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Is Power-to-Gas always beneficial? The implications of ownership structure

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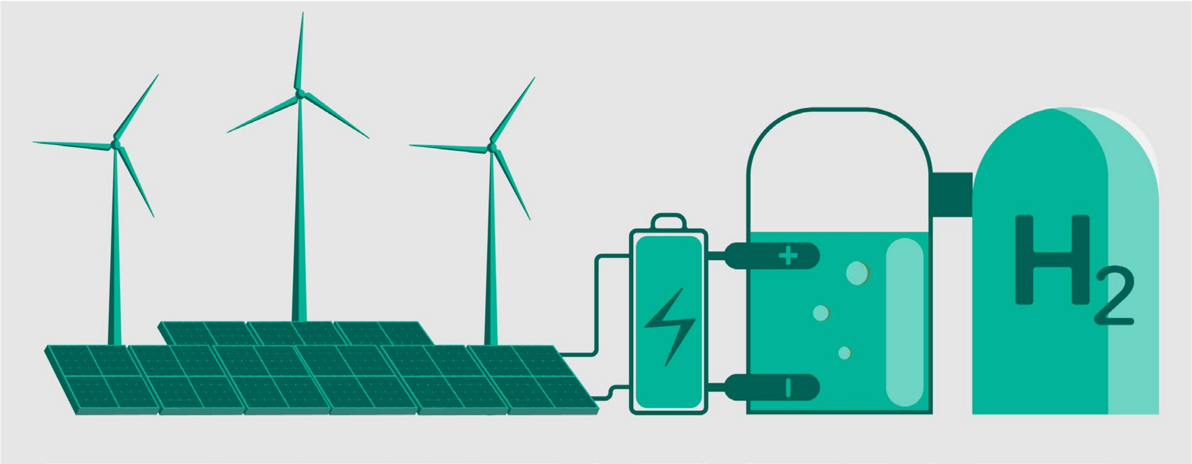


BACKGROUND

Renewable-based hydrogen

1. Green H_2 is **projected to play a major role** in the decarbonization of the economies

Indeed, when produced from renewable electricity, hydrogen can:

- **Provide the flexibility needed for low-carbon power systems**
- **Replace fossil fuels and conventional "grey" hydrogen**
- **Enhance energy security by lowering dependency on imported fossil fuels**

2. An **emerging cornerstone of the European energy strategy** (H_2 is presented as a key priority)

The kick-start phase
Develop pilot projects and Hydrogen Valleys

→

The ramp-up phase
Create a supporting framework to facilitate the development of the hydrogen economy

→

The market-growth phase
Obtain a market transparent and liquid

Sources: European Commission & Hydrogen Act (Hydrogen Europe)

LITERATURE & MOTIVATION

Power-to-Gas as a sector coupling technology:

- A recent – but growing – literature in engineering and/or economics
  - Vandewalle & al. (2015)
  - Lynch & al. (2019)
  - Roach & Meus (2020)
  - Li & Mulder (2021)

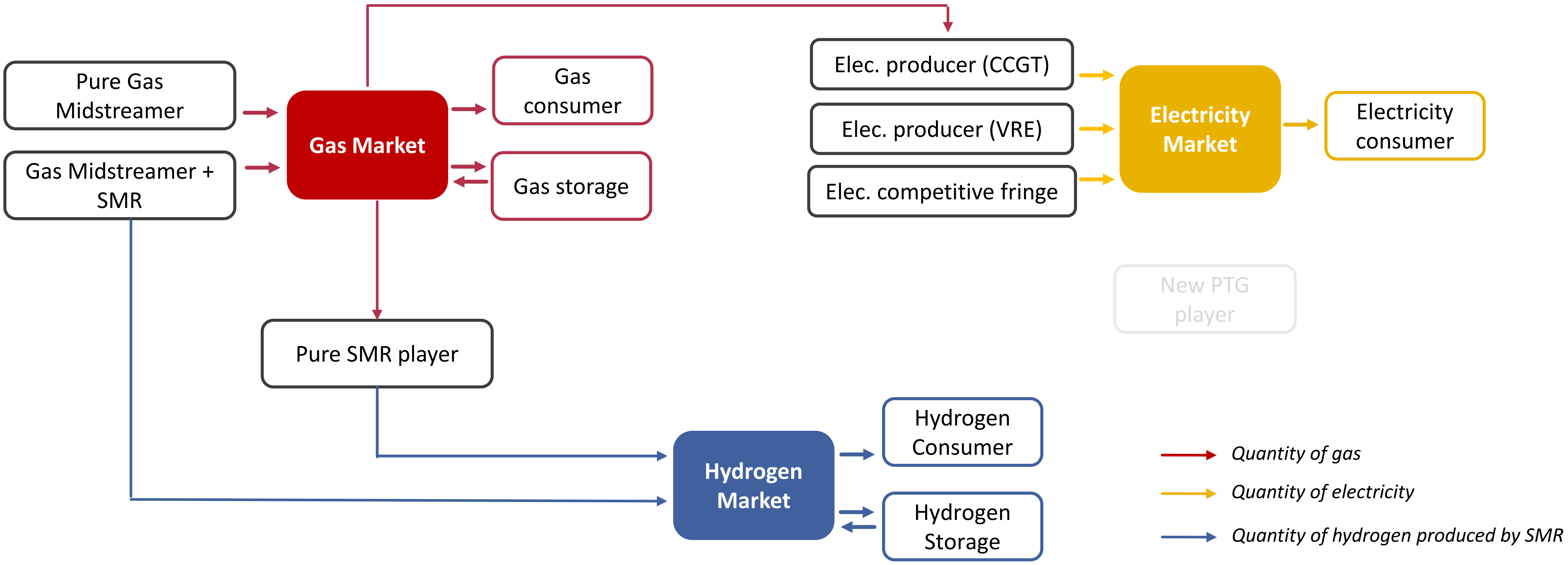
  => These articles consider a perfectly competitive energy system

- However, first movers in PTG are firms with a **strong oligopolistic presence** in either the power, gas, or H_2 markets (e.g., existing electricity producers, gas midstreamers, H_2 producers, independent private players…).

To what extent do I.O. and asset ownership considerations affect the projected impacts of PtG?

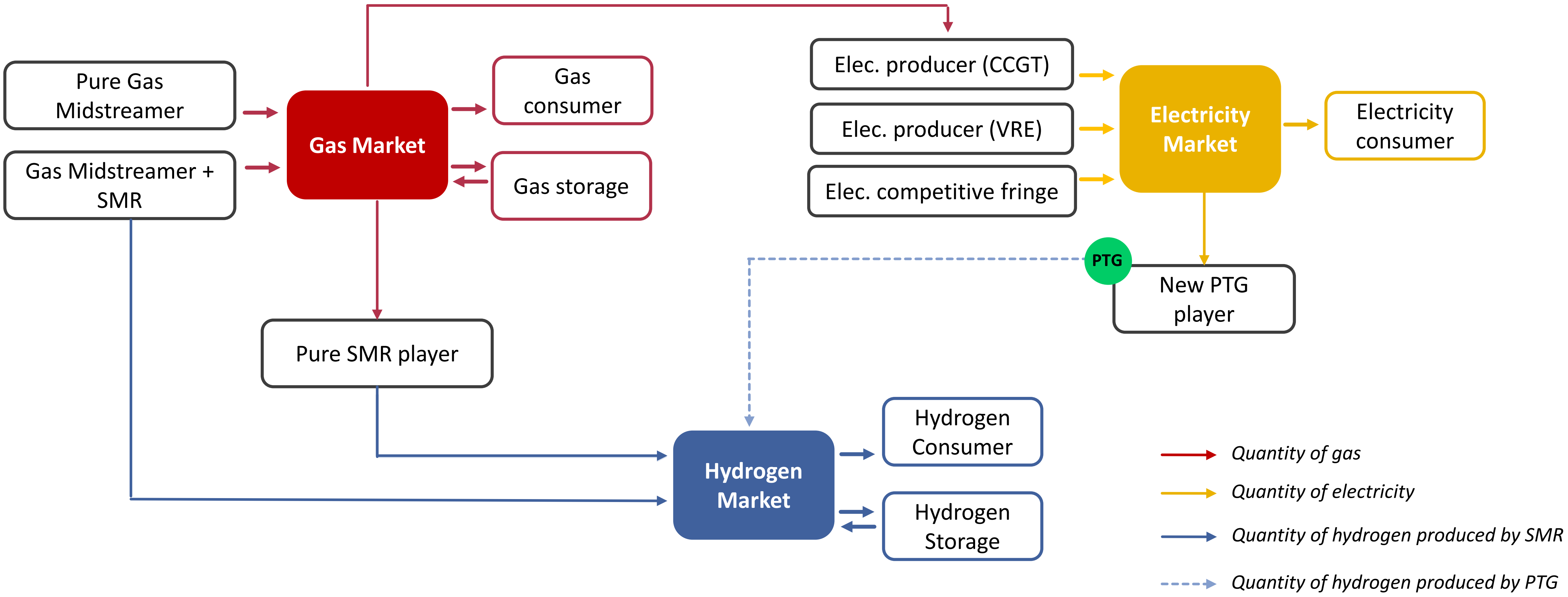
Methodology: a stylized partial equilibrium model

Baseline scenario (No PtG)



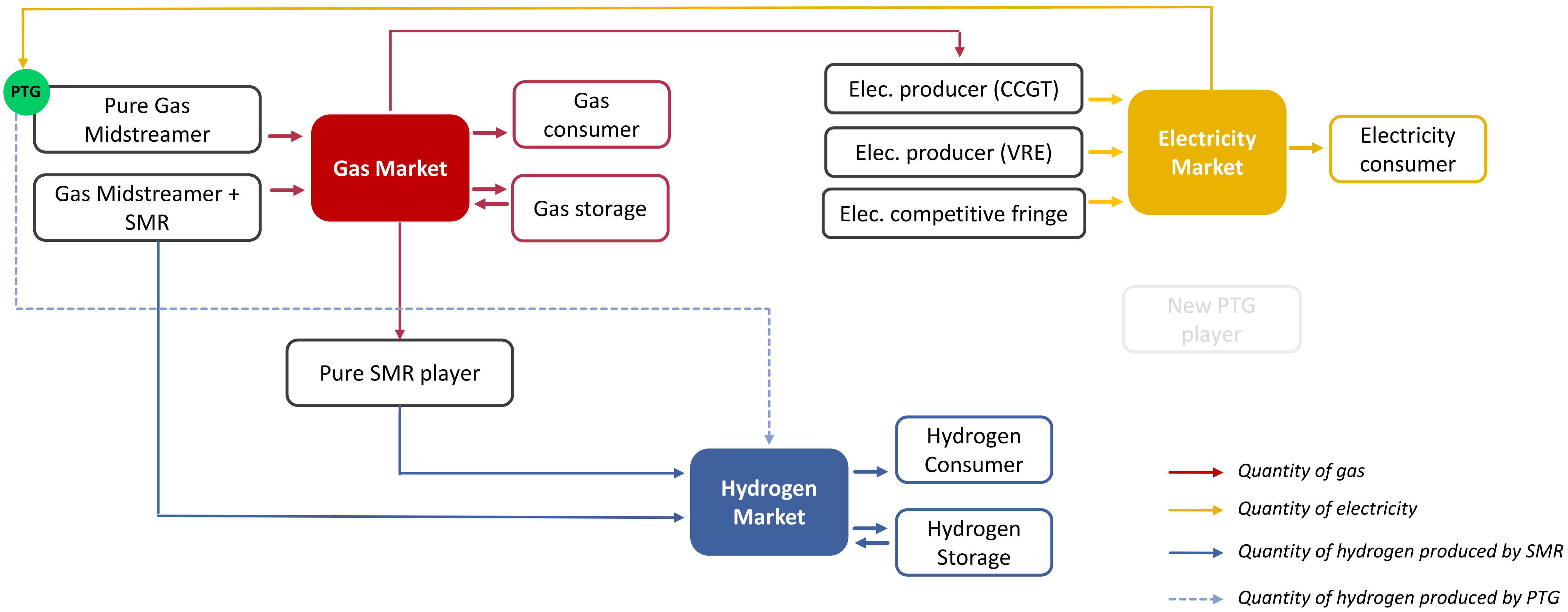
METHODOLOGY – The different ownership scenarios

PtG as a pure player (NewProd)



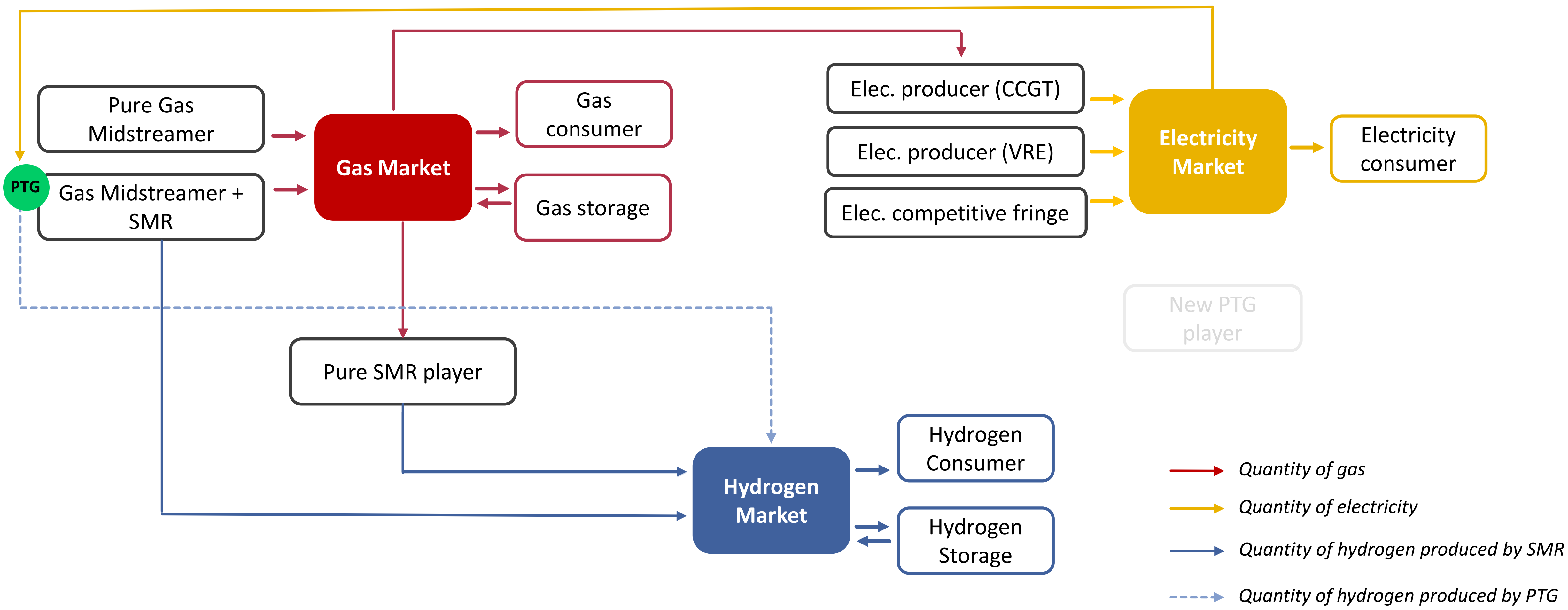
METHODOLOGY – The different ownership scenarios

PtG owned by a gas midstreamer (GGas)



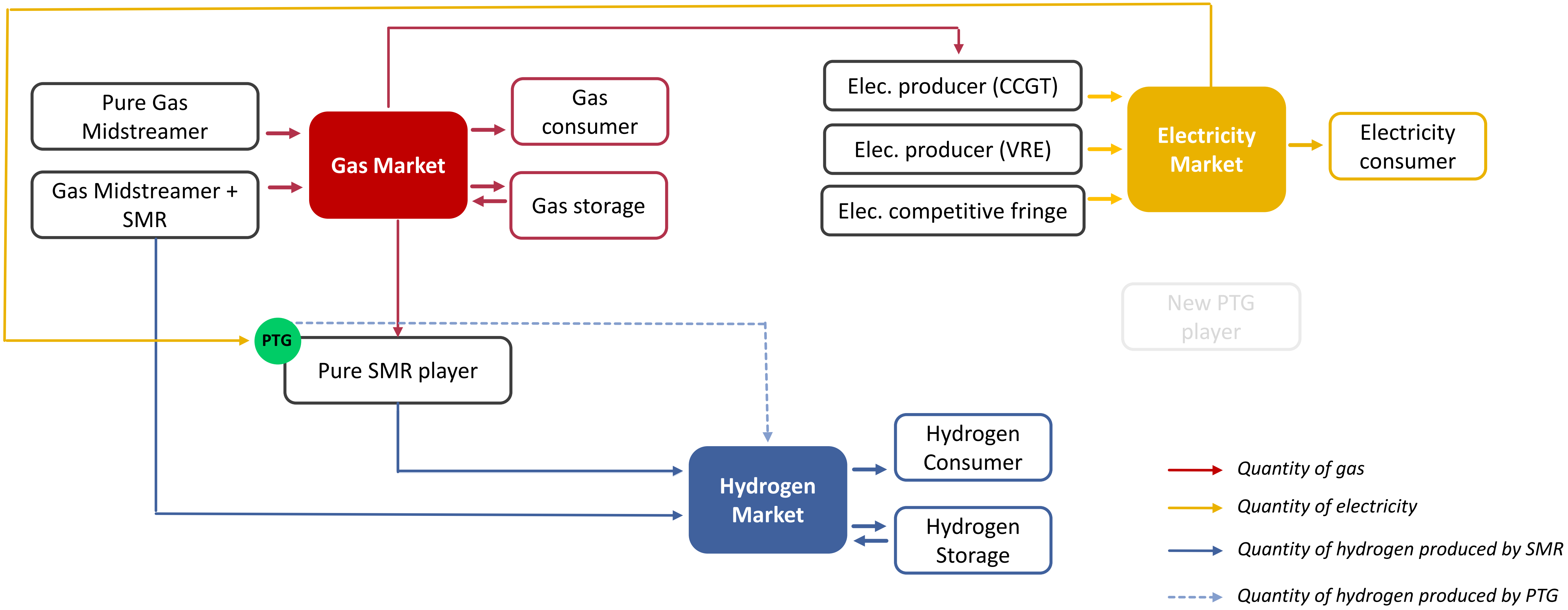
METHODOLOGY – The different ownership scenarios

PtG owned by a gas midstreamer that also supplies blue H_2 (GGas)



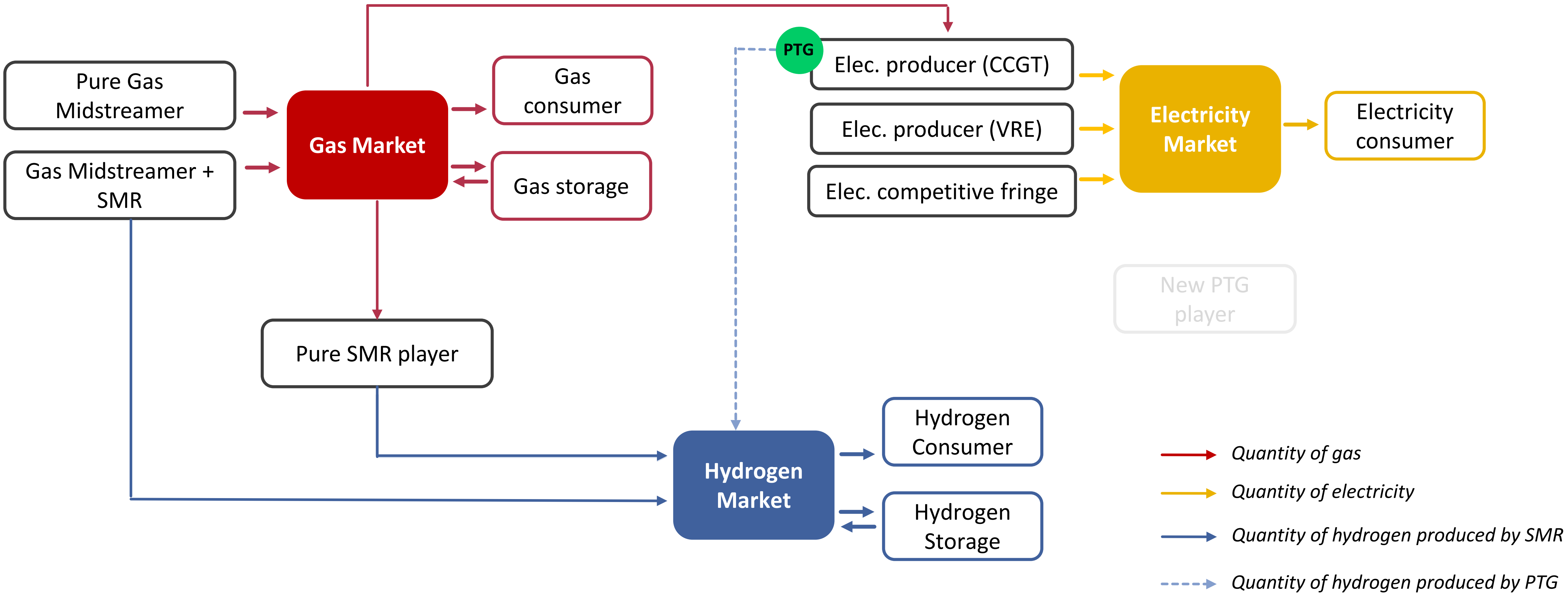
METHODOLOGY – The different ownership scenarios

PtG owned by a supplier of blue H_2 (G-Gas+SMR)



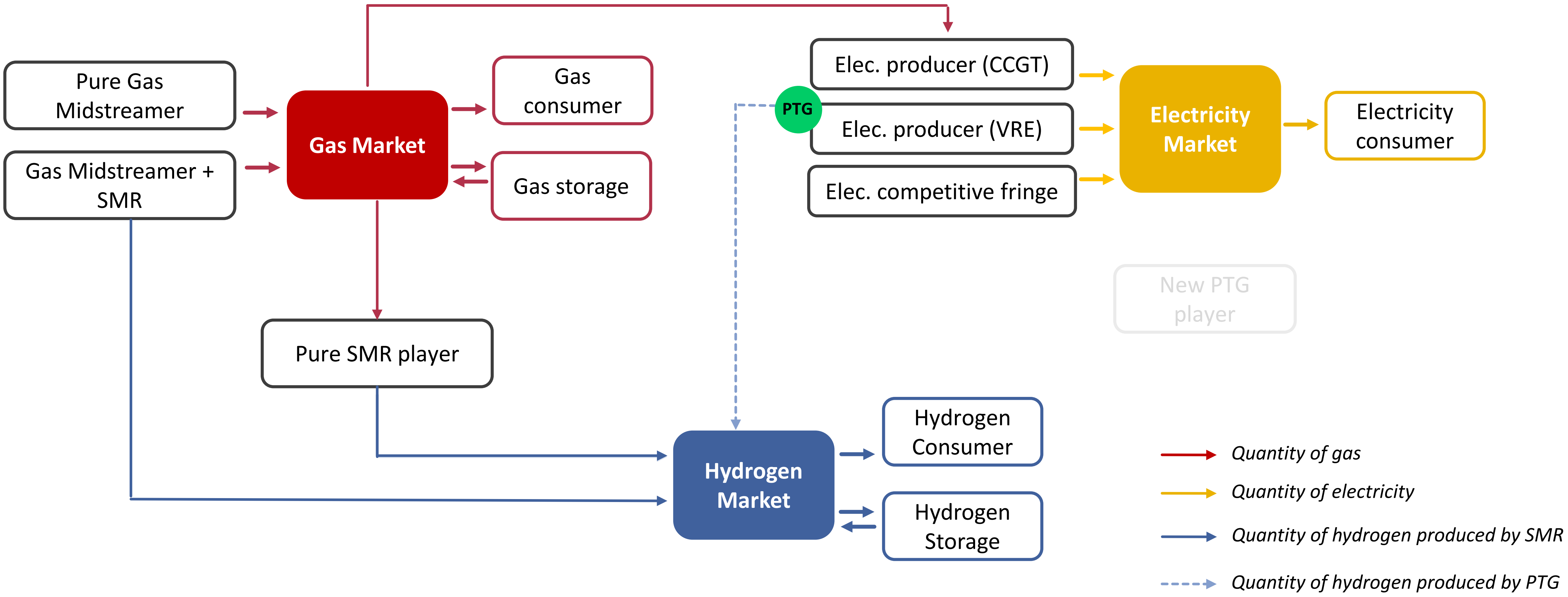
METHODOLOGY – The different ownership scenarios

PtG owned by thermoelectric generator (E-CCGT)



METHODOLOGY – The different ownership scenarios

PtG owned by a large firm generating VRE (E-VRE)



METHODOLOGY - A detailed partial equilibrium model

A deterministic Nash-Cournot oligopoly model

- One-year time horizon
- Linear demand functions for Power, Gas & H_2
- Energy producers behave à la Cournot / Storage operators (gas & H_2) are price taking firms
- Short-term model – the model focuses on operations
  => Capacities are exogeneously determined.

Formulated & solved as an instance of a **Mixed Complementarity Model (MCP)**

Agents' maximization problems
Max. Profits
s.t. constraints (capacity, efficiency, ramp-up constraints...)
Market Clearing conditions

We calibrate and solve the model to examine:
- the use of PtG
- the market outcomes and the social performance
- the environmental performance

APPLICATION

We calibrate the model to study a **future energy system**.

- We use the Dutch energy system as a reference.
- Posited carbon prices: € 90 and €150 per ton of CO_2
- Power & gas demand and RES variability: based on historical patterns
- H_2 demand: based on GIE projections
- Capacities are based on European Commission projections for 2030

<u>Posited capacities:</u>

PtG capacity: 4 GW

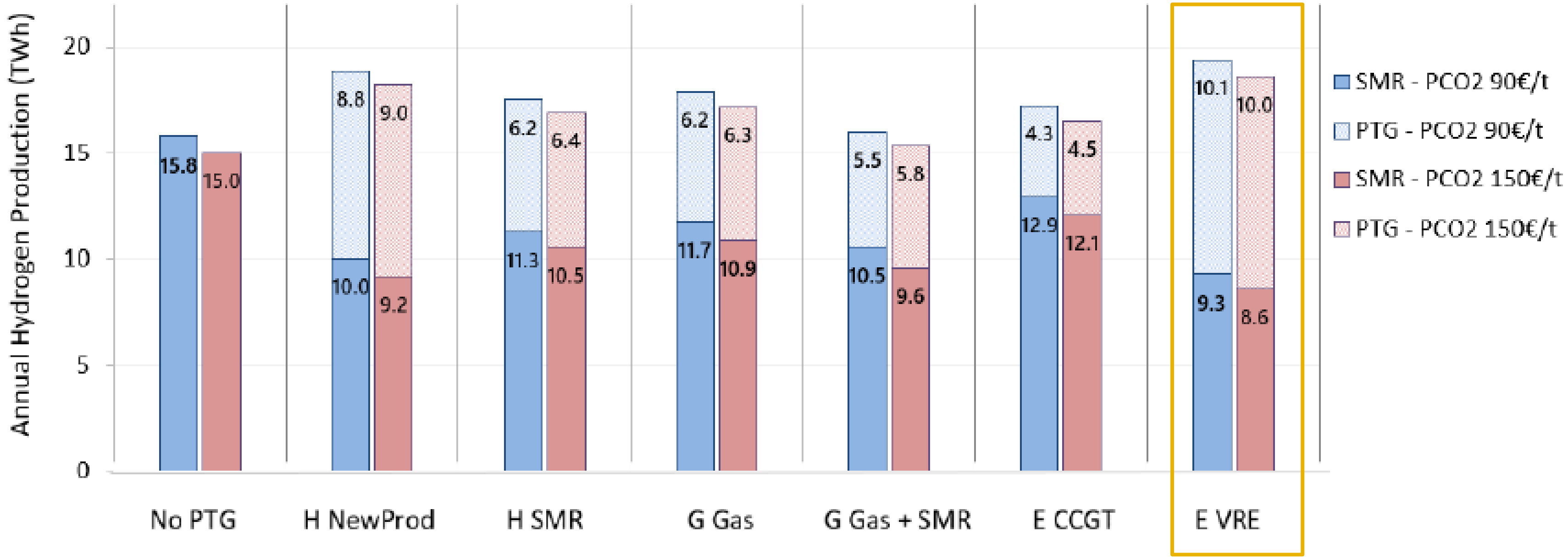
Total SMR capacity : 10GW equally shared by the two players

Table 2: Generation capacity of each power producer per technology (GW)

	Fringe	E-VRE	E-CCGT
VRE	27	26	-
CCGT	6	-	6

RESULTS – PtG Utilization

Total annual hydrogen production by technology in TWh (for P_{CO2} =90€/ t_{CO2} and P_{CO2} =150€/ t_{CO2})



Annual average power, gas and hydrogen prices for P_{CO2} =90€/ t_{CO2}) (€/MWh)

	NoPtG	H-NewProd	H-SMR	G-Gas	G-Gas+SMR	E-CCGT	E-VRE
Hydrogen	86.29	76.71	80.82	79.73	85.48	81.71	75.06
Gas	34.70	34.48	34.48	34.54	34.66	34.59	34.50
Electricity	63.79	72.97	69.56	69.48	68.48	66.90	75.14

RESULTS – Social performance

Annual surpluses in the baseline scenario and relative changes (for P_{CO2} =90€/ t_{CO2})

		NoPtG	H-NewProd	H-SMR	G-Gas	G-Gas+SMR	E-CCGT	E-VRE
Electricity	E-VRE	1.84	+ 0.88	+ 0.66	+ 0.65	+ 0.59	+ 0.44	+ 1.09
	E-CCGT	0.00	0.00	0.00	0.00	0.00	+ 0.27	0.00
	E-Fringe	2.04	+ 0.63	+ 0.41	+ 0.41	+ 0.34	+ 0.21	+ 0.75
Gas	G-Gas+SMR	3.17	- 0.25	- 0.17	- 0.18	+ 0.08	- 0.13	- 0.28
	G-Gas	2.70	- 0.05	- 0.05	+ 0.21	- 0.01	- 0.03	- 0.04
Hydrogen	H-SMR	0.03	- 0.03	+ 0.22	- 0.03	0.00	- 0.02	- 0.03
	H-NewProd	-	+ 0.18	-	-	-	-	-
Total producer surplus		**9.79**	**+ 1.35**	**+ 1.07**	**+ 1.06**	**+ 1.00**	**+ 0.74**	**+ 1.49**
Gas storage surplus		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen storage surplus		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total storage surplus		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Electricity consumer surplus		5.65	- 1.06	- 0.72	- 0.71	- 0.60	- 0.39	- 1.30
Gas consumer surplus		4.54	+ 0.05	+ 0.05	+ 0.04	+ 0.01	+ 0.03	+ 0.04
Hydrogen consumer surplus		0.38	+ 0.17	+ 0.09	+ 0.11	0.01	+ 0.08	+ 0.20
Total consumer surplus		**10.57**	**- 0.85**	**- 0.58**	**- 0.56**	**- 0.58**	**- 0.29**	**- 1.06**
Revenue yielded by carbon pricing		4.83	+ 0.012	+ 0.016	+ 0.009	- 0.012	+ 0.007	+ 0.024
Net social welfare including carbon pricing		**25.19**	**+ 0.516**	**+ 0.504**	**+ 0.501**	**+ 0.411**	**+ 0.455**	**+ 0.451**

RESULTS – Social performance

Annual surpluses in the baseline scenario and relative changes in Bn € (for P_{CO2} =90€/ t_{CO2})

		NoPtG	H-NewProd	H-SMR	G-Gas	G-Gas+SMR	E-CCGT	E-VRE
Electricity	E-VRE	1.84	+ 0.88	+ 0.66	+ 0.65	+ 0.59	+ 0.44	+ 1.09
	E-CCGT	0.00	0.00	0.00	0.00	0.00	+ 0.27	0.00
	E-Fringe	2.04	+ 0.63	+ 0.41	+ 0.41	+ 0.34	+ 0.21	+ 0.75
Gas	G-Gas+SMR	3.17	- 0.25	- 0.17	- 0.18	+ 0.08	- 0.13	- 0.28
	G-Gas	2.70	- 0.05	- 0.05	+ 0.21	- 0.01	- 0.03	- 0.04
Hydrogen	H-SMR	0.03	- 0.03	+ 0.22	- 0.03	0.00	- 0.02	- 0.03
	H-NewProd	-	+ 0.18	-	-	-	-	-
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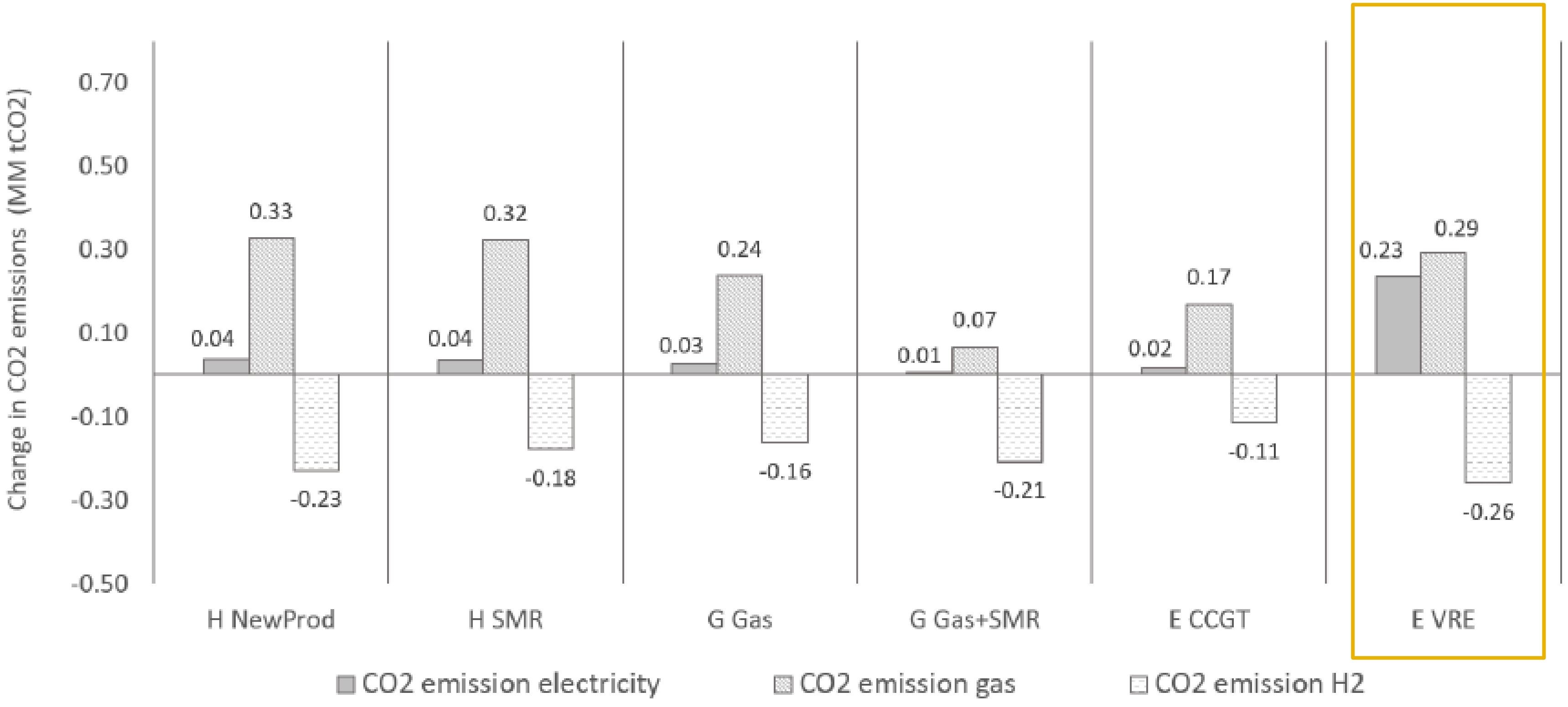
RESULTS – Environmental performance

Impact of PtG on CO_2 emissions - change in CO_2 emissions by sector compared to the Baseline case (for P_{CO2} =90€/ t_{CO2})



CONCLUSIONS

In **imperfectly competitive energy markets**:

- Ownership considerations matter!

  The **use and profitability of PtG differ** depending on the **multi-market profile of its owner**.

  - Producers of fossil-based hydrogen tend to make little use of PtG.
  - Renewable electricity producers use PtG largely and reap the highest profit from it.
  - Intensive use of PtG can indirectly stimulates polluting thermoelectric generation.

  Overall, the operation of PtG is **welfare enhancing** but it **affects the surplus gained by agents**.

- The ownership structure that provides **the largest individual gain** is also **the least desirable from a social and environmental perspective**.

CONTACT

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Thanks for your attention!

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