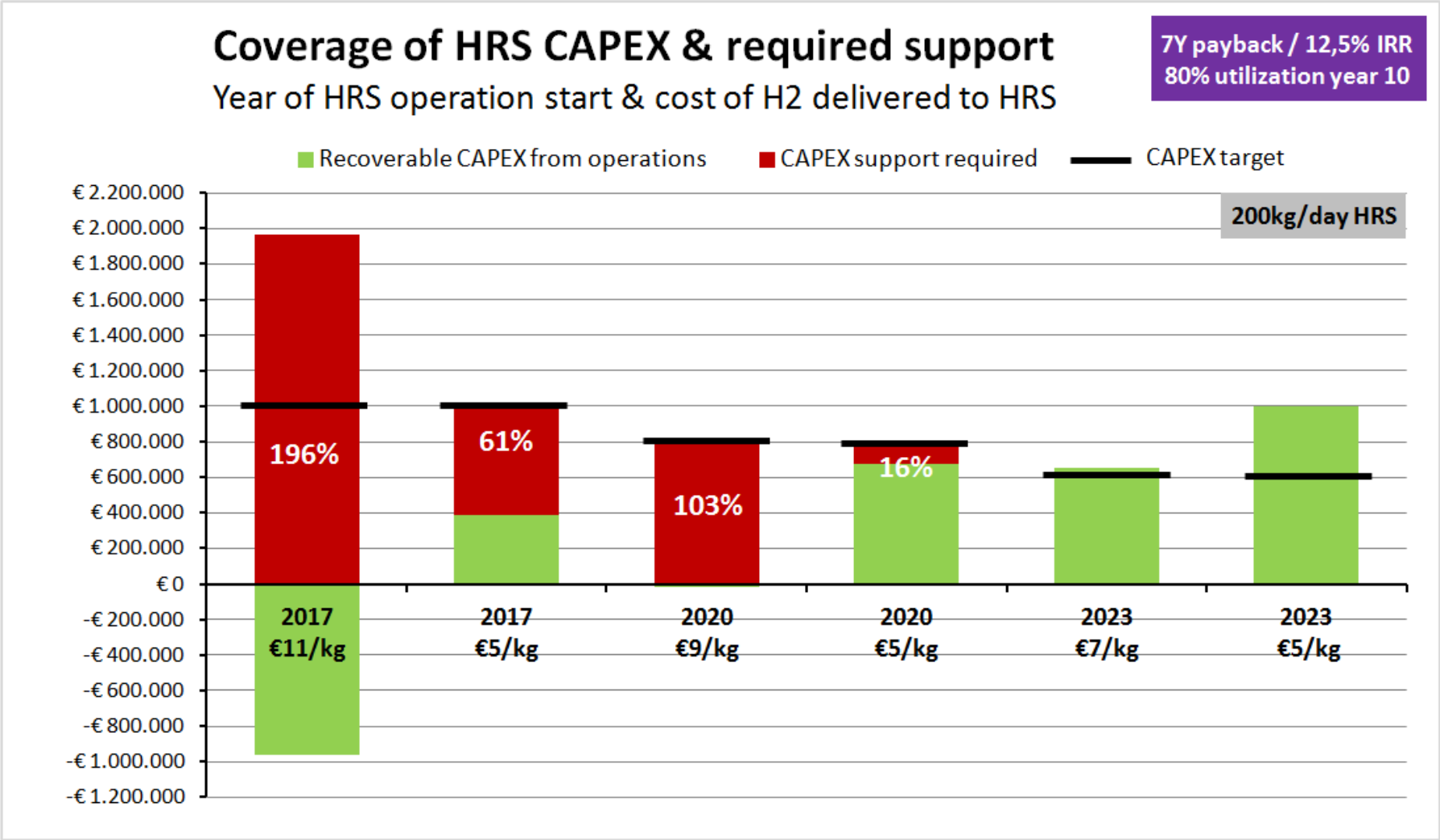
Results: 7Y payback / 12,5% IRR – 80% utilization by year 5



Results: 7Y payback / 12,5% IRR – 80% utilization by year 7



Results: 7Y payback / 12,5% IRR – 80% utilization by year 10



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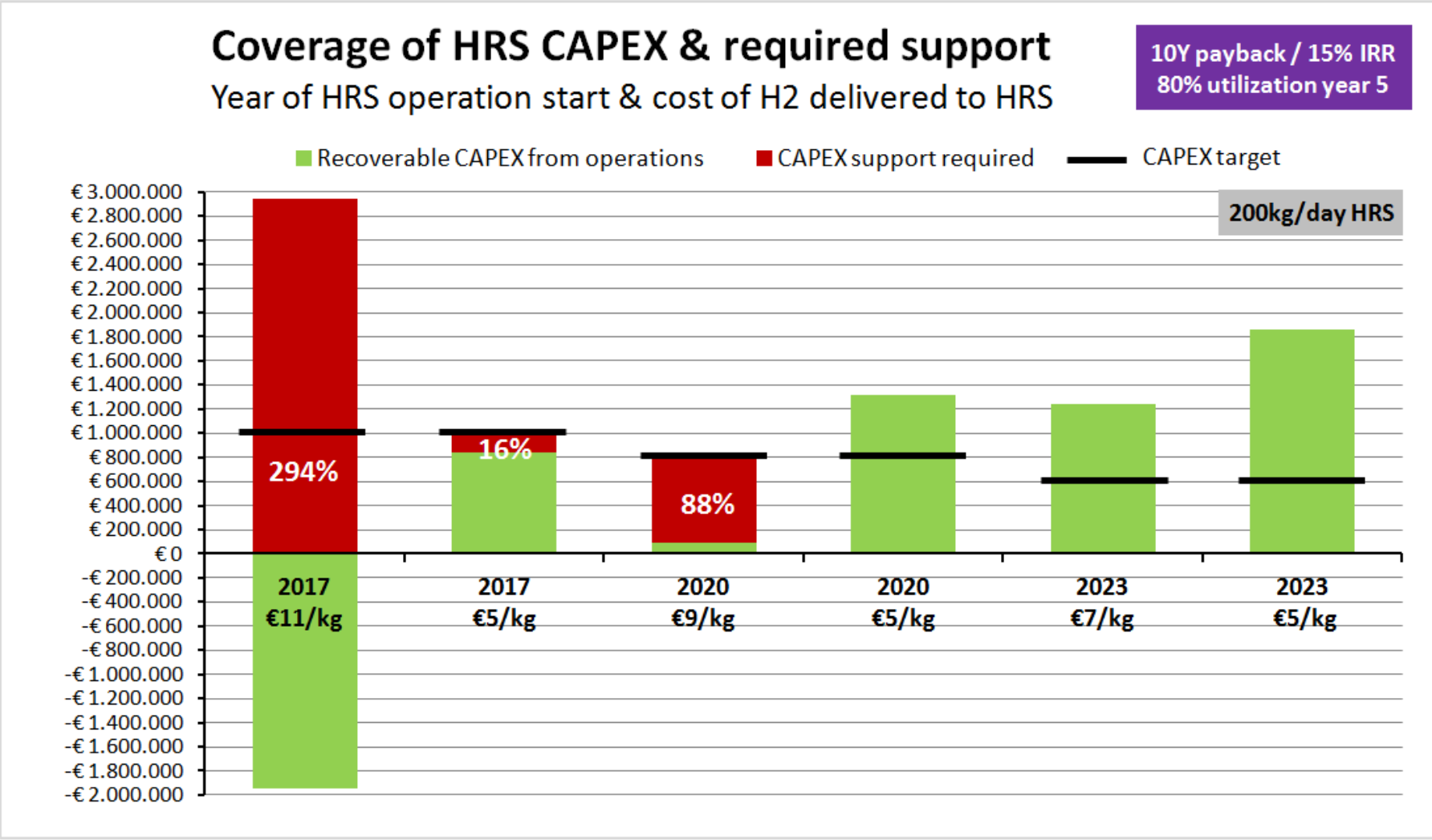

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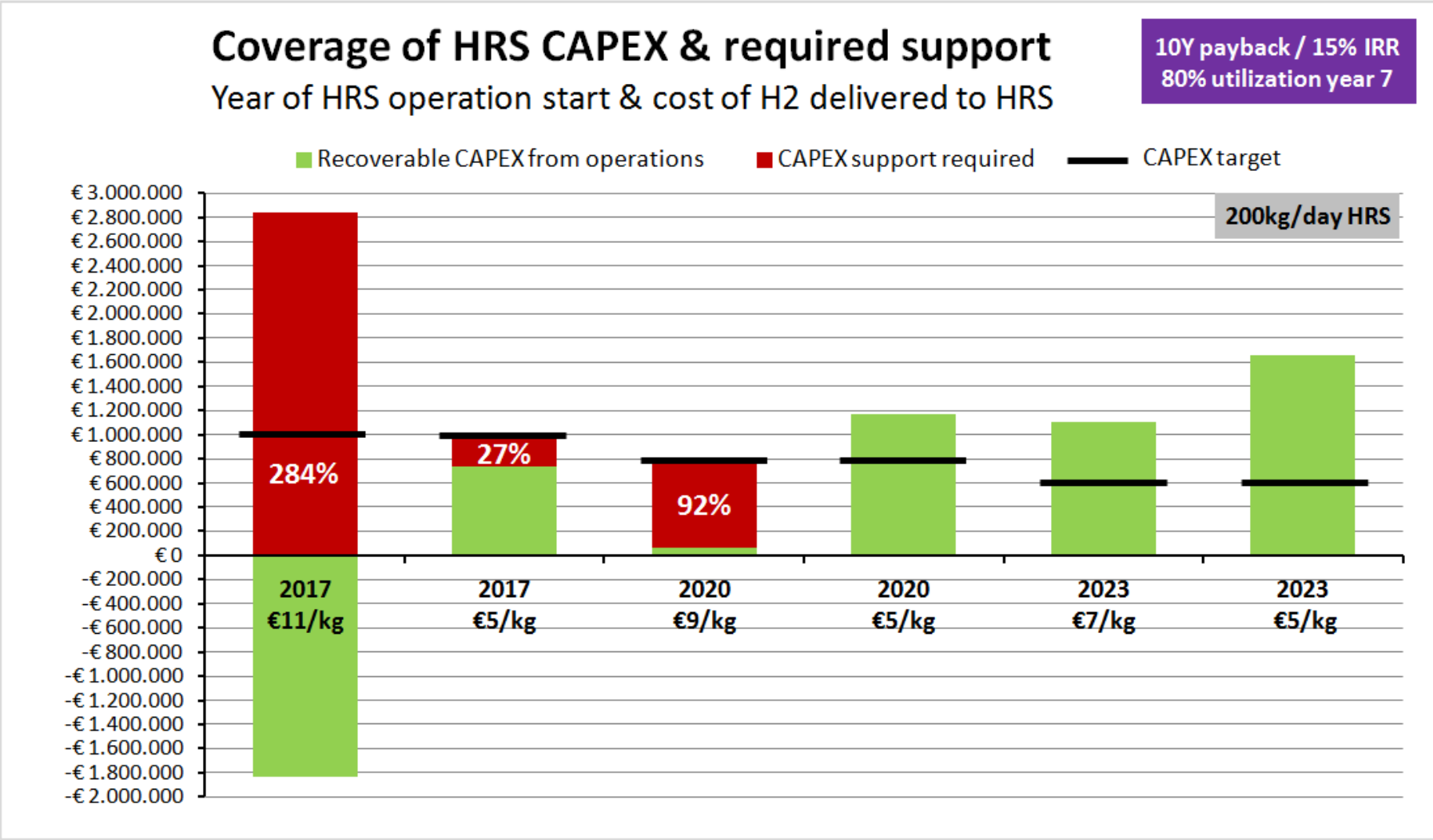

Results: 10Y payback / 15% IRR – 80% utilization by year 10