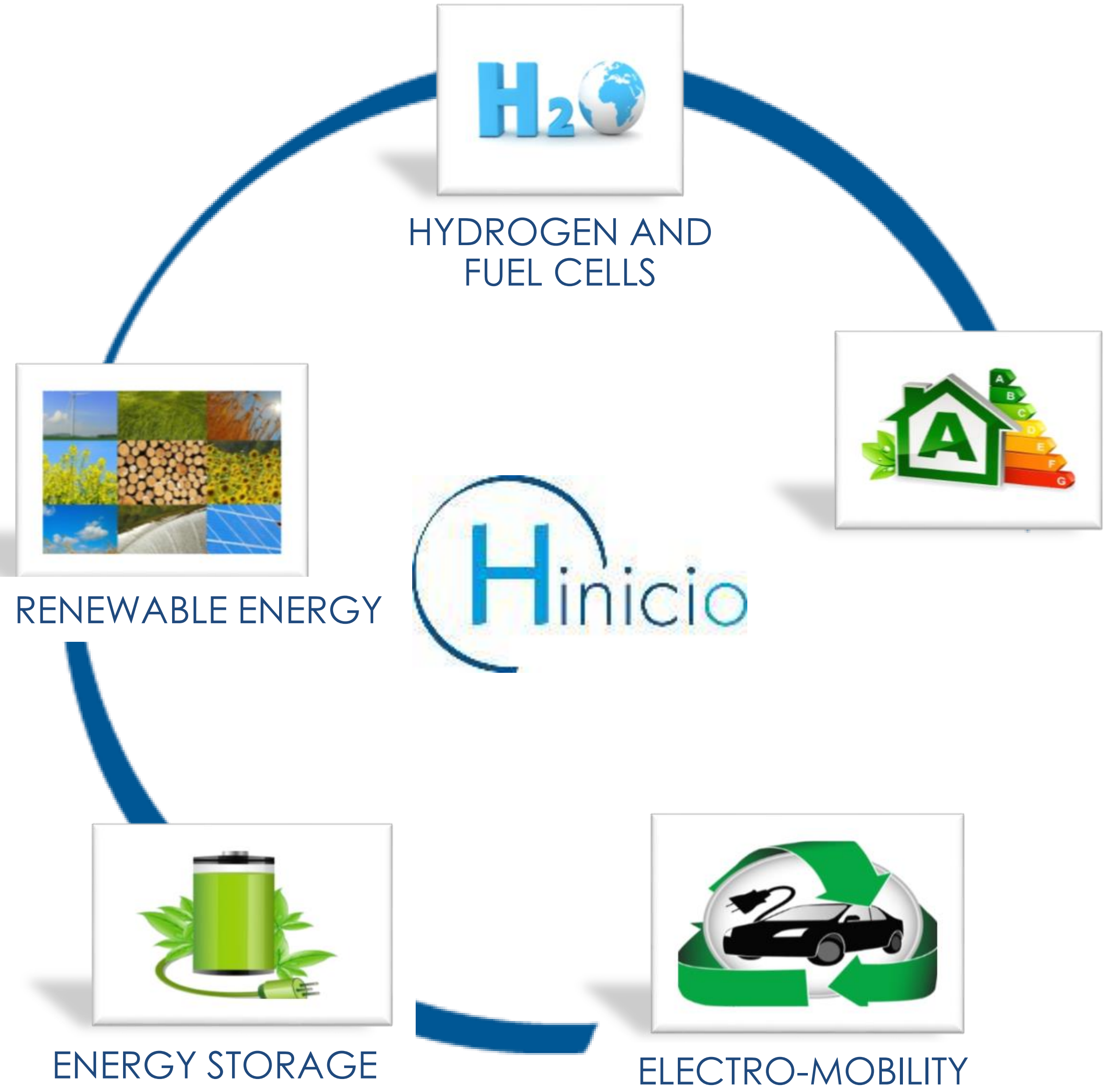
Power-to-gas
Short term and long term opportunities to leverage synergies between the electricity and transport sectors through power-to-hydrogen

18 December 2015



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Content of the presentation

1. Introduction - Setting the scene
2. Application A : Hydrogen from power-to-gas for use in refineries
3. Application B : Semi-centralised power-to-hydrogen system for coupling the electricity and transport sectors
4. Questions

Introduction

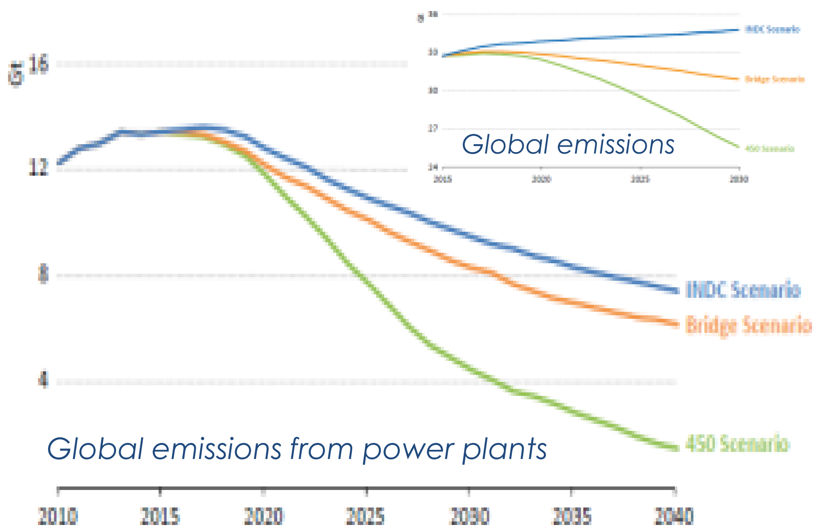
Setting the scene

Section 1

More renewables and electrification of transport are required on the road to 2°C

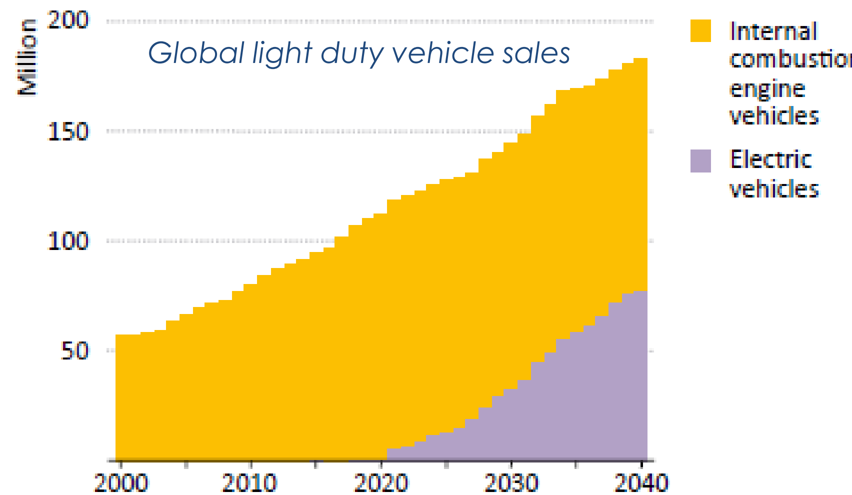
IEA 450 (2°C) scenario

2°C requires more renewables…



- Investment increase from B$270/yr in 2014 to **B$400/yr in 2025.**
- Installed capacity growing from 450 GW today to **3300 GW in 2040.**
- Variable renewables increase from 3% of generation to **more than 20% by 2040.**

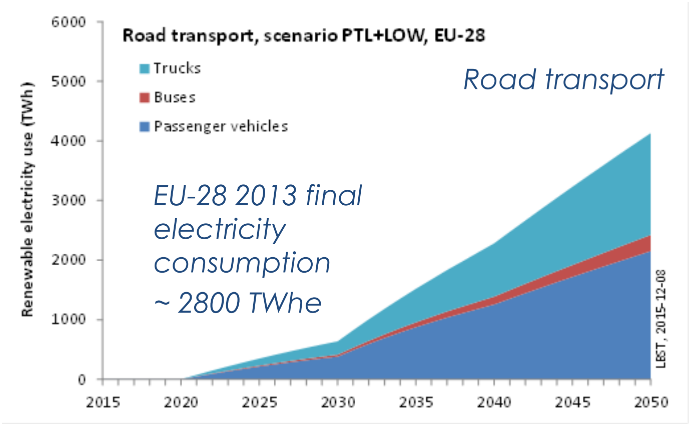
… and electrification of transport

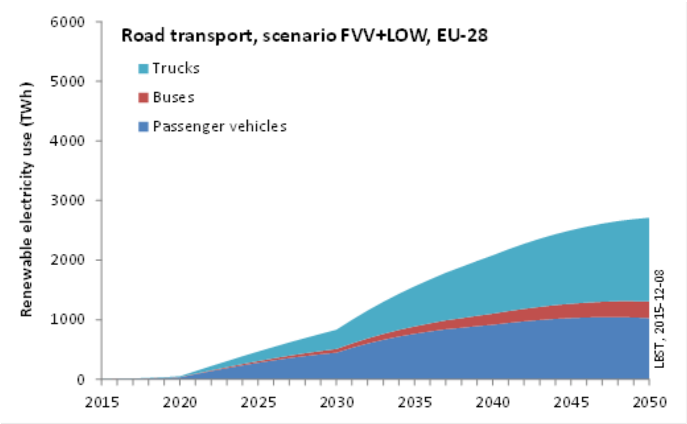


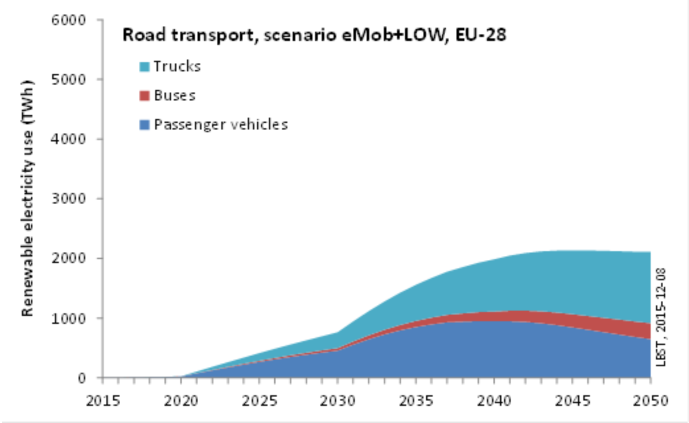
- Sales of EVs exceed **40% of total passenger car sales** worldwide in 2040.
- Sets the scene for providing the needed emissions reductions **after 2040.**

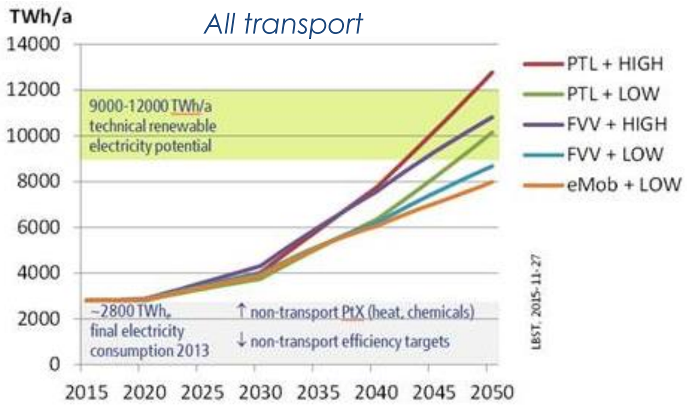
Additional power generation will be needed for transport

The required additional power generation capacity depends on the adopted powertrain technology, but is in any case substantial.





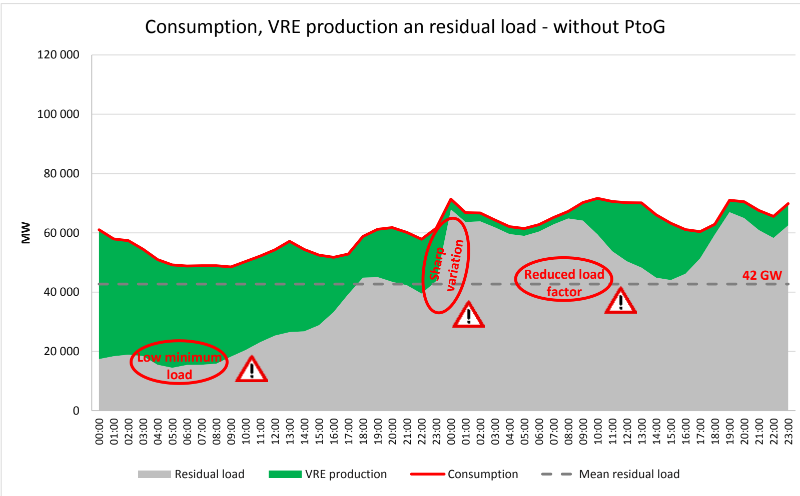




Figures: LBST, Renewables in Transport 2050 – Europe and Germany, 2015

Power-to-Gas allows to decarbonise transport while improving the power system’s operating conditions

More renewable without PtG = <u>More</u> problems



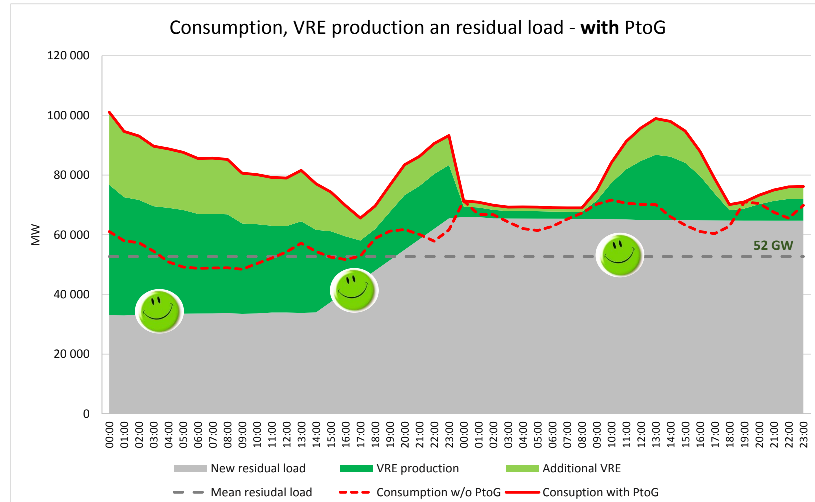
Power consumption during two days in France in Jan and Feb 2013. Actual VRE production on these days multiplied by 10*

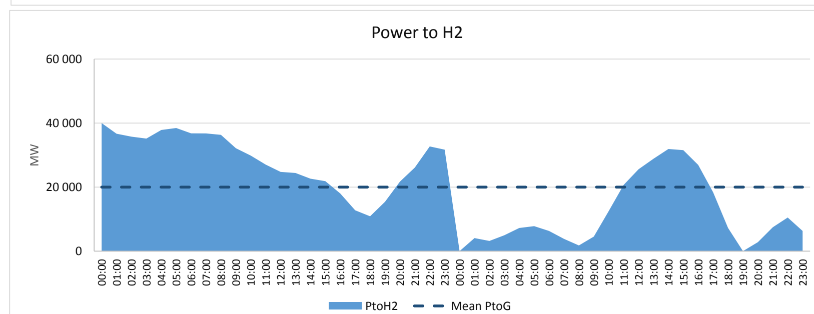
Power-to-Gas provides systemic benefits and improved economics for all:

- Improved load factors / less curtailment;
- More predictable operation of dispatchable capacity.

**VRE : variable renewable energy*

More renewable with PtG = <u>Less</u> problems

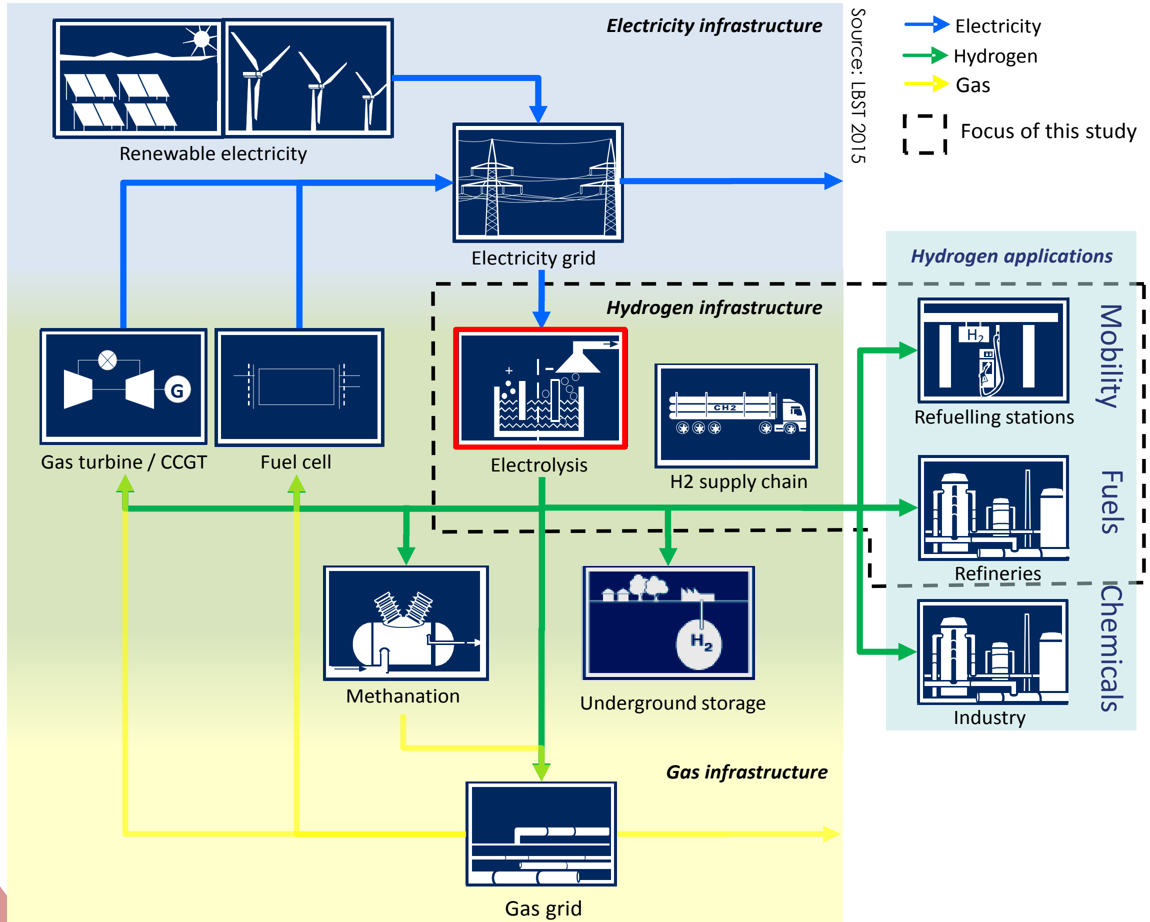




Additional consumption of 20 GW on average from H2 mobility
Only half of this is provided by additional VRE
The other half is provided by the existing capacity:

Figures: Hinicio, Compensating VRE intermittency with Power-to-gas with data [RTE,2015]

Power-to-Gas:
Linking renewable electricity and transport



Scope of the study

Definition

Power-to-Gas – PtG :

Production of a high-energy-density gas via water electrolysis

Image: LBST.

Power-to-Gas can support balancing at any time scale and at any point in the T&D system

1. With a high degree of **flexibility** and supported by large amounts of storage, PtG can **support balancing at any time scales**, from supply of **primary reserve** to **seasonal storage** (with underground storage).

2. PtG can **close growing gaps between local production and consumption**, **reducing the need to expand the distribution grid**, which carries most of the burden

3. **PtG can be used along with other flexibility options** such as CHP & heat pumps with heat storage, batteries and demand response.

Power-to-hydrogen can be implemented at different scales, from distributed to centralised

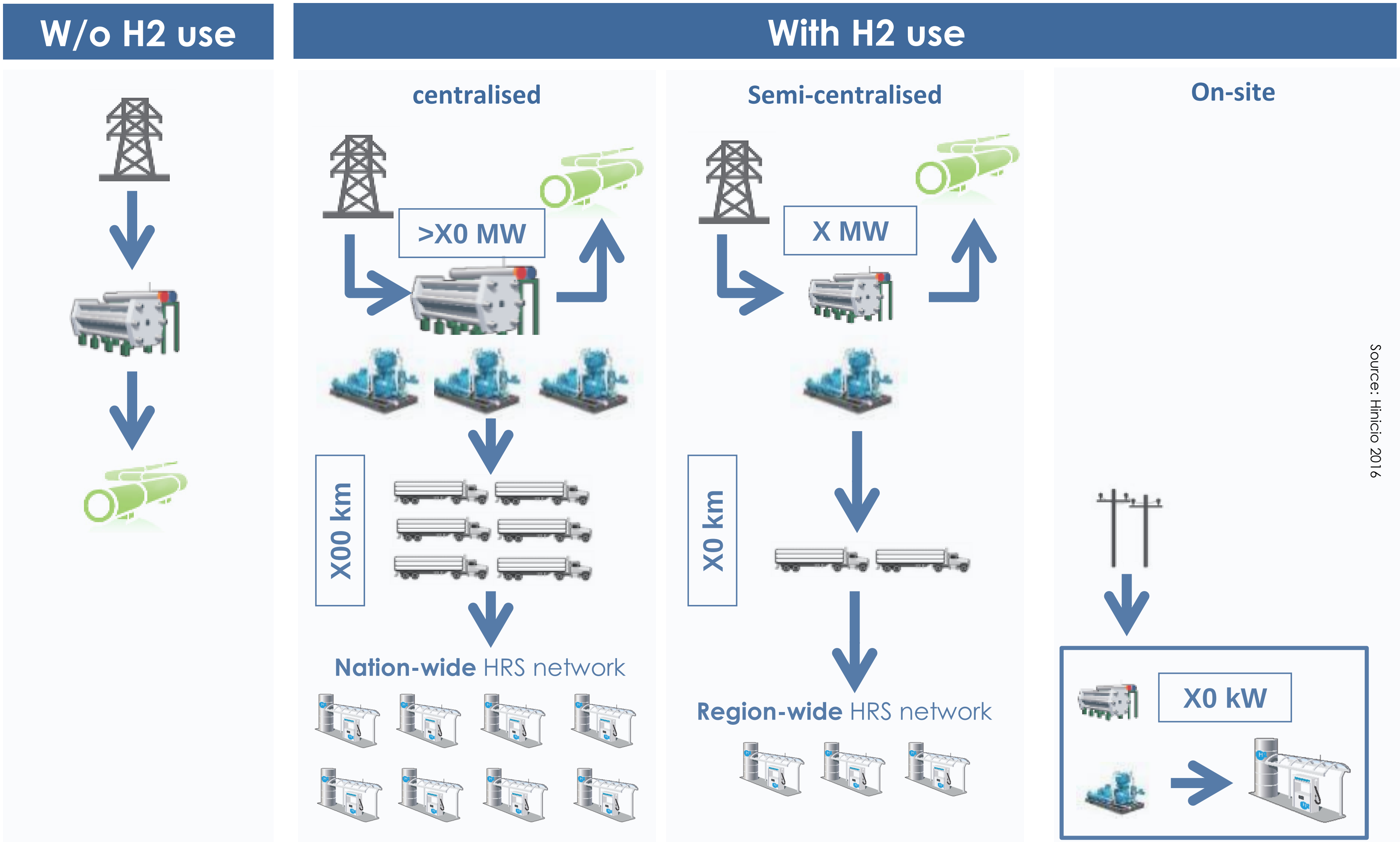


Image: Hinicio

Comparing electrolyser technologies

	Alkaline	PEM
Development stage	Industrial since 1920s	Early stage commercialization
Maximum capacity	Unit : 3.8 MW/67,7 kg/h Plant : 100 MW/1900 kg/h (Zimbabwe)	6 MW/ 120 kg/h (3 x 2 MW pilot unit)
Current density	Up to 0.4 A/cm²	Up to 2 A/cm² (R&D: 3.2 A cm⁻² at 1.8 V at 90°C)
Dynamic response	Less than one minute	Within seconds
Peak load	100%	200% (30 min)
Turn down	20 – 40 %	<10 %
Operating pressure (typical)	A few bars	Tens of bars
Investment costs	1.1 M€/MW*	1.9 M€/MW*
Operating cost	5 - 7 %	4 %

*Includes installation and balance of plant costs

Direct injection is the cheapest way to "dump" hydrogen from excess RE into the gas grid

	Advantages	Disadvantages
DIRECT INJECTION 	• Natural gas specification **allows the blending of hydrogen** • **Less costly** than methanation	• **Maximum injection limit** (technical and regulatory). • There is **no business case** for direct injection unless regulatory changes are made (FIT…)
METHANATION *(Sabatier process)* 	• **No maximum injection limit** • Exothermal – potential **synergies with CO2 generating process**	• Requires a **concentrated CO2 source** • **More costly** than direct injection: **no business case** without regulatory changes

Regulation drives the energy transition in both the power and transport sectors

Topic	Sector	World	EU	France	Germany
Greenhouse gases	All sectors	< 2°C (COP21)	**2020: -20%** **2030: -40%** **2040: -60%** **2050: -80/-95%** vs. 1990	**2030: -40%** **2050: -75%** vs. 1990 (LTE)	**2020: -40%** **2030: -55%** **2040: -70%** **2050: -80/-95%** vs. 1990
	Transport		**2020: -6%** (FQD) **2050: -60%** (COM 2011 144)	**2020: -10%$_{2010}$** (code de l énergie) **2028:-22%$_{2013}$** **2050:-70%$_{2013}$** (SNBC proj)	**2015: -3.5%$_{2010}$** **2017: -4%$_{2010}$** **2020: -6%** (BImSchG)
Renewable energy	All sectors		**2020: 20%** **2030: 27%**	**2020: 23%** (LTE)	**2020: 18%** **2030: 30%** **2040: 45%** **2050: 60%** (Energiekonzept)
	Transport		**2020: 20%** (RED)	**2020: 10.5%$_{2013}$** (SNBC proj)	
Energy consumption	All sectors		**2020: -20%1990** (COM 2011 112)	**2020: -7%$_{2005}$** (SNBC)	**2020: -20%** **2030: /** **2040: /** **2050: -50%**
	Transport				**2020: -10%** **2030: /** **2040: /** **2050: -40%**

Power-to-hydrogen systems can simultaneously address multiple applications

Business model assessed

Applications	Options	BM1	BM2
H2 sales to other markets	• **H2 fuelling stations** • **Industry – H2 refineries**	✓	✗
H2 injection into gas grid	• **Direct** • **Methanation**	✓	✓
Ancillary services to power grid	• **Primary and/or secondary reserve**	✓	✓

BM1: Business model 1

- Electrolyser investment and operation by an independent entity
- Income from hydrogen sales to market and gas grid and from provision of ancillary services to the power grid

BM2: Business model 2

- Electrolyser considered as a part of the T&D infrastructure
- Costs fully covered by costs-based grid charges

Application A
Hydrogen from power-to-gas for use in refineries

Section 2

Regulatory framework
Fuel greenhouse gas emission reduction

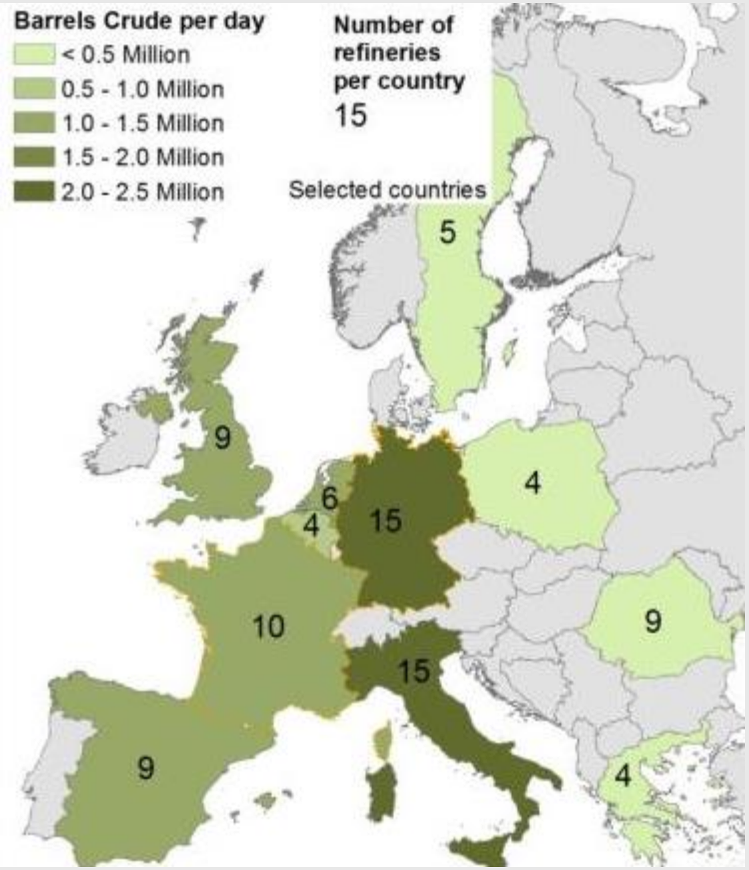
Criteria	EU Fuel Quality Directive (FQD)	France Code de l'énergie	Germany BImSchG/V
Lifetime	2020	2020	2020
GHG targets	-2 % by 2015 -4 % by 2017 -6 % by 2020	-10% by 2020	-3.5 % by 2015 -4 % by 2017 -6 % by 2020
Responsibility	Supplier	Energy tax responsible entity (usually the fuel refinery)	Energy tax responsible entity (usually the refinery)
Options **upstream:**	Flaring/venting	Flaring/venting	–
refinery:	–	Refinery GHG emissions reduction	–
downstream:	Biofuels and alternative fuels from non-biological sources	Biofuels, electricity	Biofuels
Hydrogen	H_2 eligible as transportation fuel (2015/652/EU, ANNEX I), <u>not</u> for use in refineries yet	H2 <u>not</u> yet eligible as transportation fuel. Reduction of refinery emissions through use of low carbon hydrogen is eligible	H_2 <u>not</u> yet eligible; 'further renewable fuels' (e.g. PtG) and 'other measures' are subject to enforcement of a legal ordinance (§37d (2), point 13
Infringement penalty	Subject to national implementation, which shall be 'effective, proportionate and dissuasive'	Not yet defined (Application decrees to be published in 2017)	470 €/t CO_{2eq}

Refinery landscape Europe

France and Germany are among the ‘top 5’ countries in Europe with regard to the number of refineries and the total installed refinery

Germany is the leading refinery location in Europe, by installed distillation capacity as well as by the number of refineries installed

France ranks fourth in Europe by number and capacity



Source: LBST with data [E3M et al. 2015]

Refineries in France and Germany

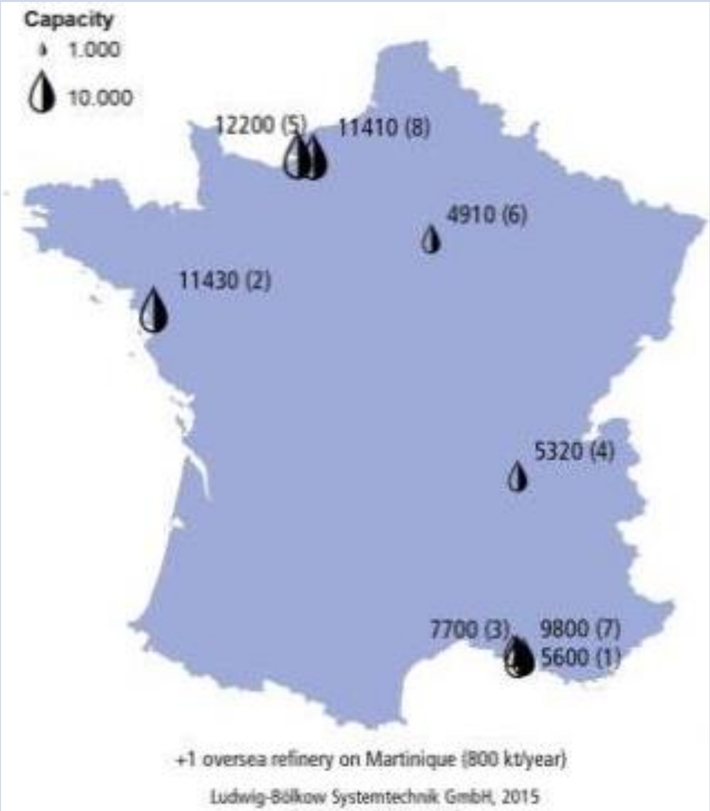
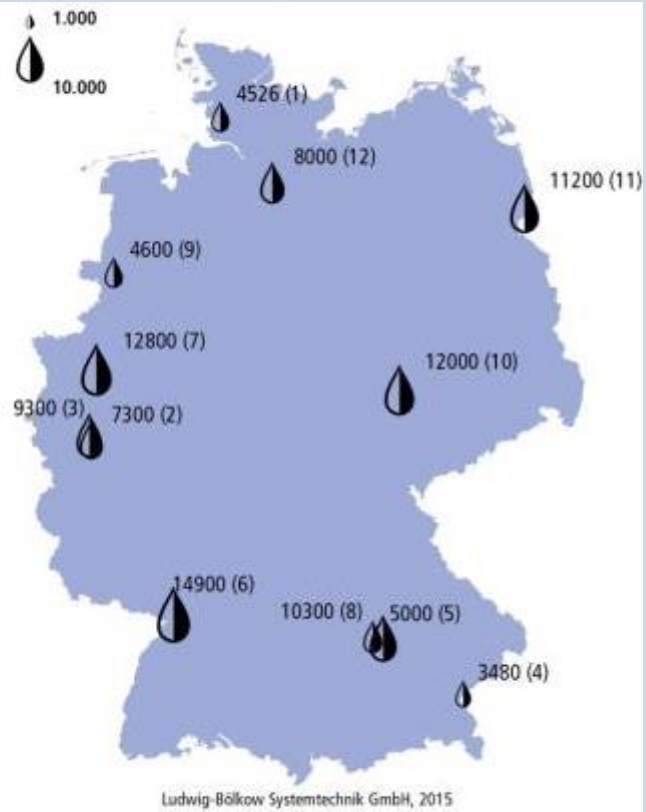
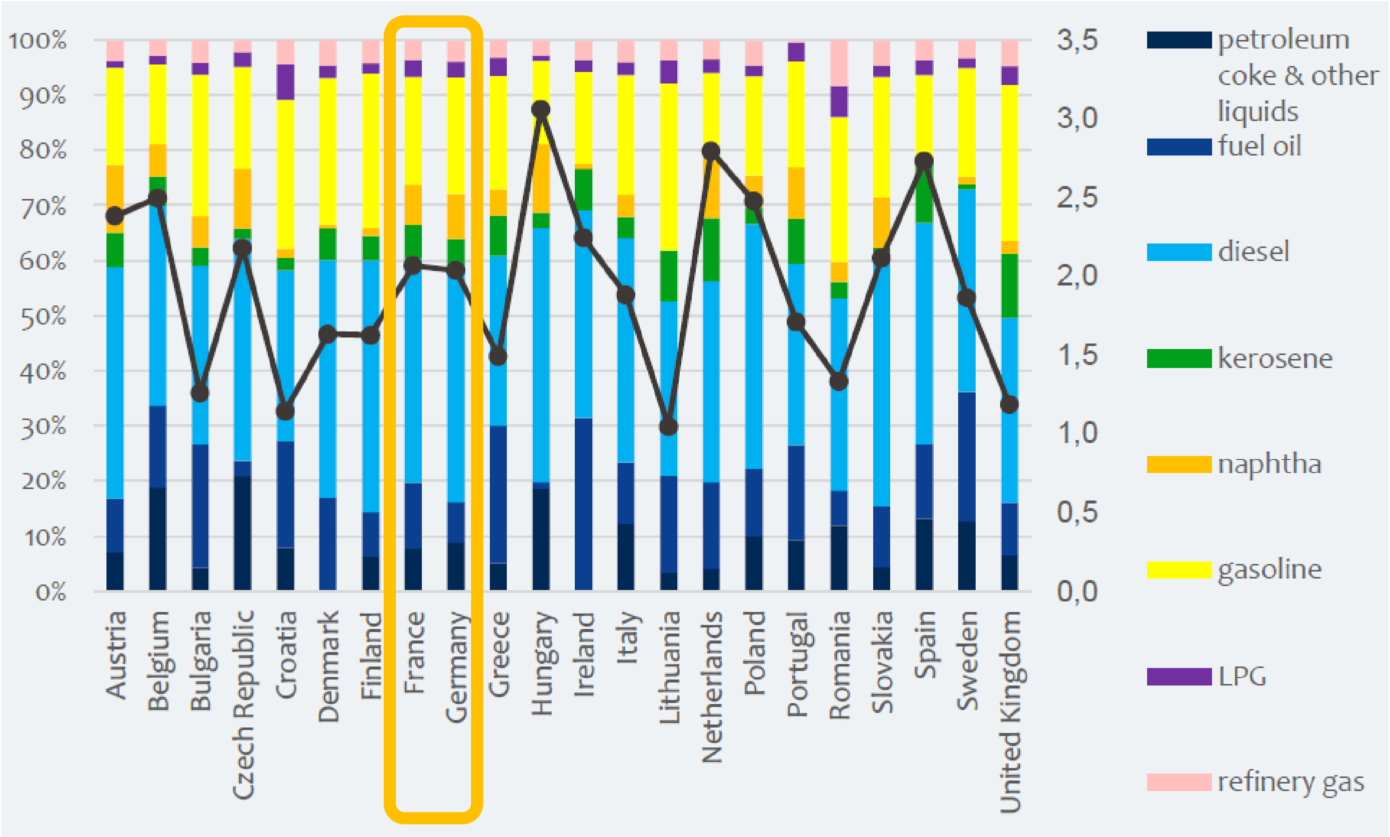
FRANCE	GERMANY
	
Σ 68.4 million t/yr capacity	Σ 103.4 million t/yr capacity

Image: LBST with data [MEDDE 2015]

Image: LBST with data [MWV 2015]

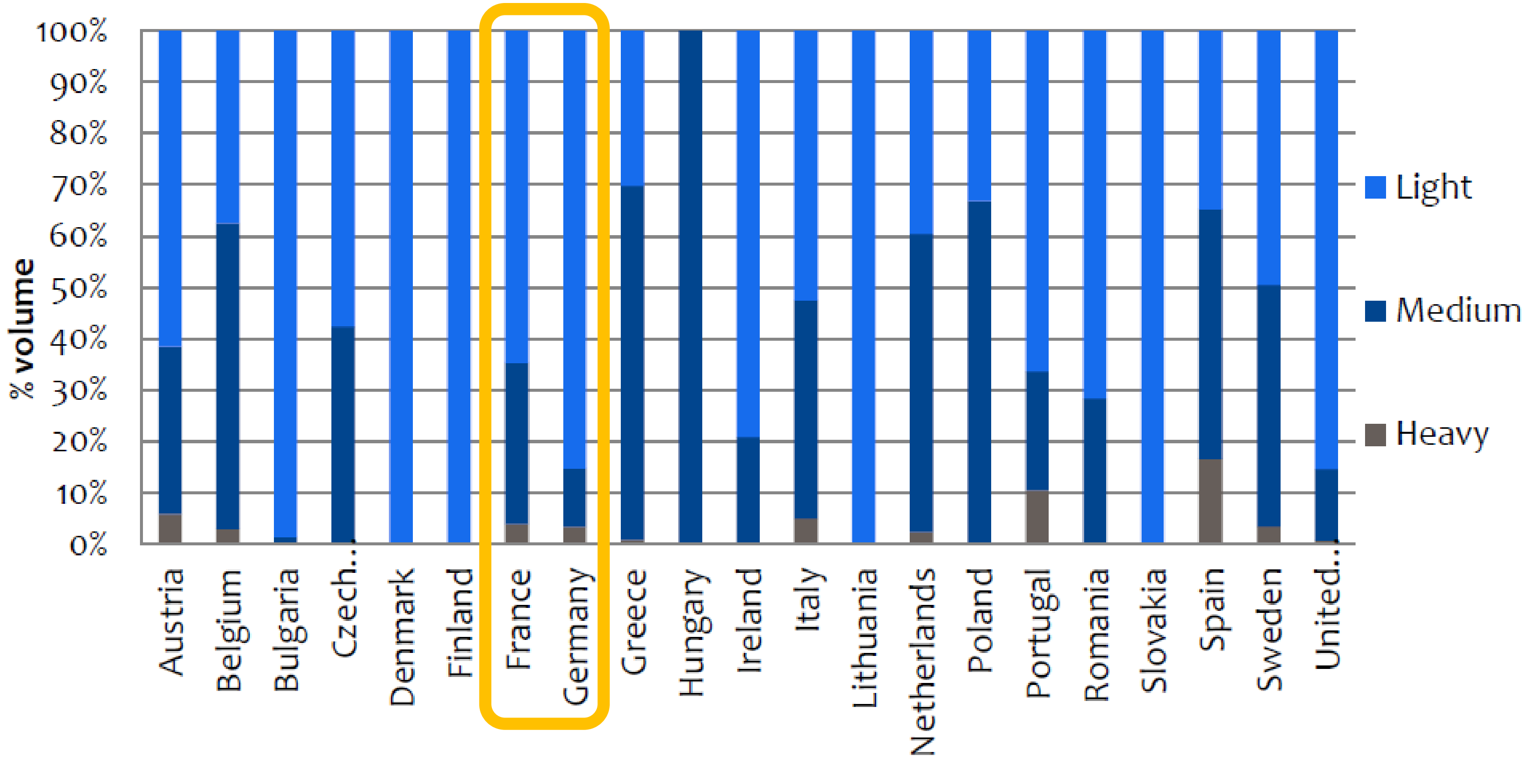
Product portfolio of European refineries



- The product mix from European refineries is diesel oriented (31-49% diesel, 13-30% gasoline, 1-12% kerosene – in % of total refinery output)
- Marginal differences between French & German refineries' product mixes only
- France and Germany are well within the average of European refineries

Image: [EXERGIA et al. 2015]

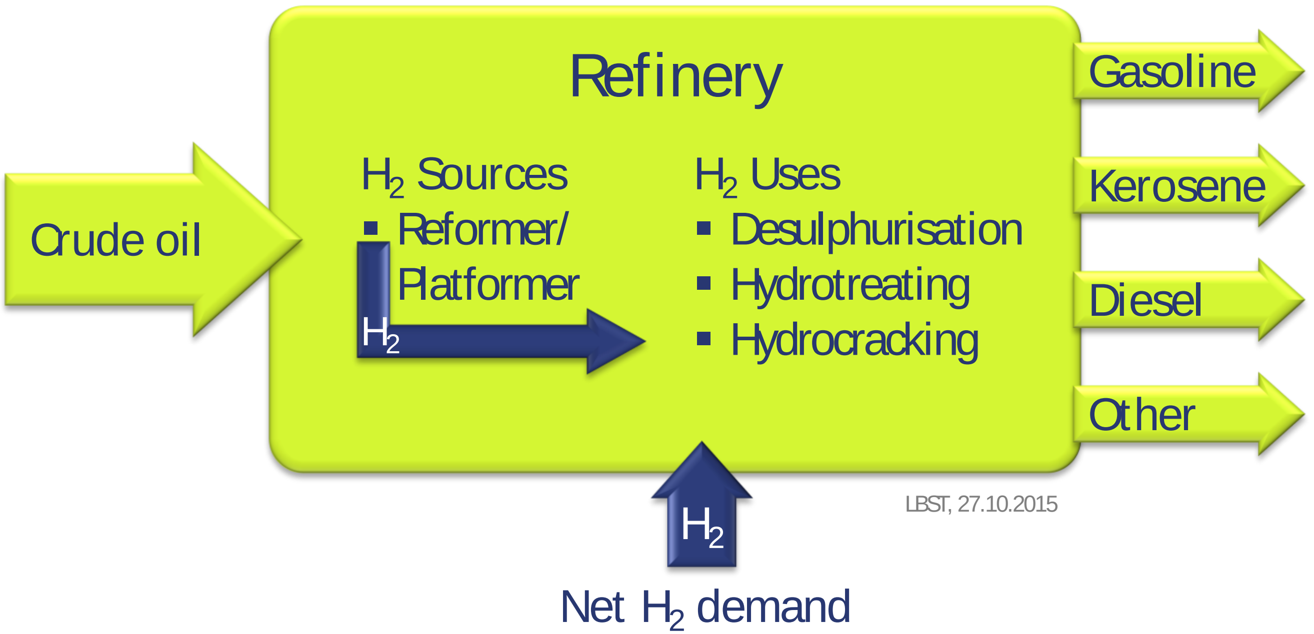
Crude oil qualities in European refineries



- There is a trade-off between crude oil cost and quality
- In Europe, a wide range of crude oil qualities is processed
- French and German refiners source rather better qualities
- Average crude oil quality [EXERGIA et al. 2015]:
  - France: 36.0 API gravity, 0.7 wt.-% sulphur
  - Germany: 37.3 API gravity, 0.5 wt.-% sulphur

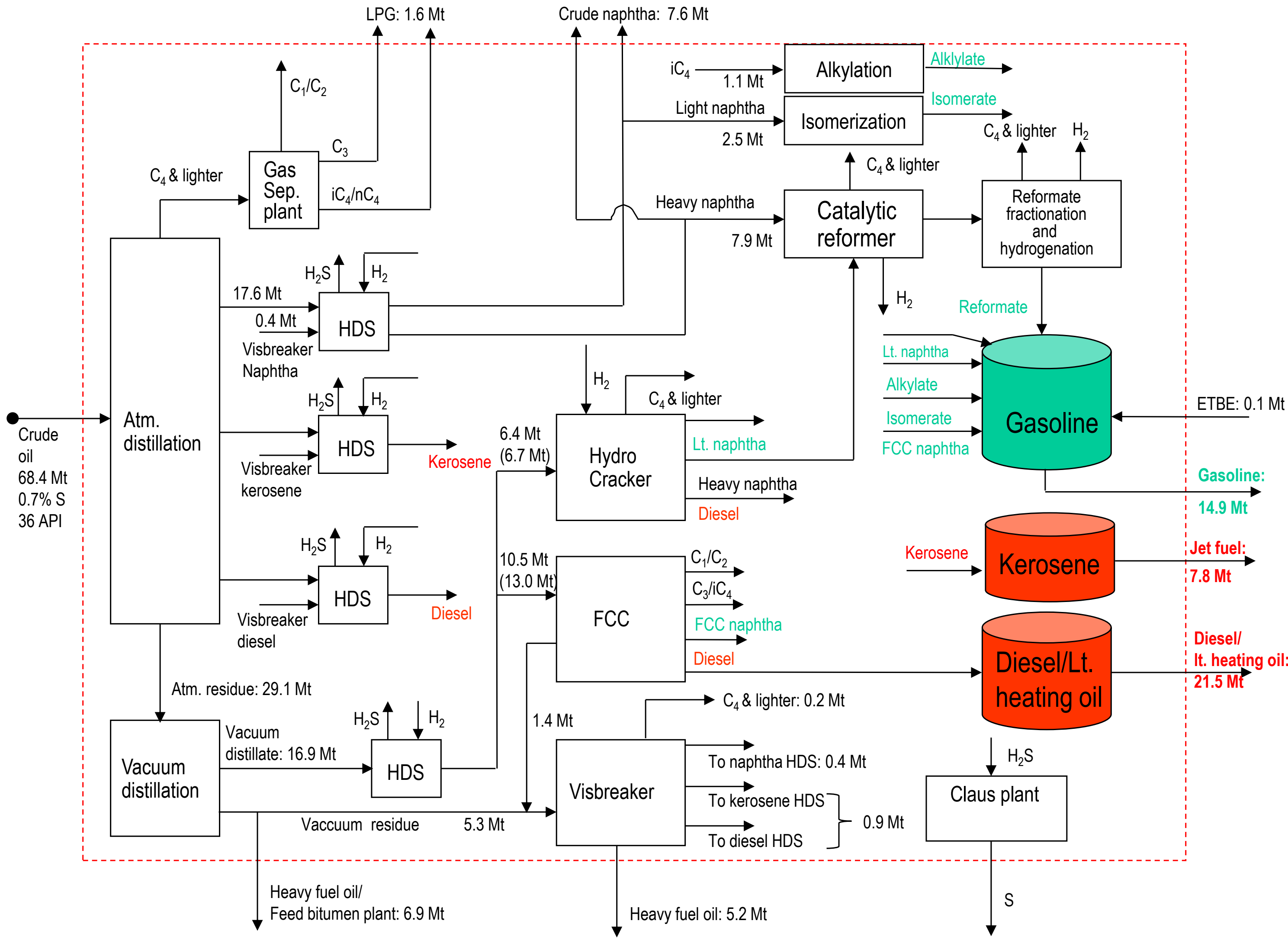
Image: [EXERGIA et al. 2015]

Hydrogen sources and uses in a refinery



- Calculation: Net hydrogen demand = process sources – process uses
- Desulphurisation is a sensitive parameter to net hydrogen demand
- By tendency,
  - crude oil quality is further deteriorating → increasing sulphur content
  - demand for heavy fuel fractions is decreasing → maritime emission areas

Synthetic refinery France



Source: LBST refinery model

Hydrogen demand and production French & Germany crude oil refineries (kt/yr)

France [kt/yr]

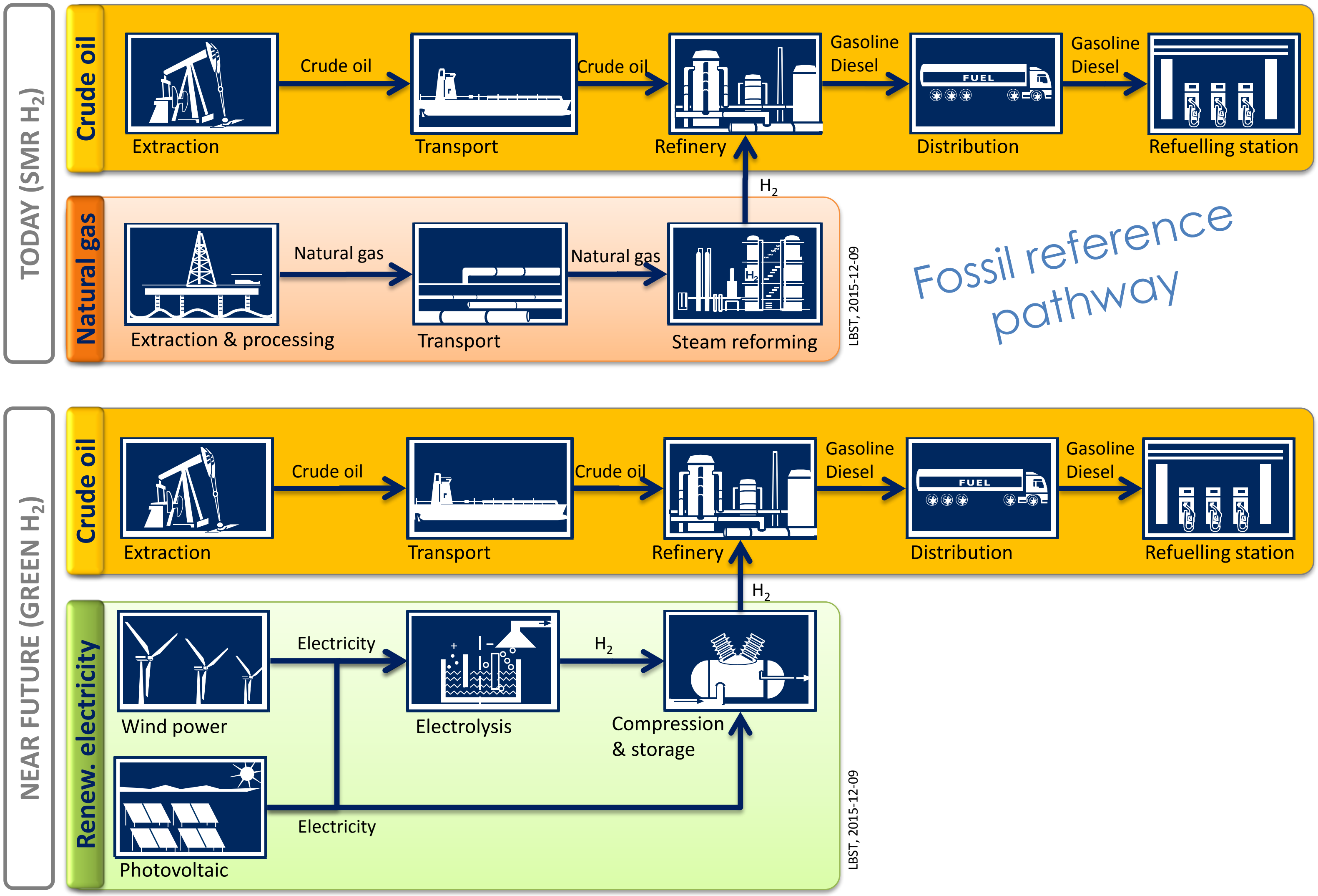
Refinery process	H_2 demand	H_2 production	Net H_2 demand
Hydrocracking	220.3		
Vacuum distillate desulfurisation	29.2		
Middle distillate desulfurisation	48.9		
Naphtha desulfurisation	21.7		
FCC cracker		0*	
Catalytic reformer		158.9	
Total	**320.1**	**158.9**	**161.3****

Germany [kt/yr]

Refinery process	H_2 demand	H_2 production	Net H_2 demand
Hydrocracking	327.2		
Vacuum distillate desulfurisation	22.3		
Middle distillate desulfurisation	65.1		
Naphtha desulfurisation	37.0		
FCC cracker		0*	
Catalytic reformer		307.7	
Total	**452.1**	**307.7**	**144.4****

* H_2 from FCC plus other gases for heat supply; ** assumed to be supplied by steam-methane reformer (SMR)

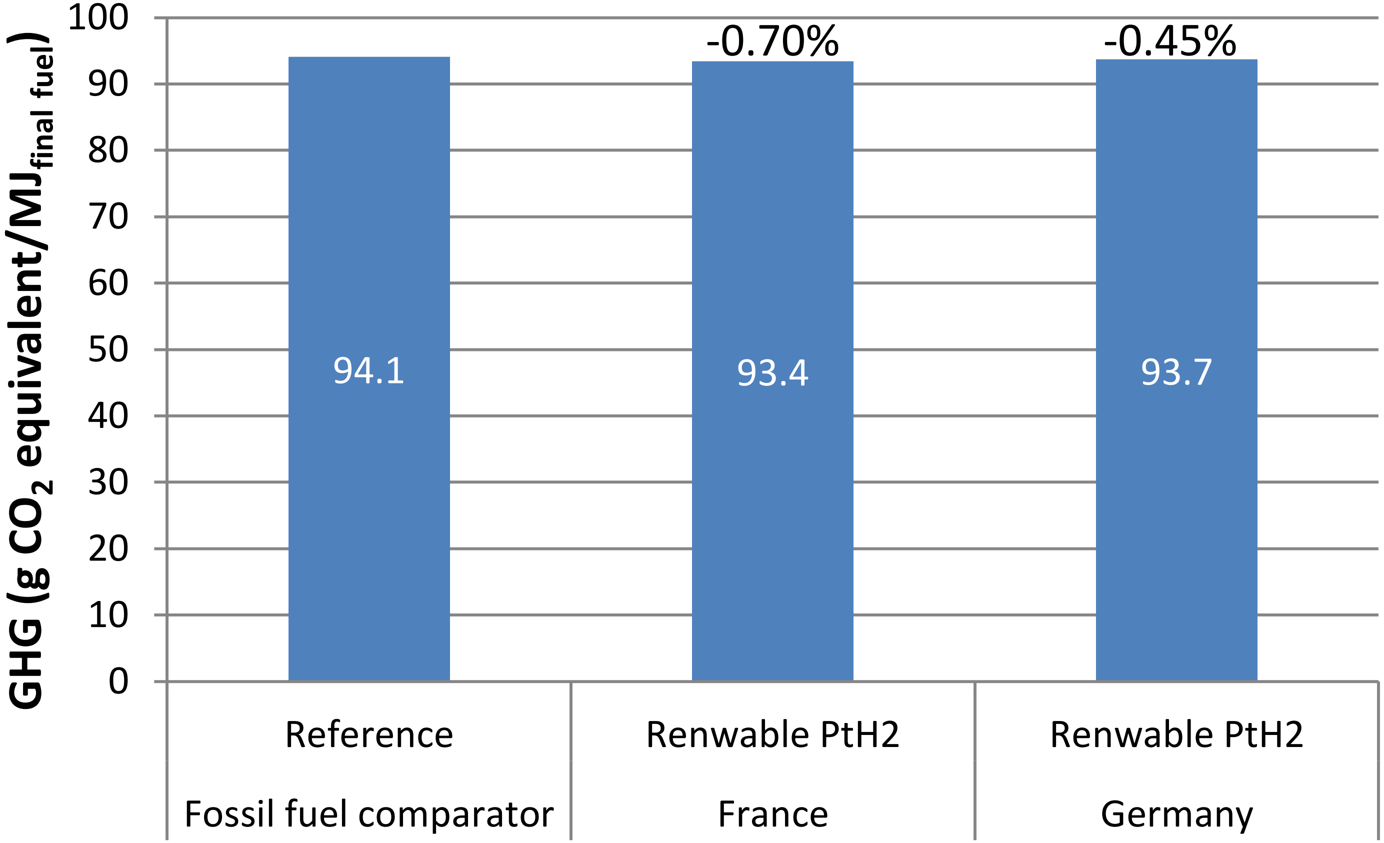
Life-cycle assessment (LCA)
Pathways for gasoline and diesel supply



Scenario

Refinery net H_2 demand from 100% green H_2

Greenhouse gas emissions per final fuel France and Germany [g CO_{2eq}/$MJ_{final\ fuel}$]



- FQD minimum target is -6% GHG emissions by 2020

Refinery GHG emission reduction (gate-to-gate) France and Germany

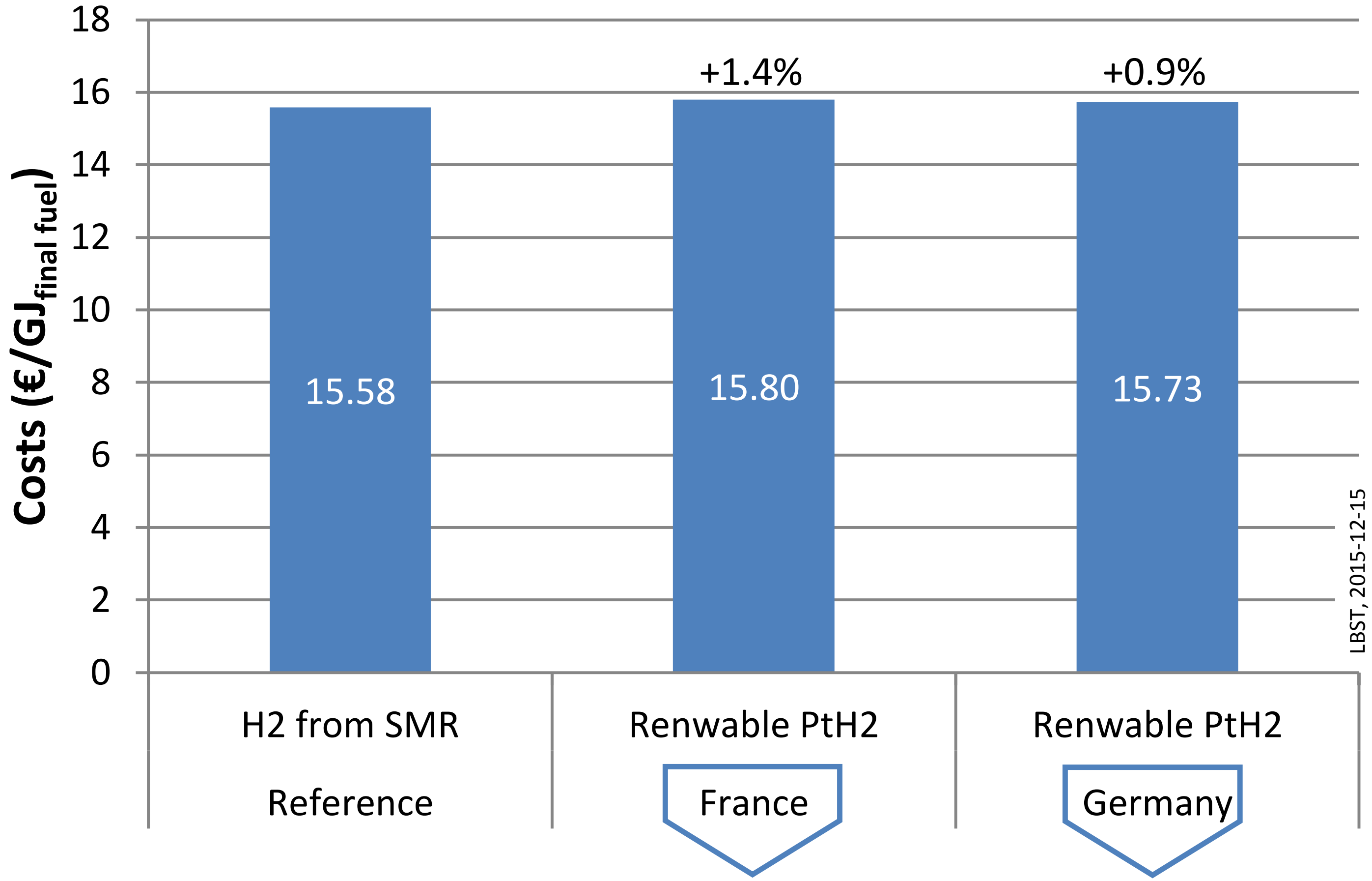
	France	Germany
GHG mitigation of refinery emissions	1.33 Mt CO_{2eq}/a	1.50 Mt CO_{2eq}/a
	14.1 %	7.2 %

To give an impression about the quantities, this is equivalent to annual GHG emission of C segment cars in the order of

Gasoline car @ 7.0l/100km	575,000	648,000
Diesel car @ 5.5l/100km	658,000	740,000

→ Tangible action for refinery corporate social responsibility (CSR)

Gasoline and diesel production costs France and Germany [€/GJ$_{final\ fuel}$]



	France	Germany
Impact on fuel costs:	+0.8 ct/$l_{Diesel-eq}$	+0.5 ct/$l_{Diesel-eq}$
GHG abatement costs:	331 €/t CO_{2eq}	339 €/t CO_{2eq}

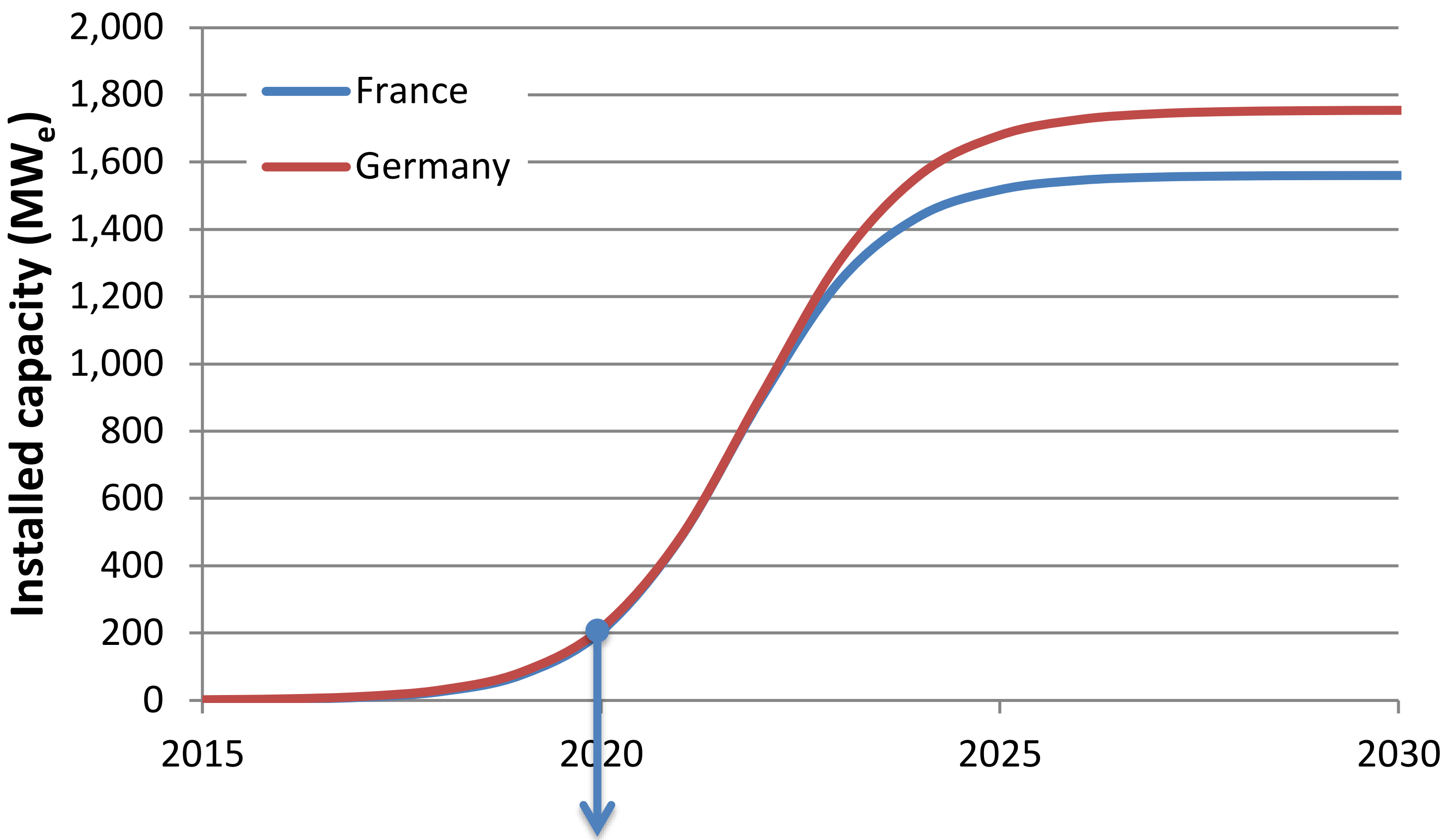
- Penalties for non-compliance are 470 €/t CO_{2eq} in Germany

Cumulated investments France and Germany

	40 % PV : 60 % wind onshore	
	France	Germany
Net H_2 input per crude oil input	0.66 % (LHV)	0.39 % (LHV)
GHG mitigation of refinery emissions	1.33 Mt CO_{2eq}/a	1.50 Mt CO_{2eq}/a
	14.1 %	7.2 %
H_2 demand	4.06 TWh_{H2}/a 122 kt_{H2}/a	4.56 TWh_{H2}/a 137 kt_{H2}/a
Required electrolyser capacities	1.58 GW_e	1.78 GW_e
Electrolyser cost reduction 2025	45 $\%_{2015}$	45 $\%_{2015}$
Cumulated investments electrolysis [€]	1.5 billion €	1.6 billion €
Electricity demand H_2 production	6.24 TWh_e/a	7.02 TWh_e/a
Required RES plant capacities ▪ Wind onshore ▪ Photovoltaics	3.14 GW_e ▪ 1.90 GW_e ▪ 1.24 GW_e	3.73 GW_e ▪ 2.24 GW_e ▪ 1.49 GW_e
Cumulated investments RES plants	4.4 billion €	5.4 billion €
Cumulated investments RES + electrolysis	**5.9 billion €**	**7.0 billion €**

→ For comparison: 650,000 cars · 30,000 €/EV = 19.5 billion €

Scenario installed electrolyser capacities in French and German refineries



Example for an average refinery in France in 2020:
→ 8 units of 4 MW wind power plants + 20 MW installed photovoltaics

Green hydrogen in refineries
Take-away messages

Conclusions

- Green H_2 in refineries is an attractive GHG mitigation option
- A portfolio of options will be needed post-2020 at the latest
- Introduction of green H_2 in an established bulk H_2 application
- Volume production of H_2 reduces electrolyser costs
- Electrolysers 'valley of death' is bridged by all fuel users

→ Deployment of electrolysers for refineries is a strategic move entailing long-term benefits for all hydrogen uses.

Recommendations

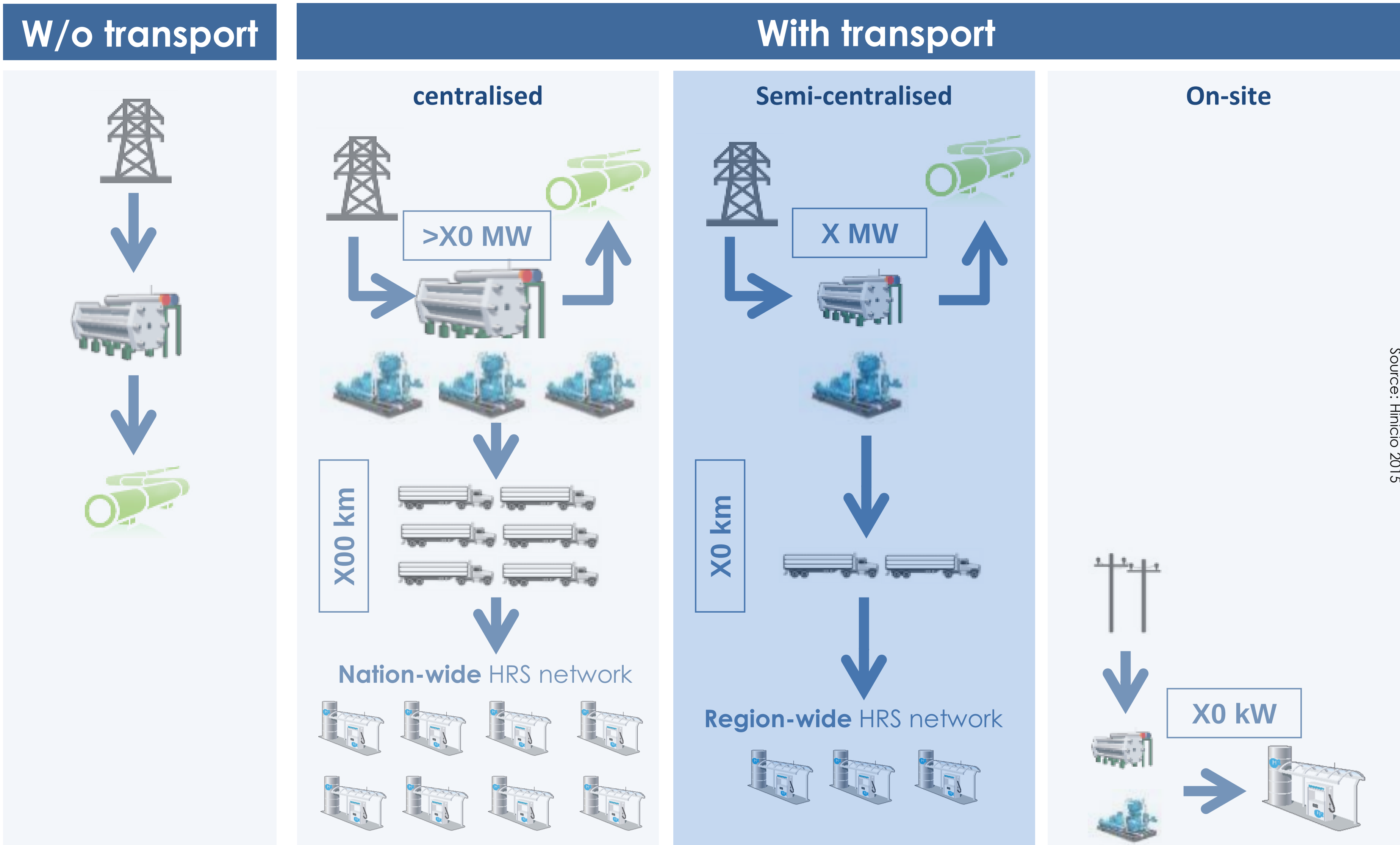
- Establish regulatory grounds for accountability at EU level
- Fast-track implementation rather at national level
- This study did full-cost analysis to explore the potentials — next:
  - Refinery specific business case analyses
  - Regional renewable electricity supply scenarios
  - Synergies between electricity, refinery, H_2 infrastructure

Application B

Semi-centralised PtG system for coupling the electricity and transport sectors

Section 3

Novel techno-economic modelling of a semi-centralised hydrogen system



Source: Hinicio 2015

Image: Hinicio

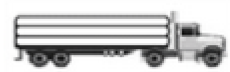
Main components of a semi-centralised Power-to-Gas system

H2 production & conditioning

Production 1 MW

Conditioning

Storage and transport



Distribution

kgH2 →

← €/kgH2

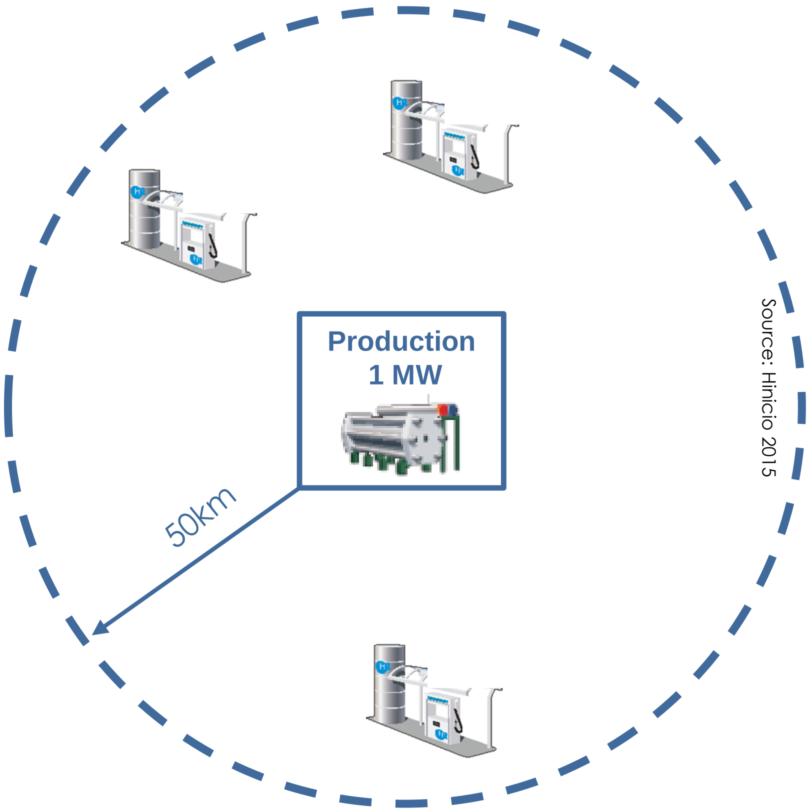
Consolidated Business Case

	H2 production & conditioning	Storage and transport	Distribution	Consolidated Business Case
CAPEX	M€	M€	X	M€
OPEX	k€/yr	k€/yr	X	k€/yr
H2 cost €/kg	€/kg_{H2}	€/kg_{H2}	X	€/kg_{H2}
Revenues	-	-	X	k€/yr

Source: Hinicio 2015

Image: Hinicio

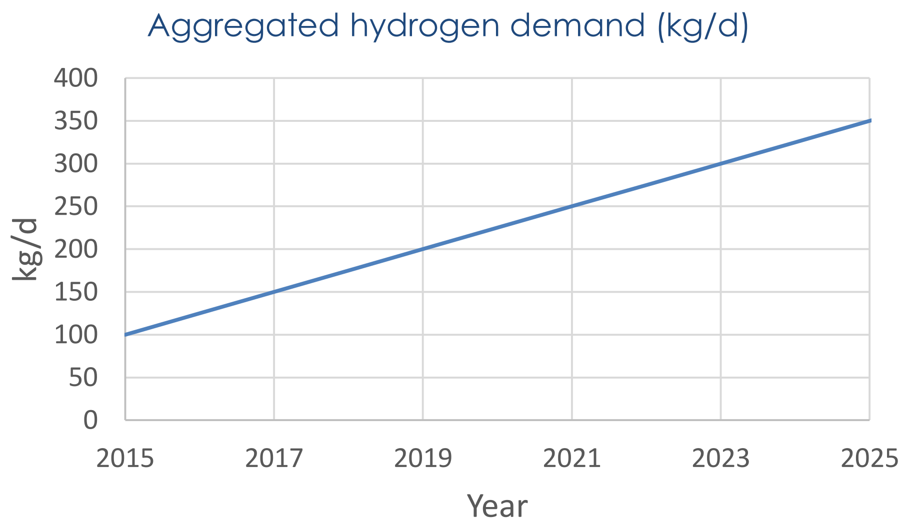
System dimensioning: starting from the demand



Electrolyser dimensioning and location

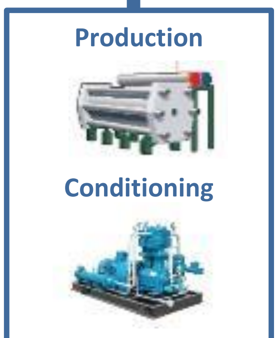
- Dimensioning:
Hypothetical demand of **325 kg/day** requiring a **1 MW** of electrolysers capacity

- Location:
The electrolyser is located where its makes most sense with regards to **interfacing with the power and natural gas grid, operations and logistics**.



Image& figures: Hinicio

System dimensioning: costs and revenues of the electolyser and conditioning center



CAPEX

1 MW electrolyser including conditioning and trailer filling center and grid injection skid:

- 2015: 2.5 M€
- 2030: 1.2 M€

OPEX

- Electricity costs
  - Spot market price/Energy purchase price
  - Grid charges and other fees
  - Grid charge exemption for electricity used for injection of H2
- O&M : 6% CAPEX/year

REVENUES

- H2 injection: 90 €/MWh
- Primary/ secondary reserve payments: 18 €/MW/h

Image: Hinicio, H2BCase model

System dimensioning: Hydrogen storage and distribution system

How to dimension hydrogen logistics and storage?

- Size of storage @ HRS

- Size of trailers
- Number of trailers

3-step dimensioning method

1. The HRS storage is sized according to the specific cost of delivery vs. the specific cost storage capacity (€/kg): **delivery every 3 to 4 days at full capacity.**

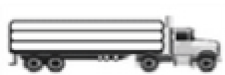
2. The trailer capacity is chosen in order to have a **filling time of less than one day** from the electrolyser.

3. The number of trailers needed in the supply chain is determined based on **time to refill vs total hydrogen consumption.**

One 200 kg trailer is sufficient for initial volumes, 3 trailers when full electrolyser capacity is reached.

System dimensioning: costs of logistics and storage

Storage and transport



CAPEX

- CAPEX trailer * N_trailers
- N_supply-chain fleet = Rotation time * Demand / Trailer cap.
- **CAPEX 200 kg trailer: 125k€**

OPEX

N_delivery X Cost of delivery

- Delivery cost:
  - 45 €/h
  - 1.0 €/km
- N_delivery = Consumption / Effective capacity

REVENUES

- H_2 sales: **8€/kgH2** (delivered from the electrolyser to the hydrogen refueling stations at 200 bar)

Image: Hinicio, H2BCase model

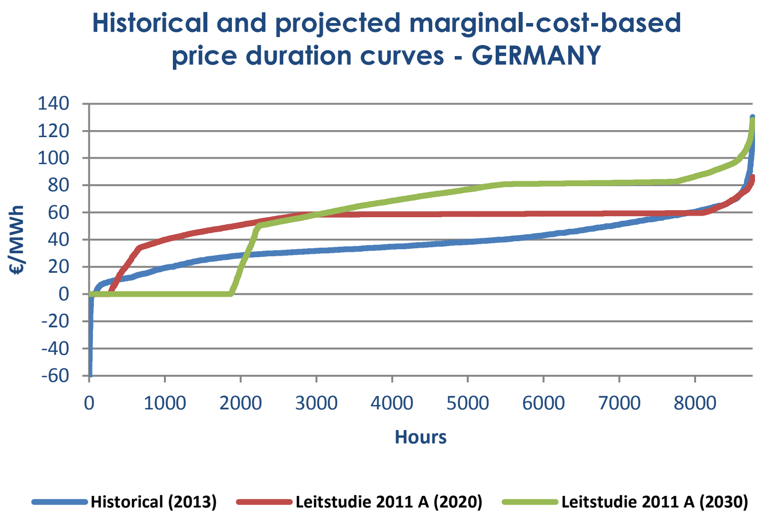
PtG can build on a more favorable electricity tax regime in France

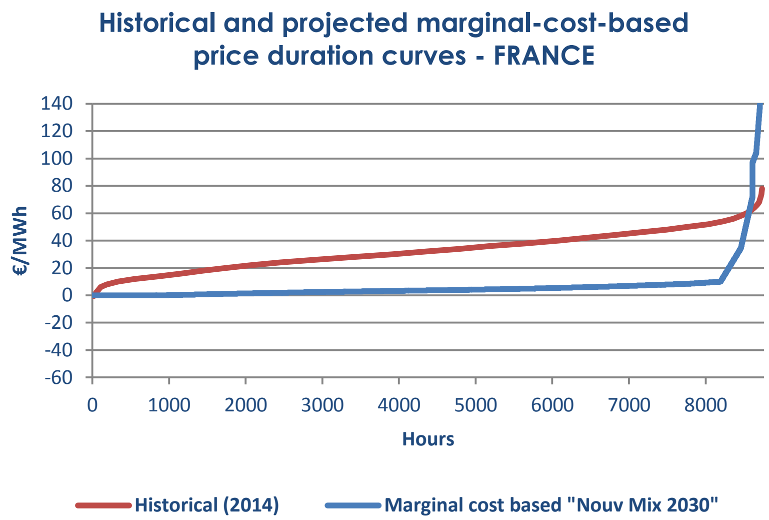
	FRANCE	GERMANY
GRID ACCESS	€ 18 / MWh	€ 0 / MWh (electro-intensive)
RENEWABLE ENERGY CHARGE	€ 0.5 / MWh (electro-intensive)	€ 70* / MWh
TOTAL	€ 19.5 / MWh	€ 70 / MWh

* Agglomerated average cost including the concession fees and appropriations

Table: Hinicio & LBST

Increasing penetration of low marginal cost generation makes PtG more attractive, in particular in France





Historical data : 2014 spot market prices for France ; 2013 spot market prices for Germany

For 2020 and 2030, curves are based on marginal costs of production, including CO2 price, and based on projected residual load power duration curves.

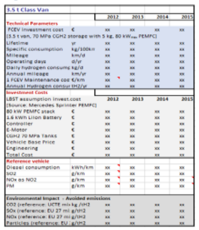
- Marginal costs are generally lower in France than in Germany, due to nuclear and increased share of variable RE.
- Visible impact of zero marginal cost RE going forward.

Figures: Hinicio with data [Leitstudies 2011, RTE 2015, EPEX SPOT 2014, EPEX SPOT 2013]

H2BCase by HINICIO: Optimising and simulating your hydrogen supply chain

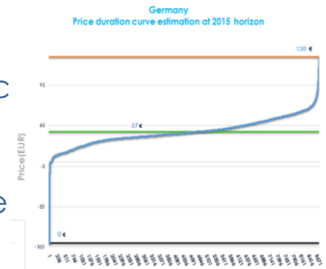
Techno-economic database of hydrogen technologies

- Production
- Conditioning
- Storage
- Logistics
- HRS
- Vehicles



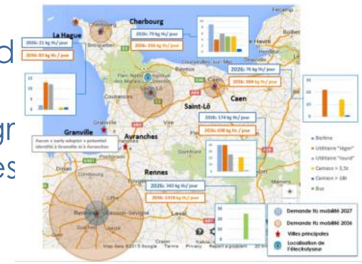
Energy markets

- Electricity spot pric
- Balancing market
- Capacity market
- Natural gas marke
- Carbon tax



Local data

- H2 Demand
- Gas grid
- Electricity gr
- Road acces
- Distances



H2BCase

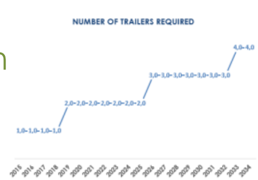
by Hinicio

All configurations

- centralised
- Semi-centralised
- On-site

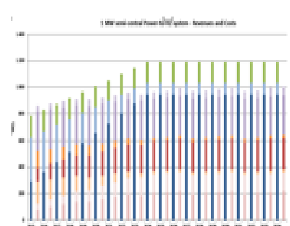
System sizing optimum

- Production
- Conditionin
- Storage
- Logistics
- HRS



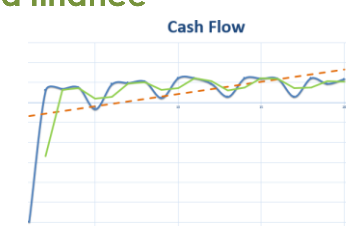
System operation

- Production
- Conditioning
- Storage
- Logistics
- HRS



Economics and finance

- CAPEX
- OPEX
- Revenues
- Cash flow
- IRR, NPV
- P&L



Images: Hinicio H2BCase model

12 scenarios assessed

Parameter	Scenario											
	1 - Ref	2	3	4	5	6	7	8	9	10	11	12
Country	France		Germany									
Year of electrolyser commissioning	2015			2020	2030						2030	
Initial/Final H2 Mobility demand (kg/d)	100/325	100/ 163					No H2 mobilit y sales		100/ 163			
Electricity price duration curve or cost	France 2014		Germ. 2014	Germ. 2020	Germ. 2030					26% of wind el. Cost France	100% of wind el. cost France	17% of wind el. Cost Germ.
Grid charge	France 2015		Germany 2015 rates									
CSPE (€/MWh)	Electr.-int. 0.5					19.5						
H2 injection price (€/MWh)	90 (FIT)				55.8			No inject.	No inject		55.8	
Electrolyser capex (M €/ MW)	1,9				0.55						0.55	
Electrolyser efficiency/stack lifetime	66%/4y				75%/ 10y						75%/ 10y	

Table: Hinicio

Scenario 1 - Reference - Hypotheses

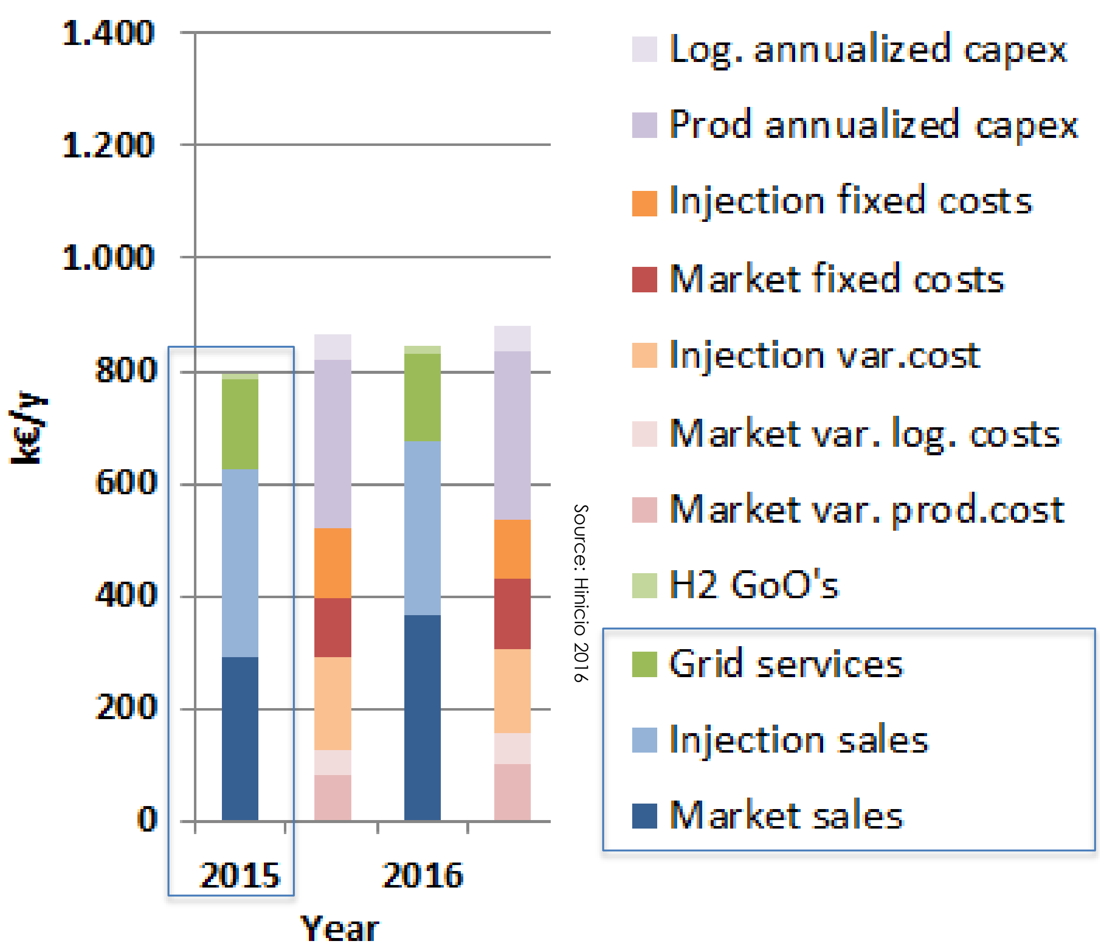
Scenario Nbr	1 (Ref)
Country	France
Year of electrolyser commissioning	2015
Initial/Final H2 Mobility demand (kg/d)	100/325
Electricity price duration curve	France 2014
Grid charge	France 2015 rates
CSPE (€/MWh)	Electro-int. 0.5
H2 injection price (€/MWh)	90 (FIT)
Electrolyser capex (M €/ MW)	1,9
Electrolyser efficiency/stack lifetime	66%/4y

Table: Hinicio

- **H2Mobility market** consumes **1/3 of electrolyser capacity in year 1** (1MW electrolyser – 100 kg/day – **100 FCEV/REX or 4 busses**) and increases to full electrolyser capacity in year 10.
- Electrolyser plant considered to be benefiting from **"electro intensif" regime** (low grid / tax fees).
- Available capacity permitting, **H2 is produced for injection into the Gas Grid** when **marginal costs of H2 production are lower than Feed-In-Tariff (assuming €90/ MWh)** to achieve increase revenue streams during market take-off phase of FCEV.
- No charges applied to the electricity consumed for producing the hydrogen injected into the gas grid

Representation of Results per Scenario (1)

1 MW semi-central Power-to-H2 system - Revenues and Costs (CAPEX depreciated)



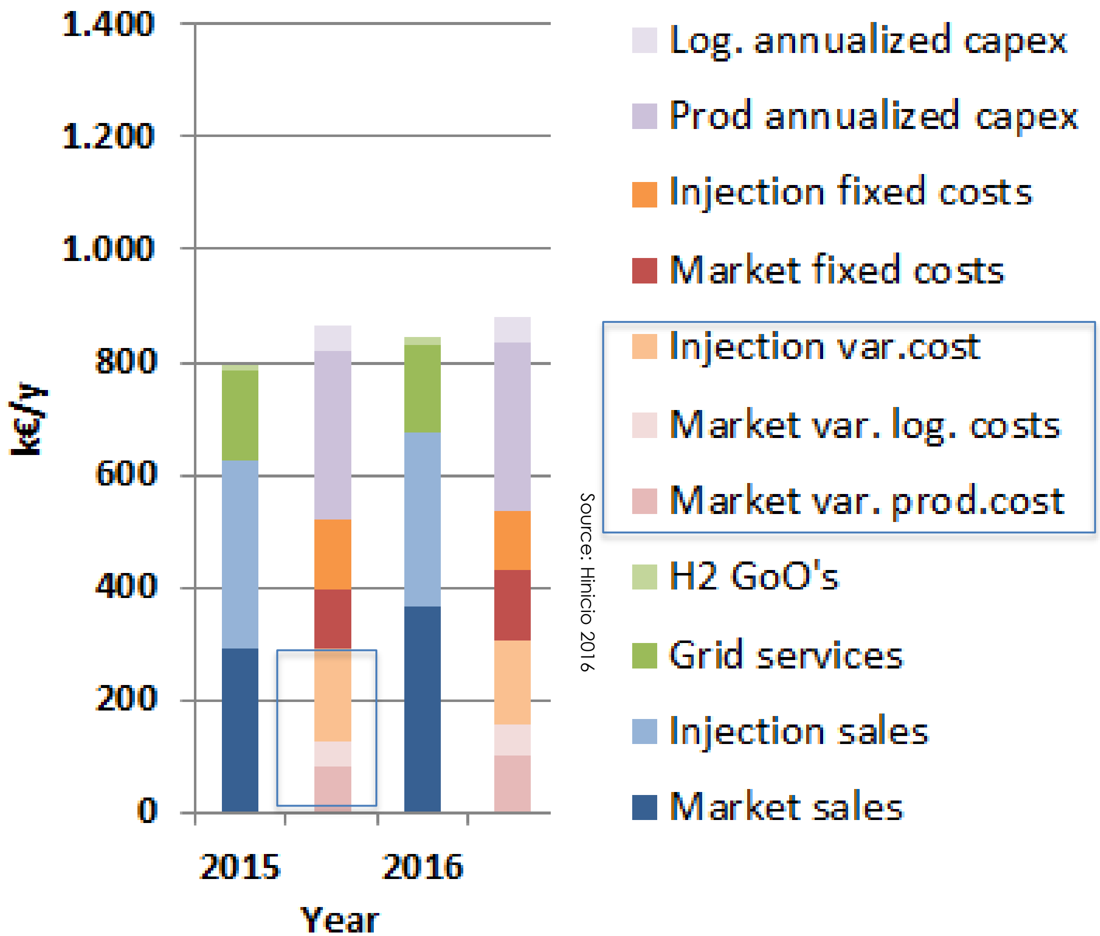
<u>Revenues:</u>

1. H2Mobility: €8 / kg @ 200 bar @ HRS
2. H2 injected @FIT: €90/MWh
3. Primary reserve: €18/MW/h

Figure: Hinicio, H2BCase Model

Representation of Results per Scenario (2)

1 MW semi-central Power-to-H2 system - Revenues and Costs (CAPEX depreciated)



Variable Costs:

1. H2Mobility: variable Electricity costs & water costs
2. H2Mobility: variable cost of trailer transport (€1/km and €45/hr)
3. Injection: variable electricity costs & water costs

Figure: Hinicio, H2BCase Model

Representation of Results per Scenario (3)

1 MW semi-central Power-to-H2 system - Revenues and Costs (CAPEX depreciated)

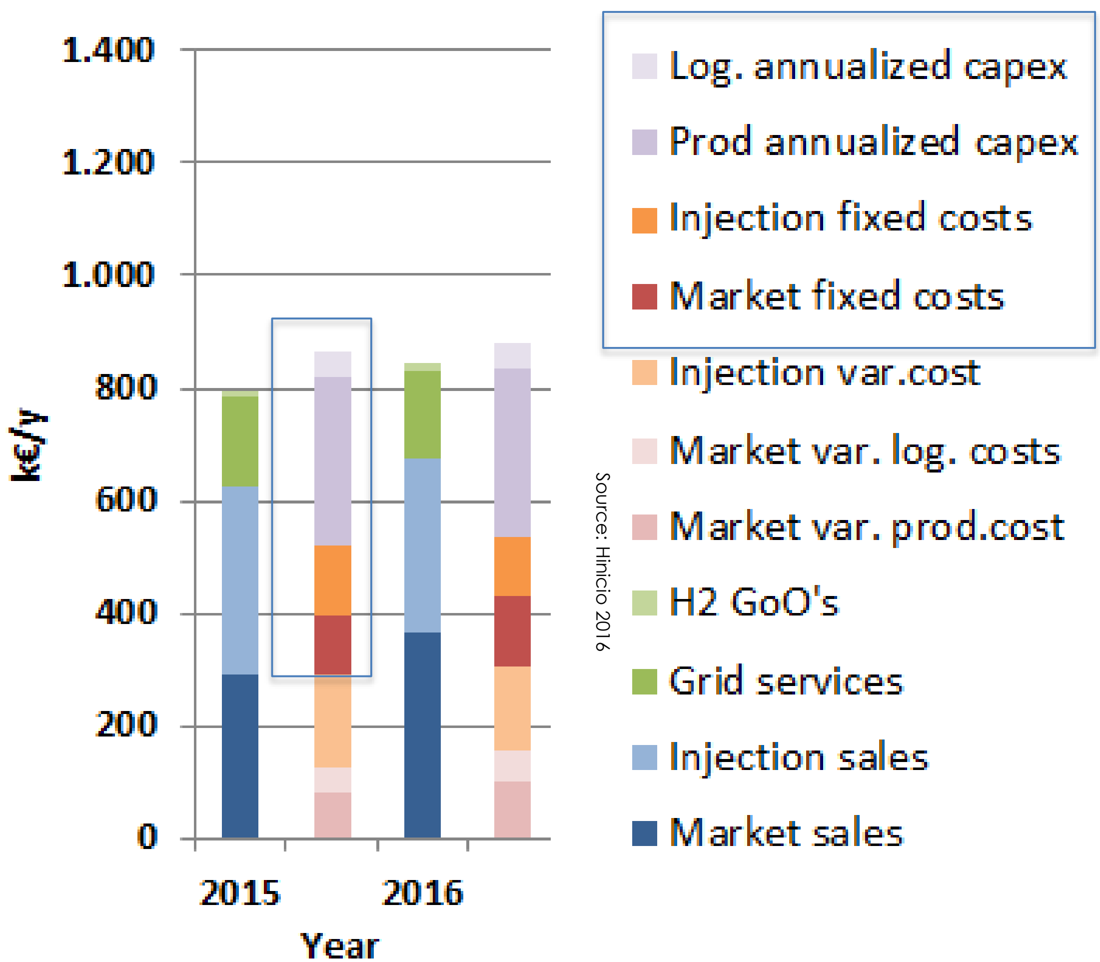
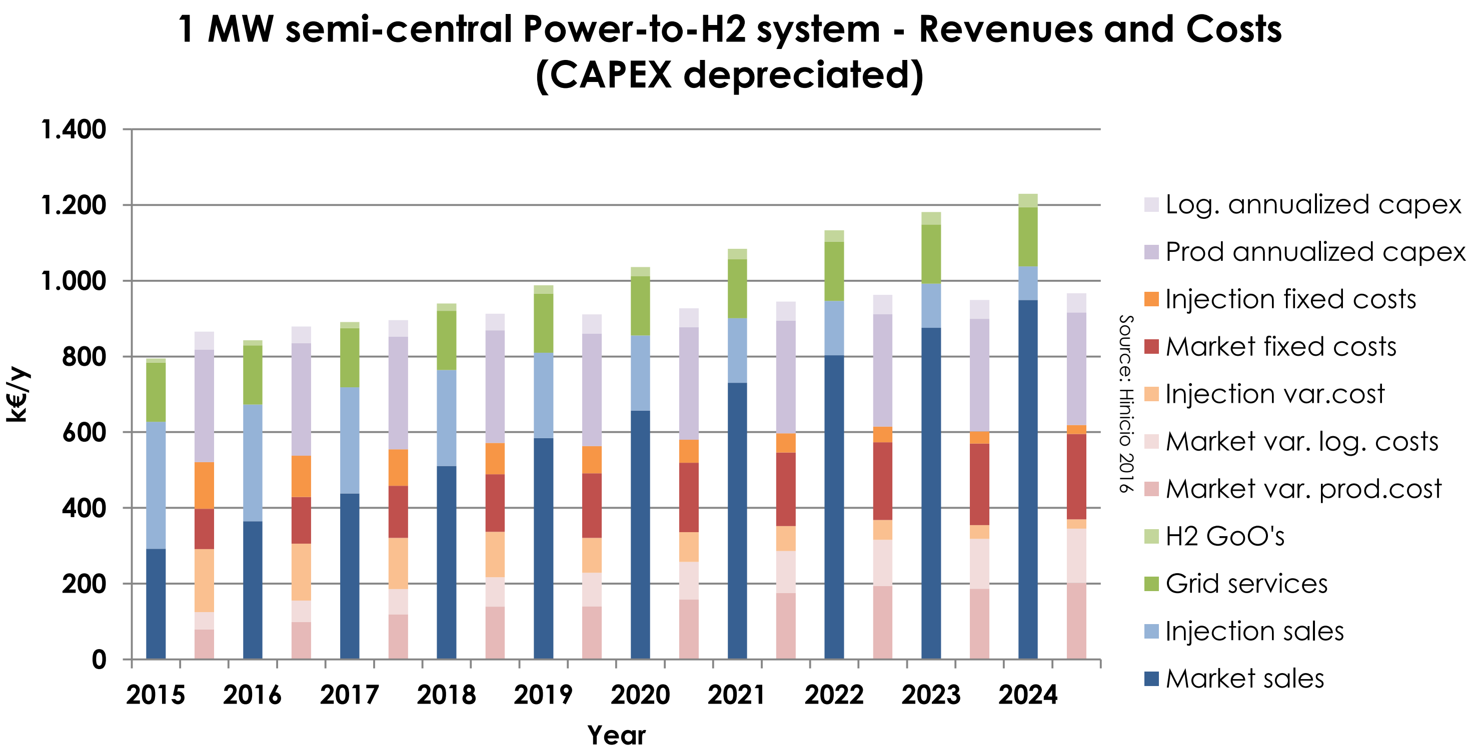


Figure: Hinicio, H2BCase Model

Fixed Costs:

1. H2 Mobility: electrolyser O&M (3% +3% of CAPEX) & Fixed part of Grid fee & Trailer & Storage @ HRS O&M
2. Injection: Electrolyser O&M (3% +3% of CAPEX) & Fixed part of Grid fee
3. Depreciation of Electrolyser + Stack Replacement + Compressor & Injection Skid
4. Depreciations of Trailer & Storage @ HRS

Scenario 1 - Reference - Results



IRR = 0% (10y)

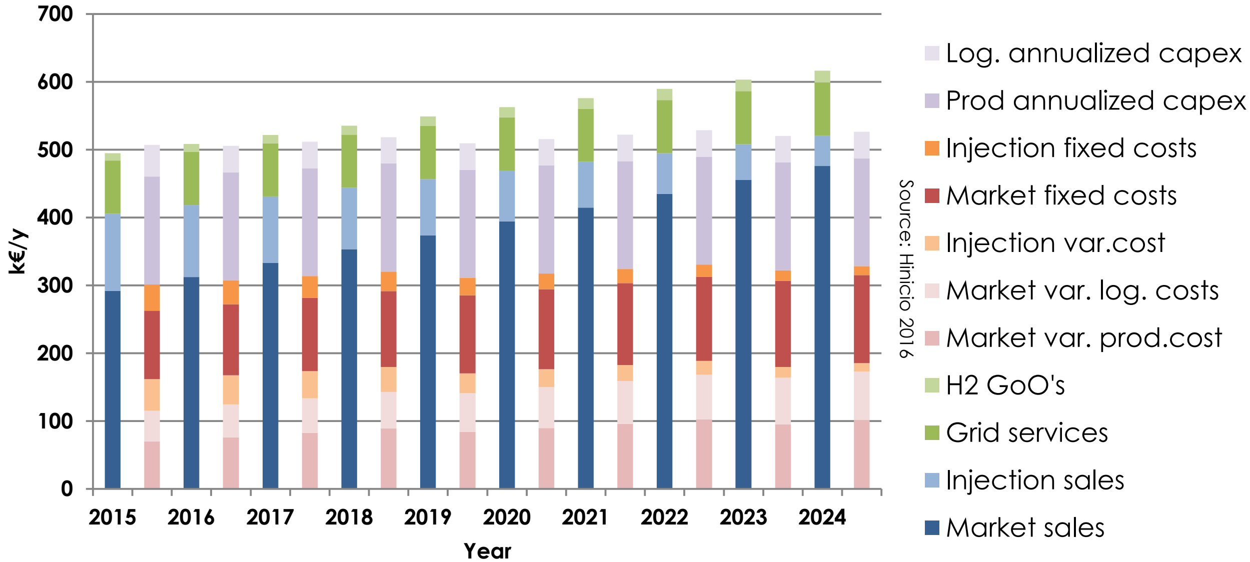
Payback = 10 years

Injection into the Gas Grid complement revenue streams during "valley of death" of FCEV market. Its contribution to margin decreases as hydrogen mobility market takes off.

Figure: Hinicio, H2BCase Model

Injection provides risk coverage against lower than expected hydrogen sales

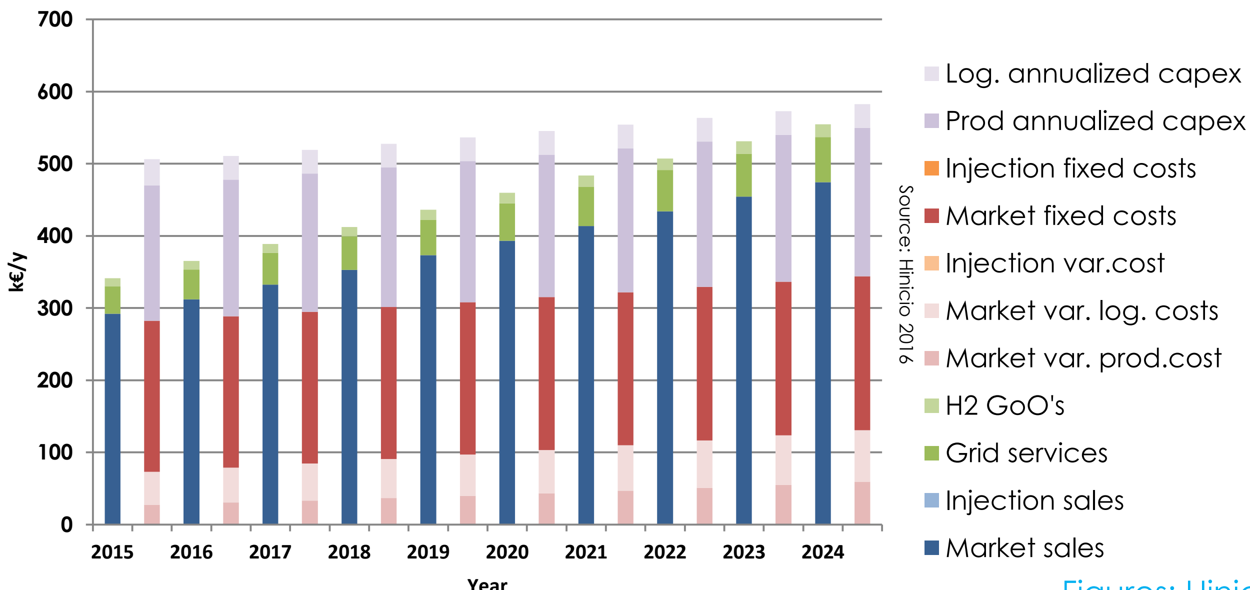
S2: low H2 Mob Market Take-Off With injection



IRR = -2% (10y)

Payback = 11 years

S9: low H2 Mob Market Take-Off Without injection



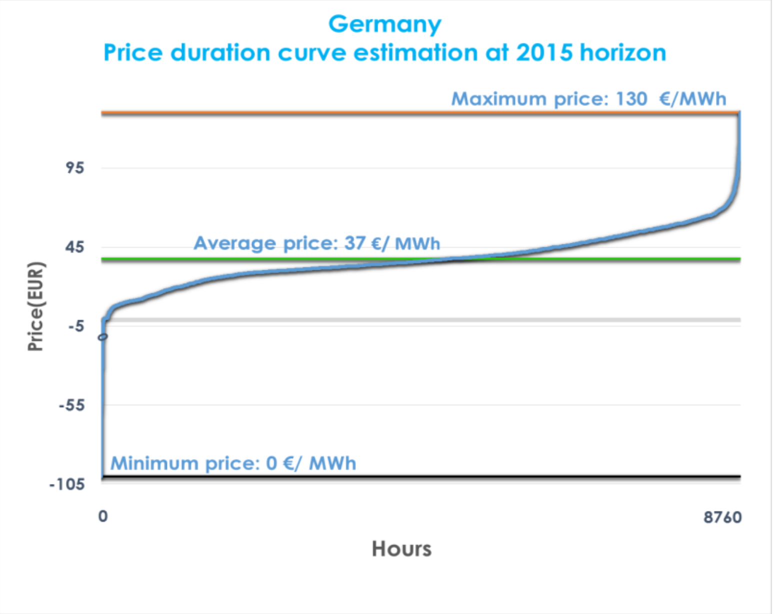
IRR = -12%

Payback = 19 years

Figures: Hinicio, H2BCase Model

Scenario 3 - Germany 2015 - Hypotheses

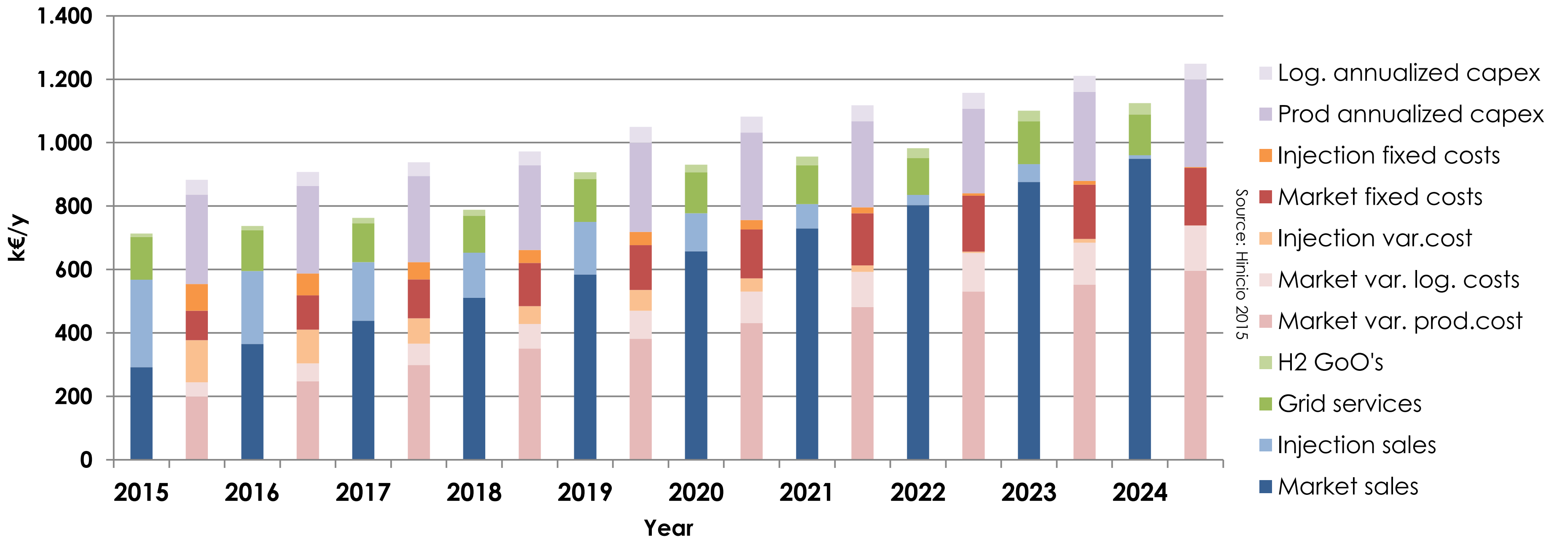
Parameter					
	1 - Ref	**2**	**3**	**4**	**5**
Country	France		Germany		
Year of electrolyser commissioning	2015			2020	2030
Initial/Final H2 Mobility demand (kg/d)	100/325	100/ 163			
Electricity price duration curve or cost	France 2014		Germ. 2014	Germ. 2020	Germ. 2030
Grid charge	France 2015		Germany 2015 rates		
CSPE (€/MWh)	Electr.-int. 0.5				
H2 injection price (€/MWh)	90 (FIT)				55.8
Electrolyser capex (M €/ MW)	1,9				0.55
Electrolyser efficiency/stack lifetime	66%/4y				75%/ 10y



Figures and Table: Hinicio, based on data [EPEX SPOT 2013, Germany]

Scenario 3 – Germany 2015 - Results

German electricity market conditions : Revenues and Costs



IRR = -28% (10y)

Payback = N/A

Figure: Hinicio, H2BCase Model

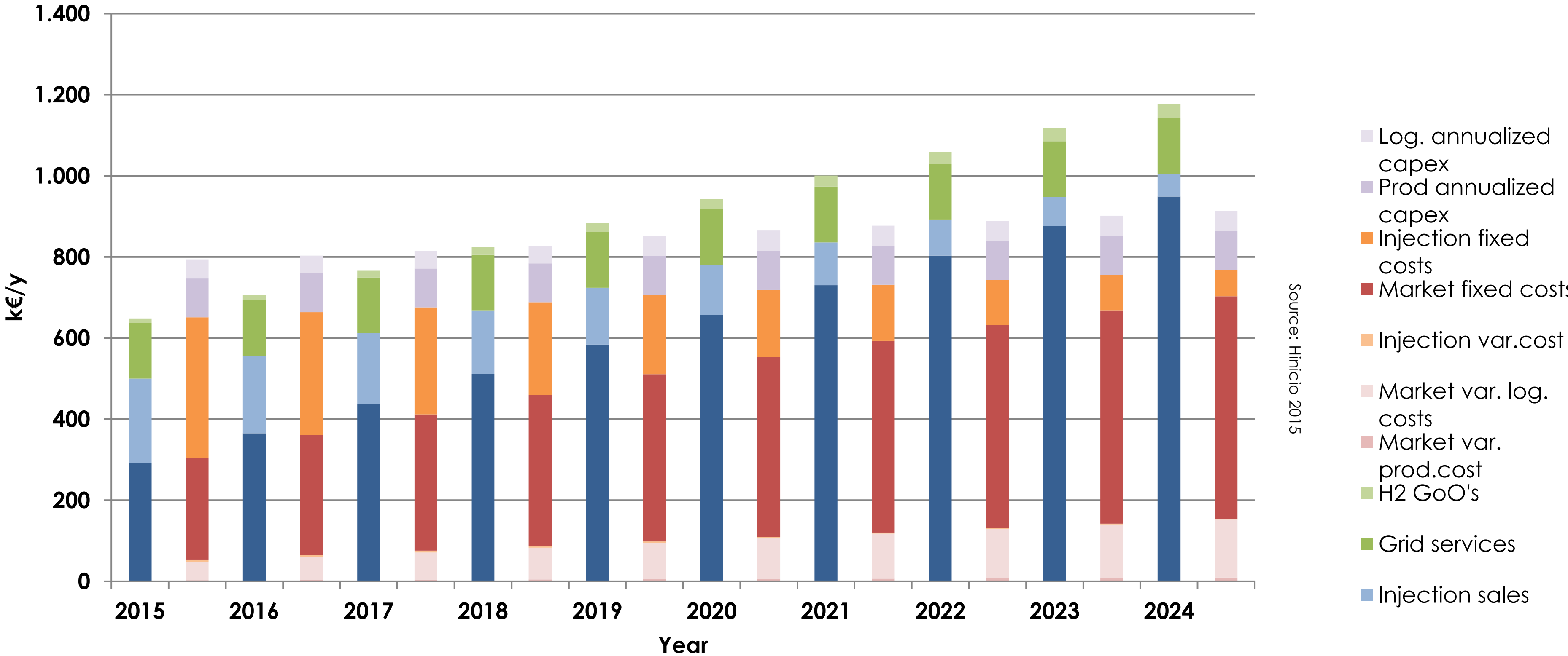
Scenario 11 – France 2030 - Hypotheses

Parameter	1 - Ref	11
Country	France	
Year of electrolyser commissioning	2015	2030
Initial/Final H2 Mobility demand (kg/d)	100/325	
Electricity price duration curve or cost	France 2014	100% of wind el. cost France
Grid charge	France 2015	
CSPE (€/MWh)	Electr.-int. 0.5	
H2 injection price (€/MWh)	90 (FIT)	55.8
Electrolyser capex (M €/ MW)	1,9	0.55
Electrolyser efficiency/stack lifetime	66%/4y	75%/ 10y

Table: Hinicio

- Upfront purchase of the production of renewable generation capacity at projected full cost
- Electrolyser technology of 2030

Scenario 11 – France 2030 - Results



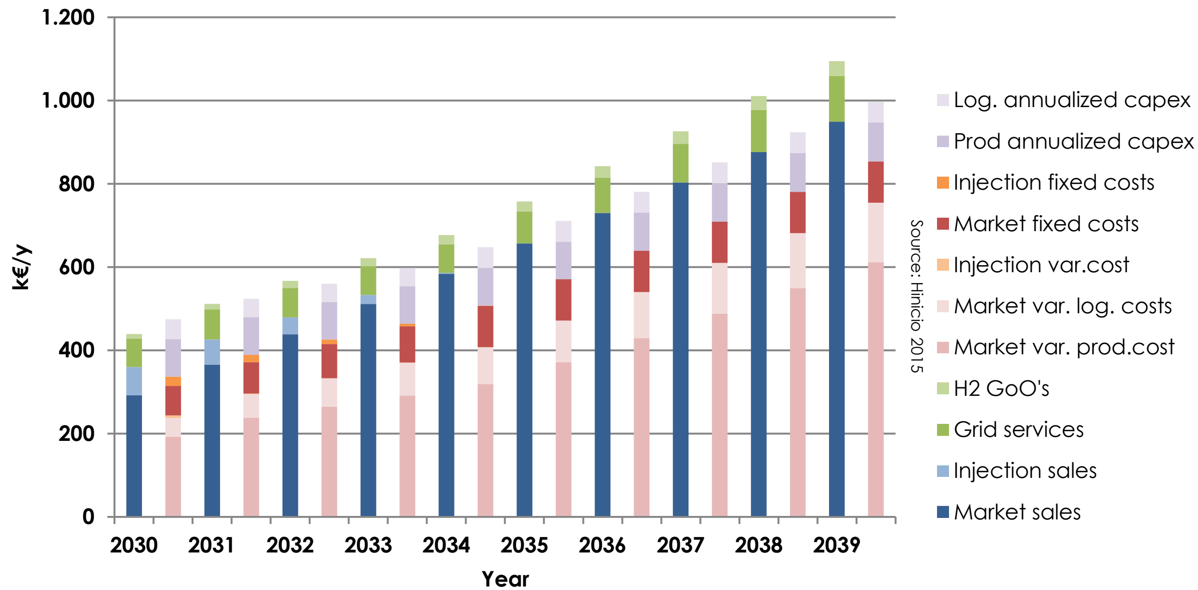
IRR = 0% (10y)

Payback = 10 years

Figure: Hinicio, H2BCase Model

Based on the marginal cost based priced duration curve considered for 2030, the Power-to-Gas application would break even

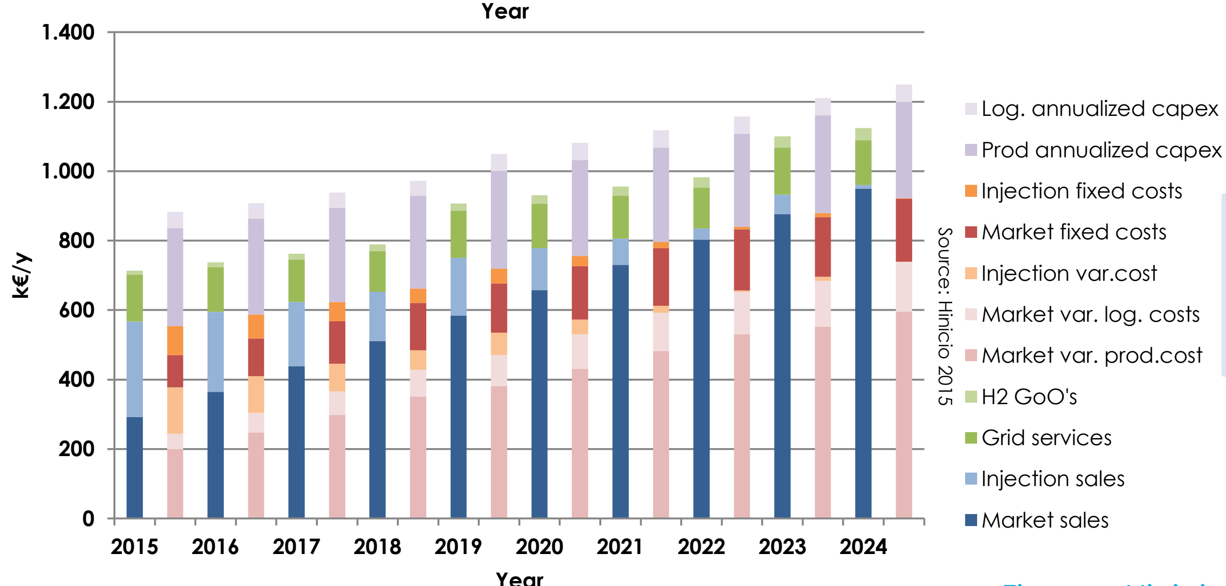
S5: German Electricity Prices & Electrolyser Performance 2030



IRR = 0% (10y)

Payback = 10 years

S3: German Electricity prices 2014



IRR = -28%

Payback = N/A

Figures: Hinicio, H2BCase Model

Results of Scenario analysis

Scenario Nbr	1 (Ref)	2	3	4	5	6	7	8	9	10	11	12
Country	France		Germany									
Year of electrolyser commissioning	2015			2020	2030						2030	
Initial/Final H2 Mobility demand (kg/d)	100/325 (50+50 / 140+185)	100/163 (50+50/(70+93)					No H2 mobility sales		100/163			
Electricity price duration curve or cost	France 2014		Germ. 2014	Germ. 2020	Germ. 2030					26% of wind el. Cost France	100% of wind el. cost France	17% of wind el. Cost Germ.
Grid charge	France 2015		Germany 2015 rates									
CSPE (€/MWh)	Electr.-int. 0.5					19.5						
H2 injection price (€/MWh)	90 (FIT)				55,8			No inject.	No inject		55,8	
Electrolyser capex (M €/ MW)	1,9				0,55						0,55	
Electrolyser efficiency/stack lifetime	66%/4y				75%/10y						75%/10 y	
IRR after 10 years	0%	-2%	-28%		0%	-5%	N/A	-3%	-12%	0%	0%	0%
1st Year EBIT > 0	Year 4	Year 2	N/A		Year 3	Year 5	N/A	year 5	year 13	year 4	Year 5	year 3
Payback Period	10 years	11 years	N/A		10 years	12 years	N/A	11 years	19 years	9 years	10 years	10 years
Alternative 1 to achieve IRR = 0%		€8.4/Kg H2 Mob	€9.5/Kg H2 Mob			€9.0/Kg H2 Mob	Primary Reserve @ 45.5/MW/h	€8.5/Kg H2 Mob	€11/kg H2 Mob			
Alternative 2 to achieve IRR = 0%		FIT €109 MWh	FIT @ €190 MWh			FIT @ €121 MWh	FIT @ €133.5 MWh	Primary Reserve @ €27/MW/h	Primary Reserve @ €70/MW/h			

Table: Hinicio, H2BCase Model

Conclusions

- Assuming a certain number of favourable regulatory conditions, achieving economic balance seems feasible for short-term deployments in France; therefore, with some further support, for instance in the form of investment subsidies, such deployments could attract private investment.
- The French fee regime applied as assumed above, would be particularly favourable for Power-to-gas. In contrast, the grid fee regime currently applied in Germany handicaps Power-to-gas.
- Injection into the natural gas grid can generate two complementary revenue streams – from sales to the gas grid, and from services to the power grid performed when hydrogen—is produced– which reduces exposure to uncertainty of revenues from the hydrogen market.
- An economic balance could potentially be achieved in both market environments and without public financial support by 2030 thanks to technological improvements.

Recommendations

- Create a feed-in tariff for the injection of green or low-carbon hydrogen into the natural gas grid of a level comparable to that of biomethane in France;
- In France, grant the hyperélectro-intensif status to hydrogen power-to-gas production;
- In Germany, provide similar tax, EEG appropriation, and grid fee benefits to hydrogen production by electrolysis as the hyperélectro-intensif status;
- In Europe, further develop sustainability criteria, certification procedures and accountability of green or low-carbon hydrogen towards EU targets, especially with regard to the EU Renewable Energies Directive (RED) and the EU Fuel Quality Directive (FQD);
- Exempt electricity used to produce green or low-carbon hydrogen injected into the natural gas grid from grid fees and energy taxes;
- Financially support the implementation of supplying hydrogen to fuel cell electric vehicles.

Acknowledgment

Hinicio and LBST would like to thank *Fondation Tuck* for supporting this study under its *The Future of Energy* programme