Car as Power Plant (CaPP):

Integrated mobility and energy systems

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Future Energy Systems, TU Delft

Congress on “Hydrogen: hype or real business opportunities”
21-02-2019, Luxumburg

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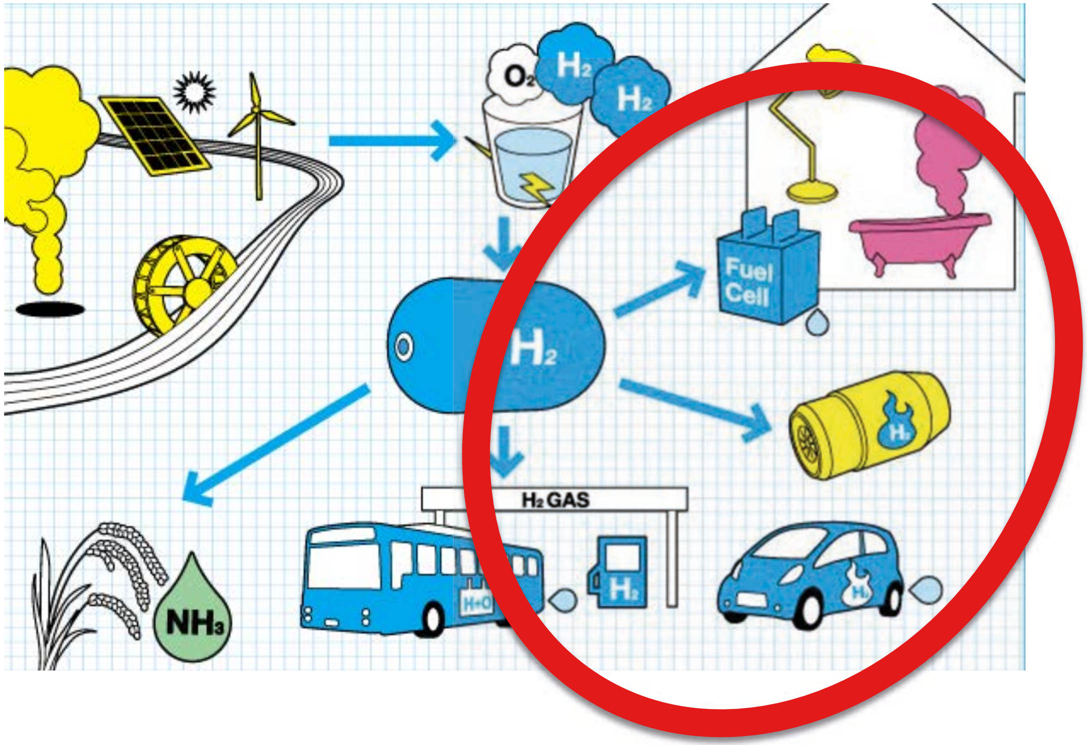
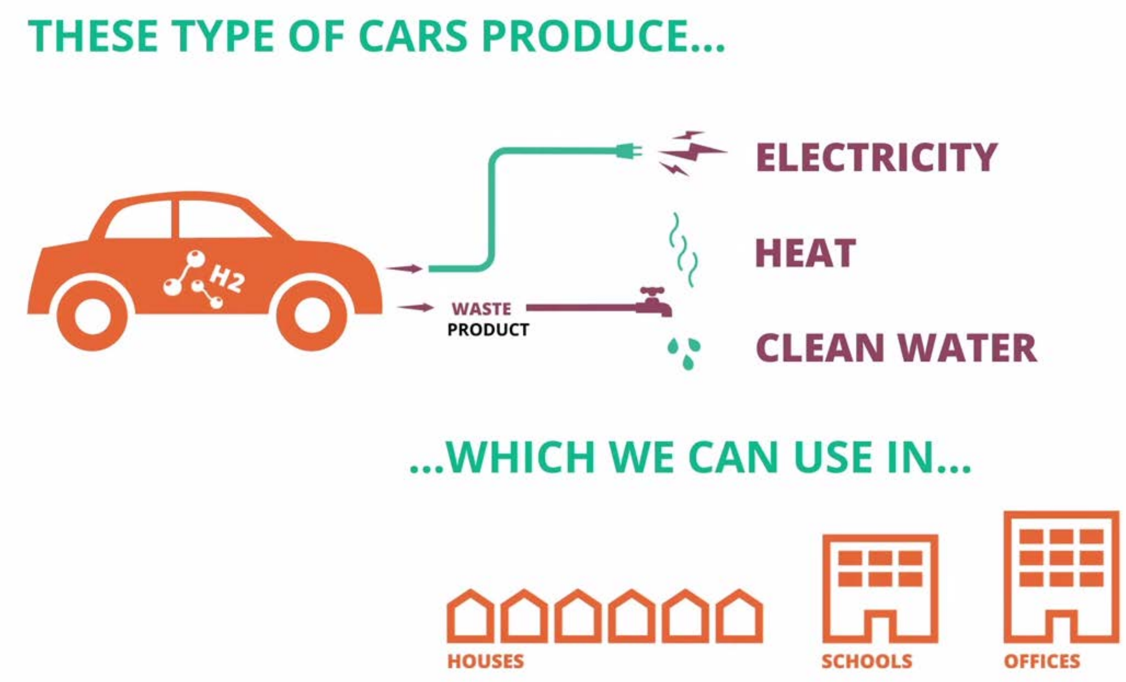
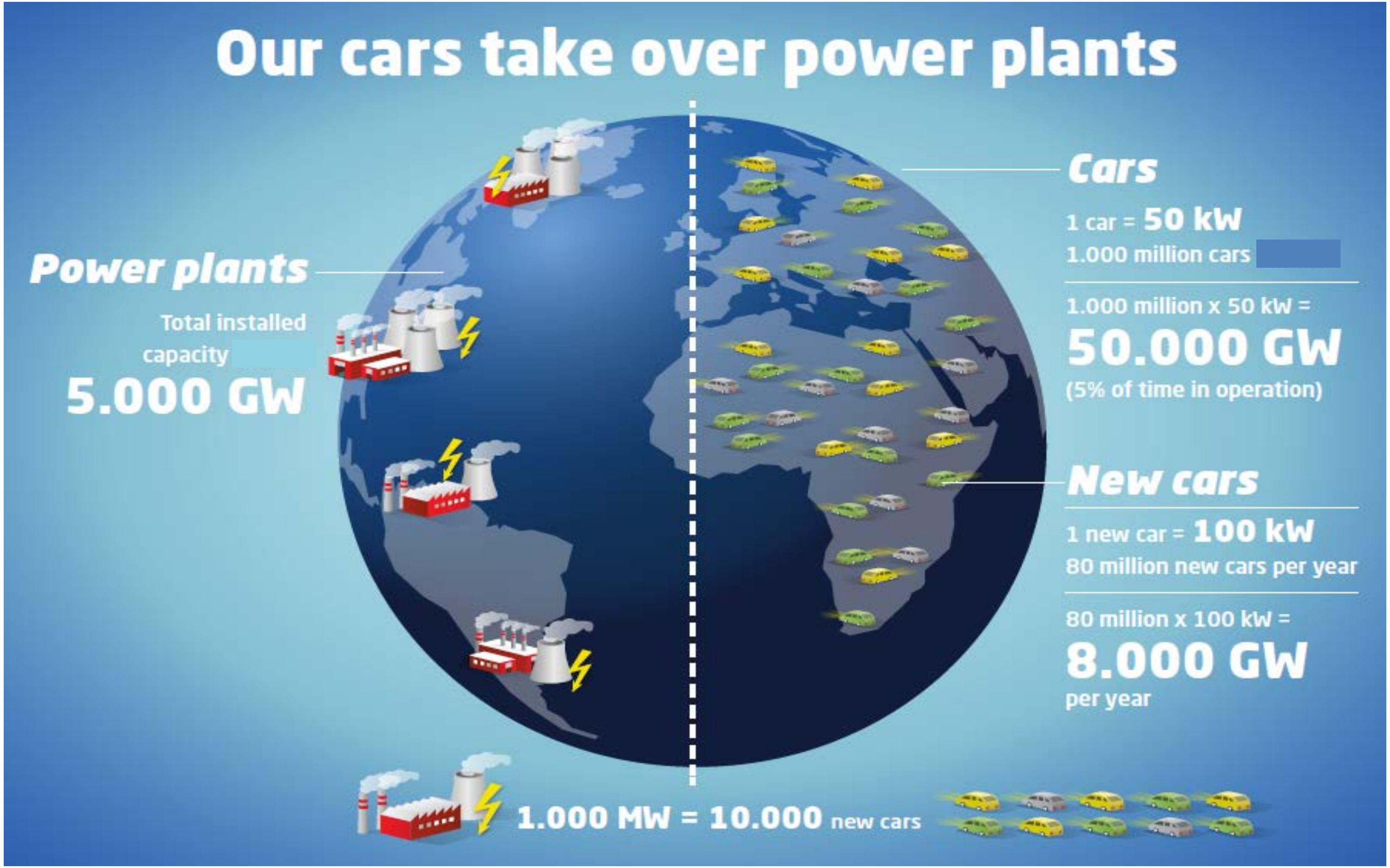
Hydrogen Market



Car as Power Plant Concept




Our cars take over power plants
Power plants
Total installed capacity
5.000 GW
Cars
1 car = 50 kW
1.000 million cars
1.000 million x 50 kW =
50.000 GW
(5% of time in operation)
New cars
1 new car = 100 kW
80 million new cars per year
80 million x 100 kW =
8.000 GW
per year
1.000 MW = 10.000 new cars

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Integrated Energy and Mobility Systems

System design- case studies:
1. Hospital
2. Smart City
3. Office

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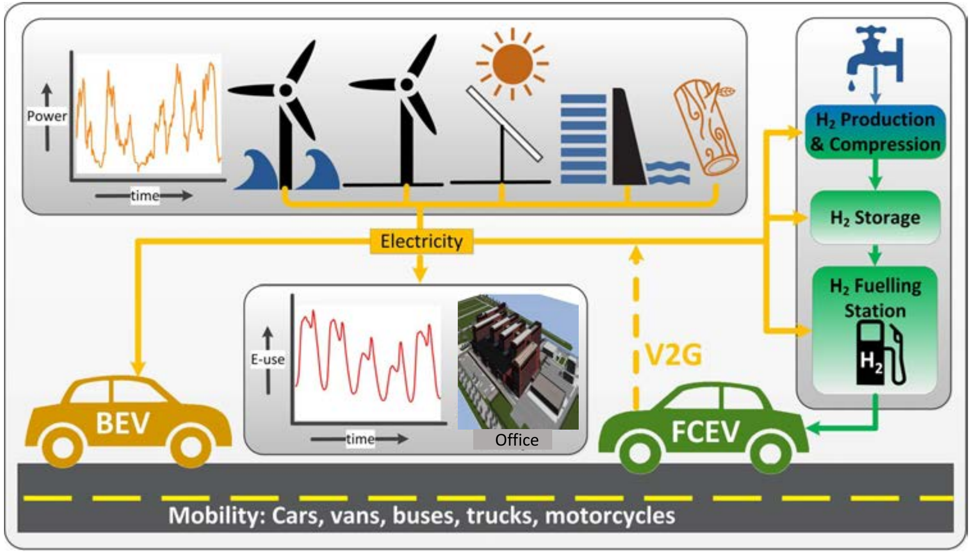
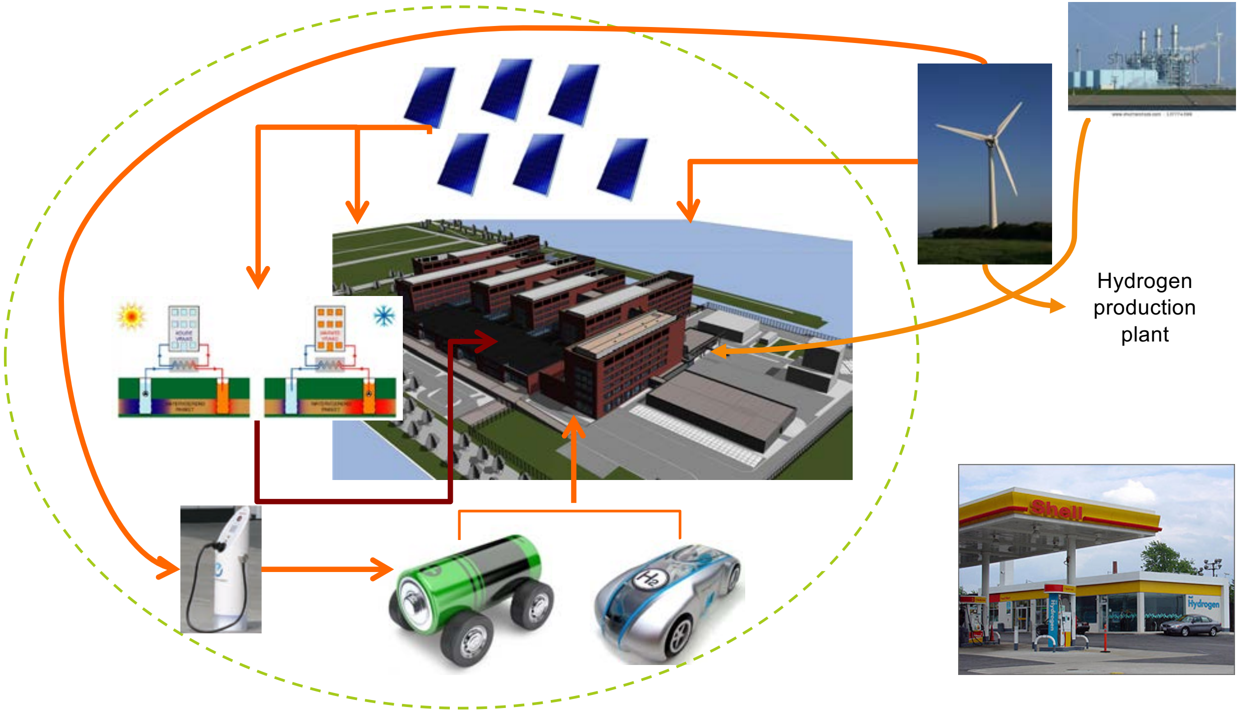
CaPP Concept @ Shell Technology Center Amsterdam

Concept design of 100% renewable energy system with two energy carriers (hydrogen and electricity) at the controlled environment of Shell Technology Centre Amsterdam



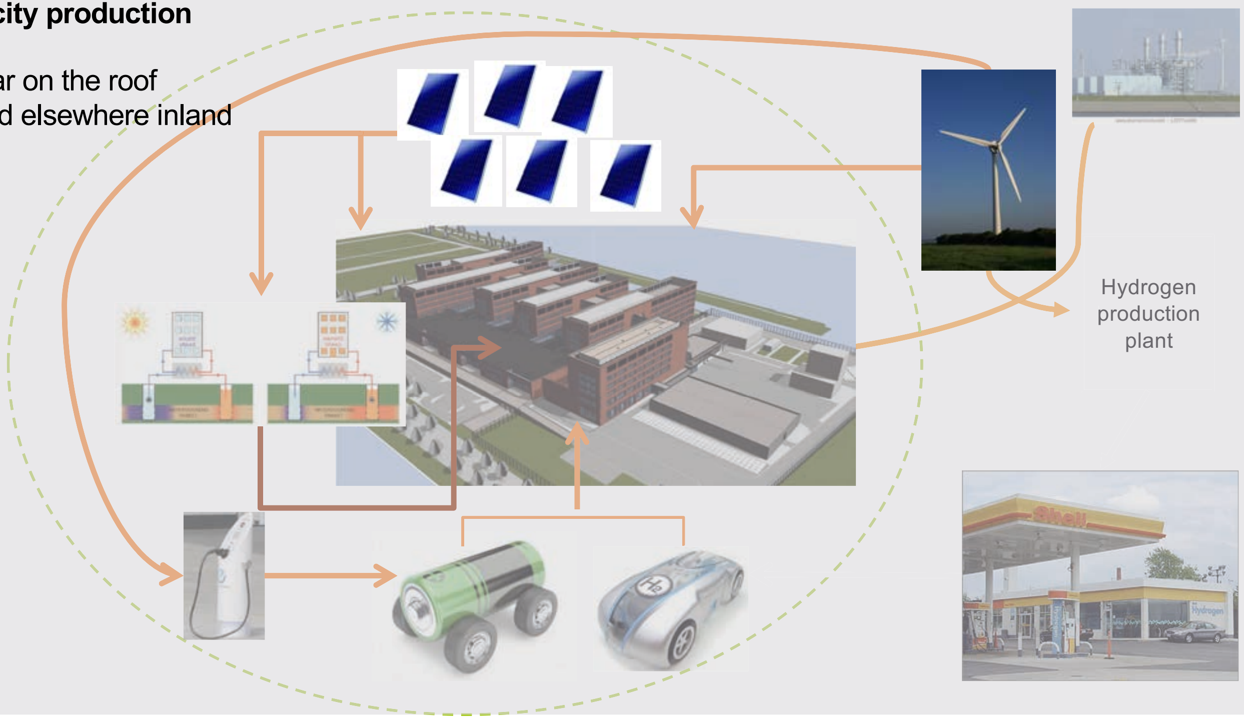
Scenario I: All electric



Scenario I: All electric

Electricity production

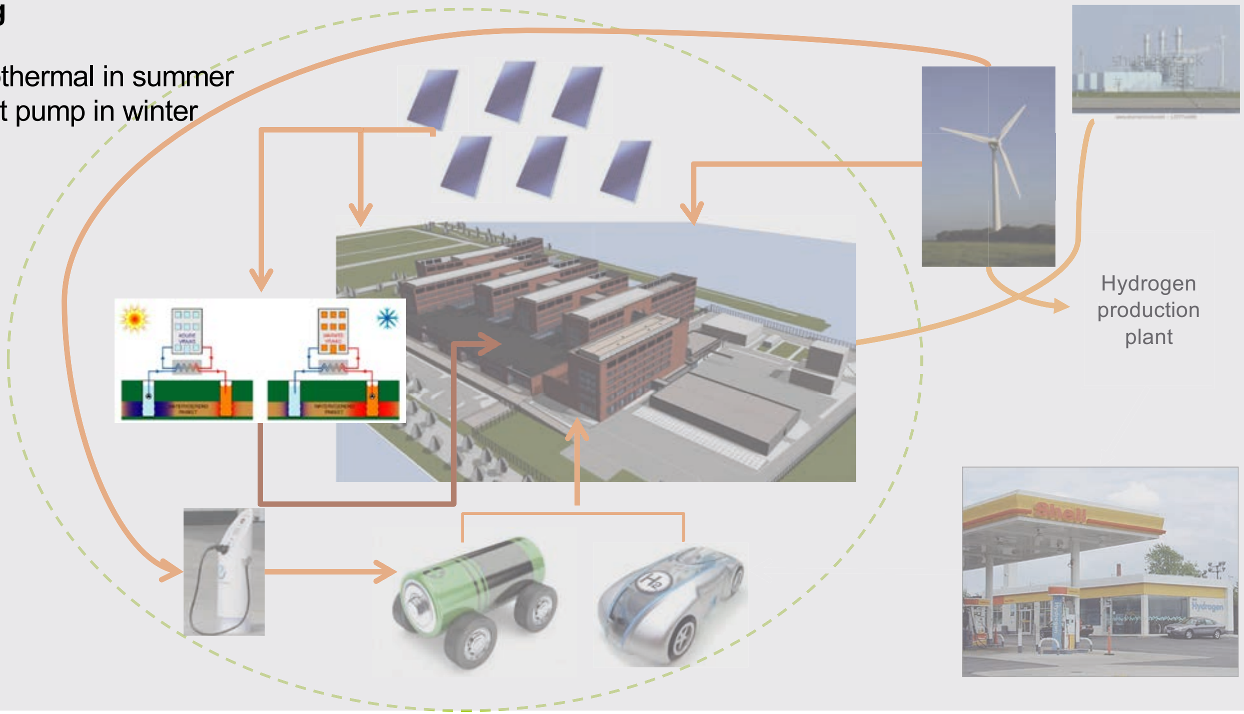
- Solar on the roof
- Wind elsewhere inland



Scenario I: All electric

Heating

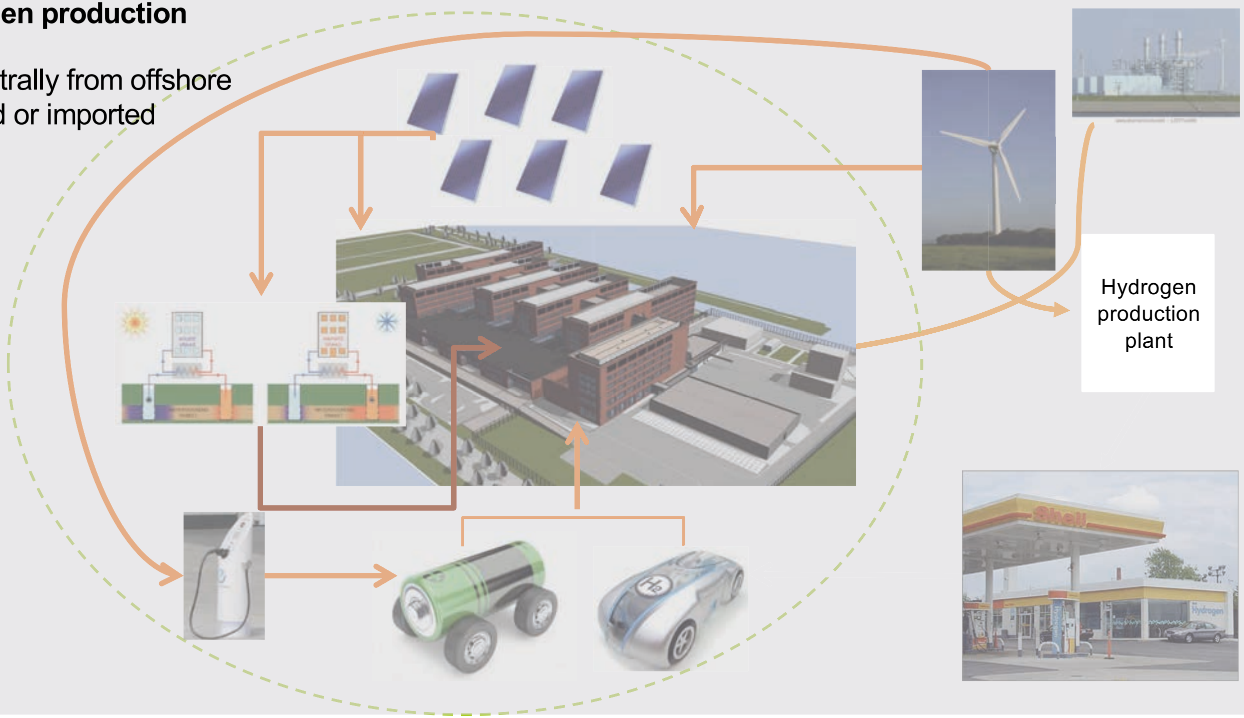
- Geothermal in summer
- Heat pump in winter



Scenario I: All electric

Hydrogen production

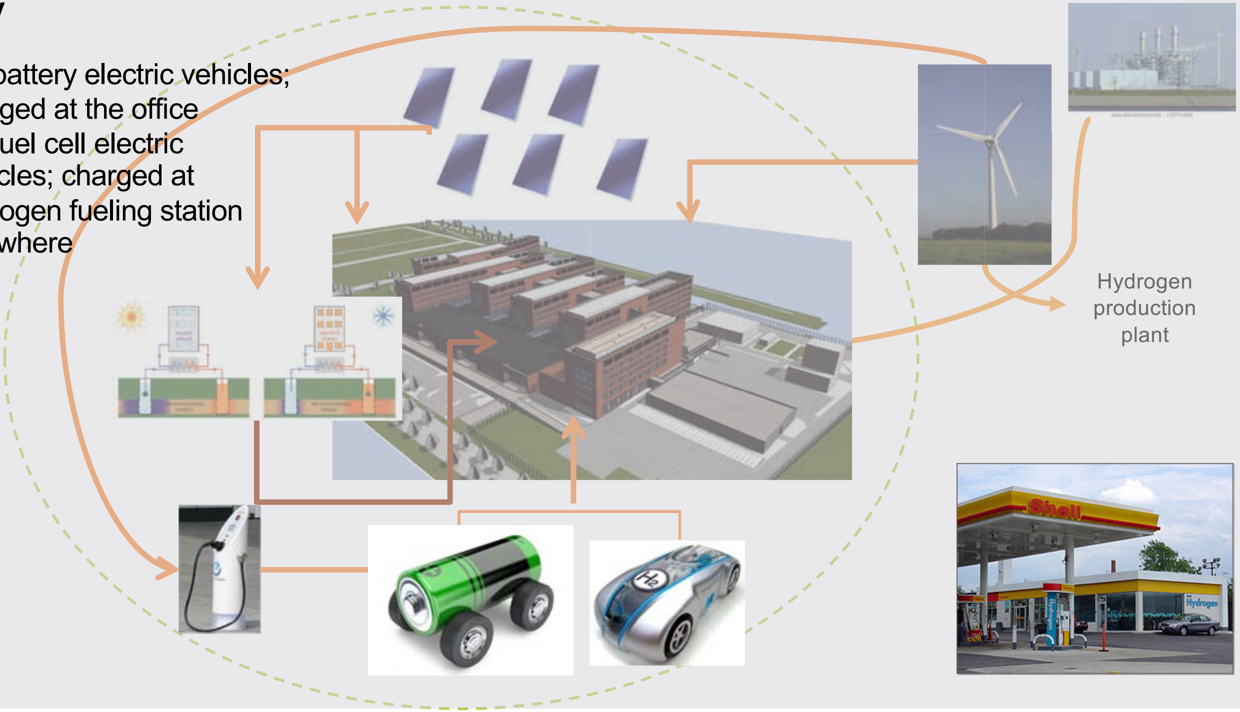
- Centrally from offshore wind or imported



Scenario I: All electric

Mobility

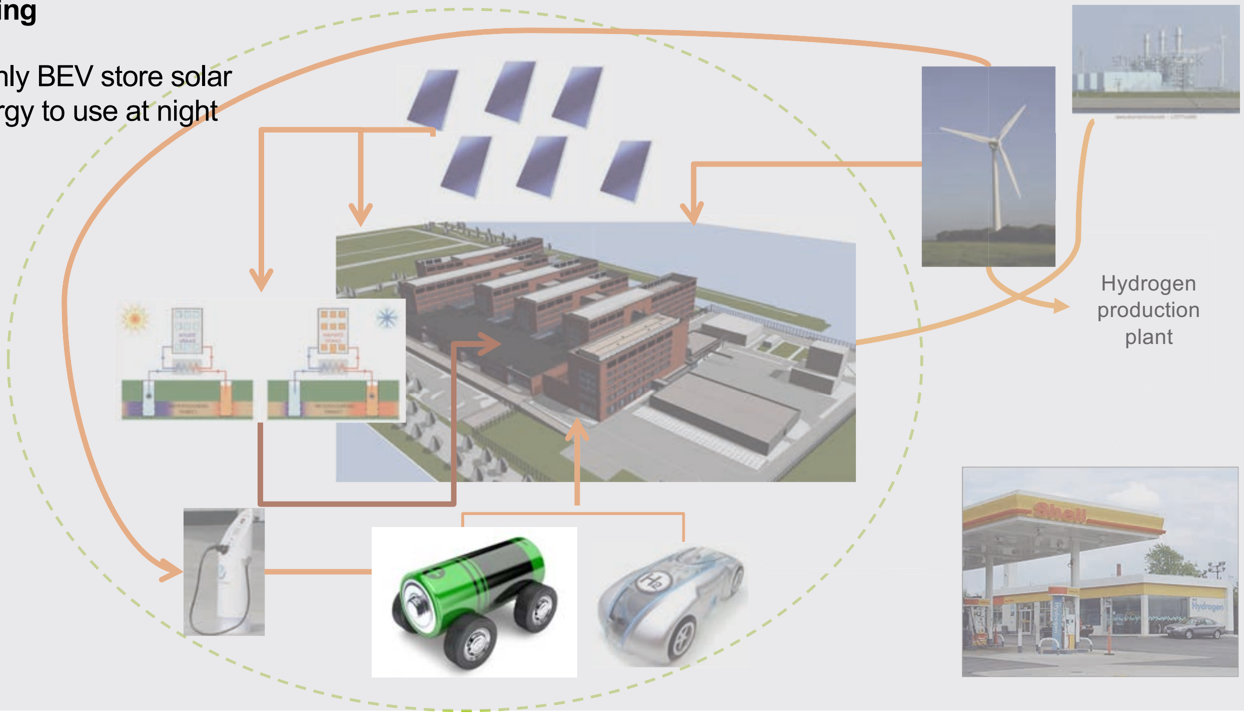
- 2/3 battery electric vehicles; charged at the office
- 1/3 fuel cell electric vehicles; charged at hydrogen fueling station elsewhere



Scenario I: All electric

Balancing

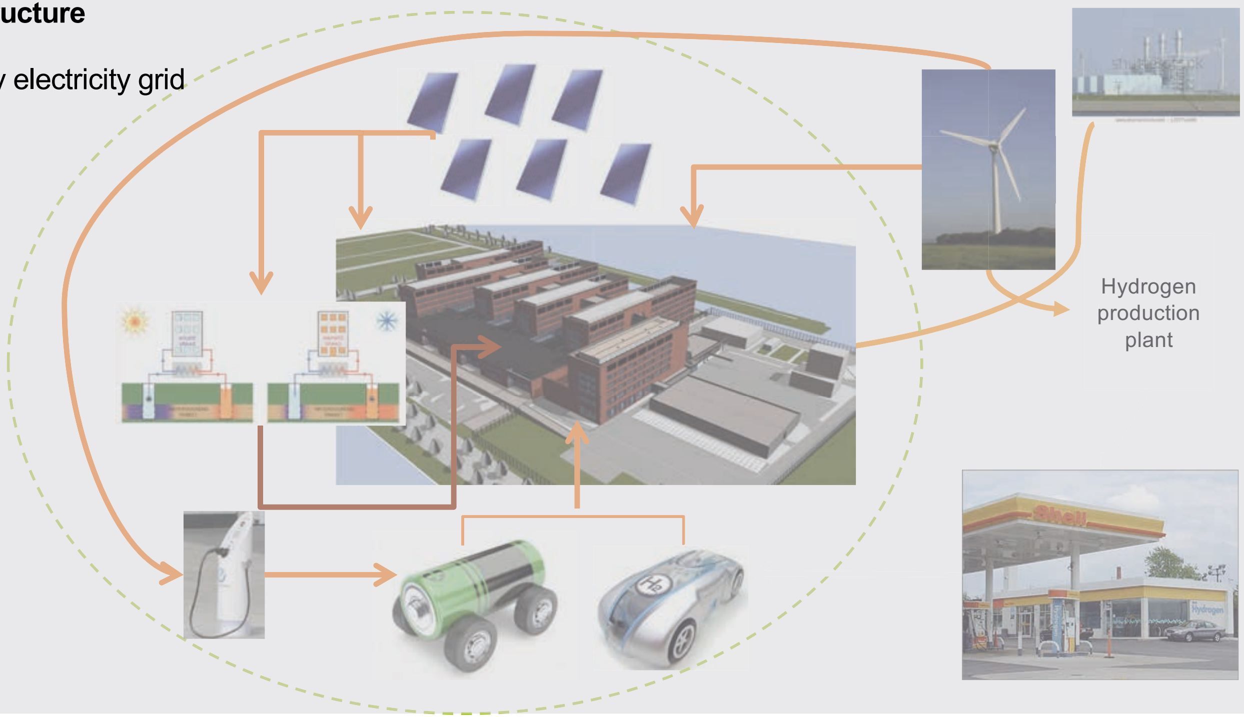
- Mainly BEV store solar energy to use at night



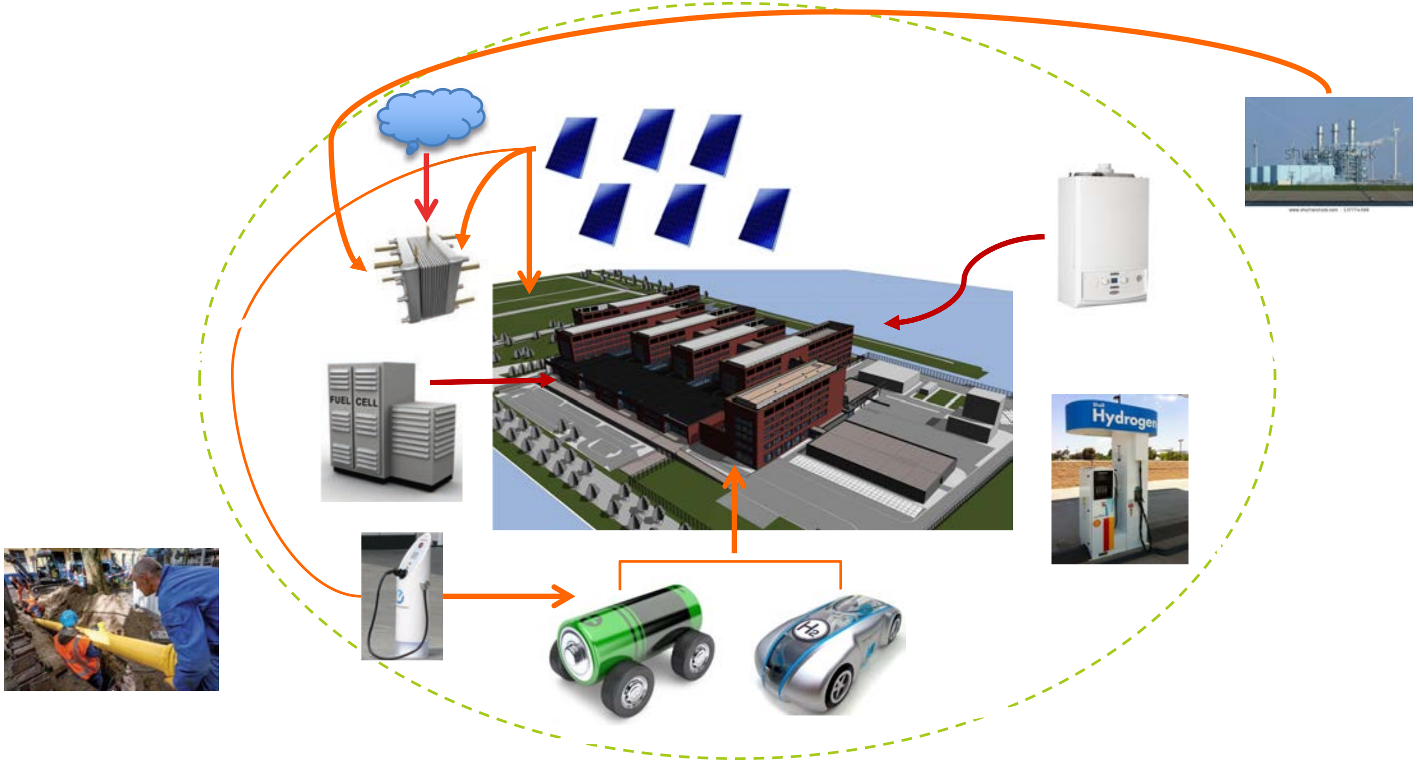
Scenario I: All electric

Infrastructure

- Only electricity grid



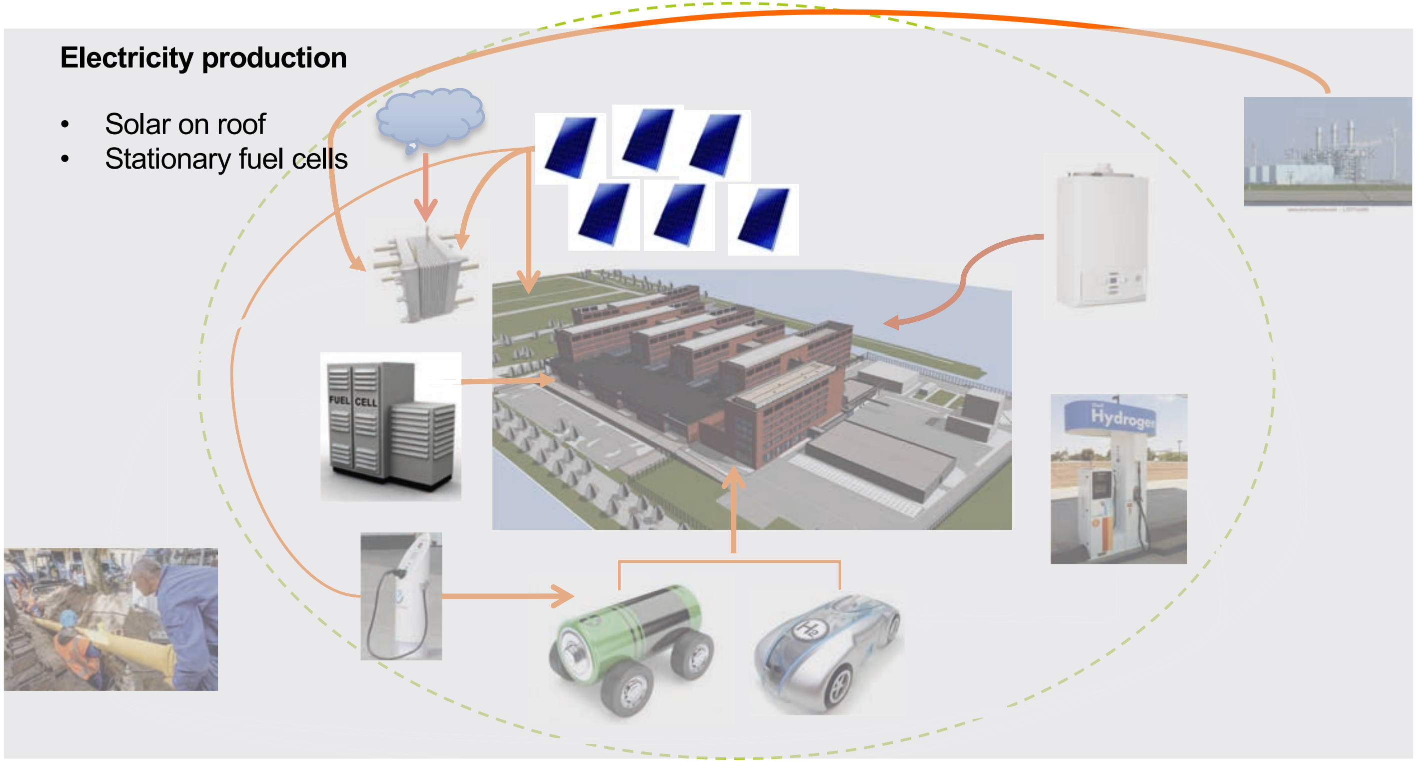
Scenario II: Hydrogen-electric



Scenario II: Hydrogen-electric

Electricity production

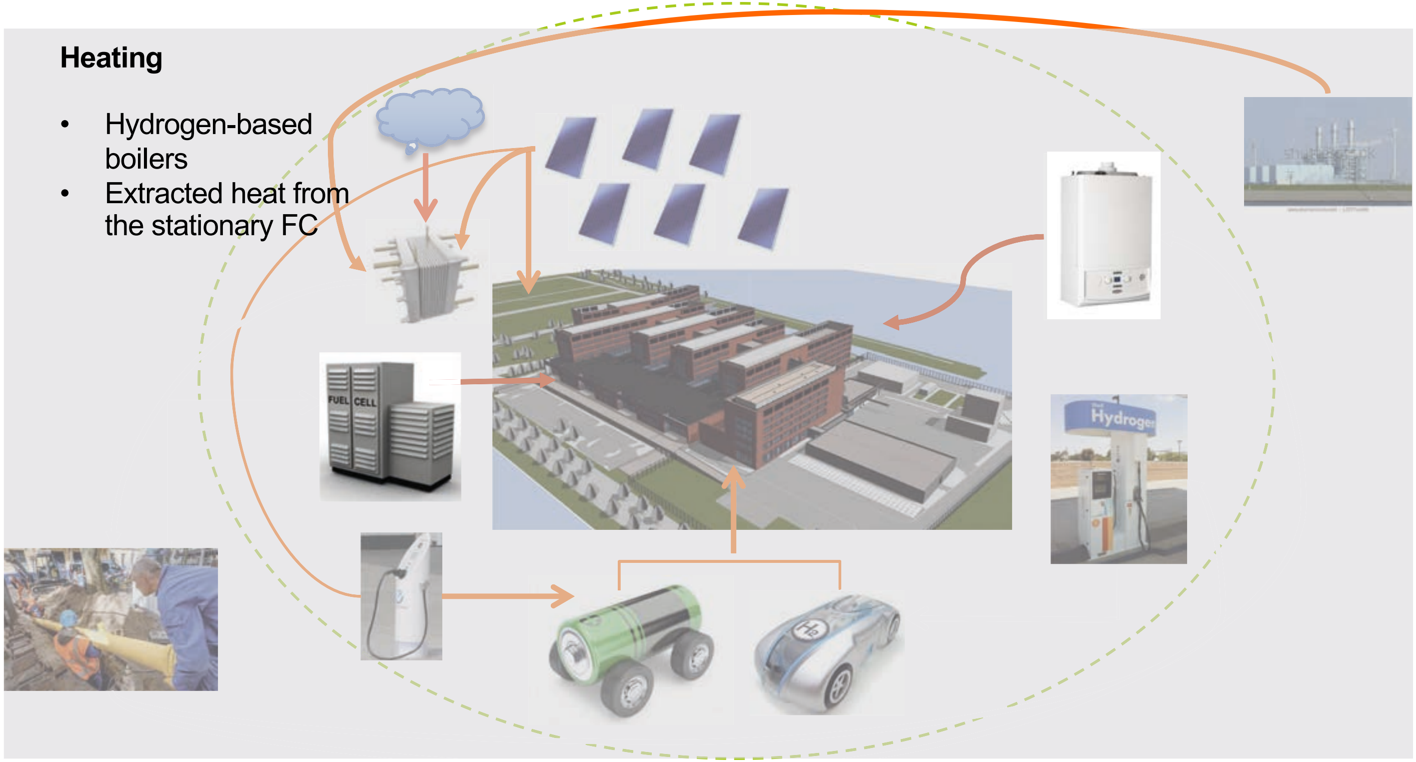
- Solar on roof
- Stationary fuel cells



Scenario II: Hydrogen-electric

Heating

- Hydrogen-based boilers
- Extracted heat from the stationary FC



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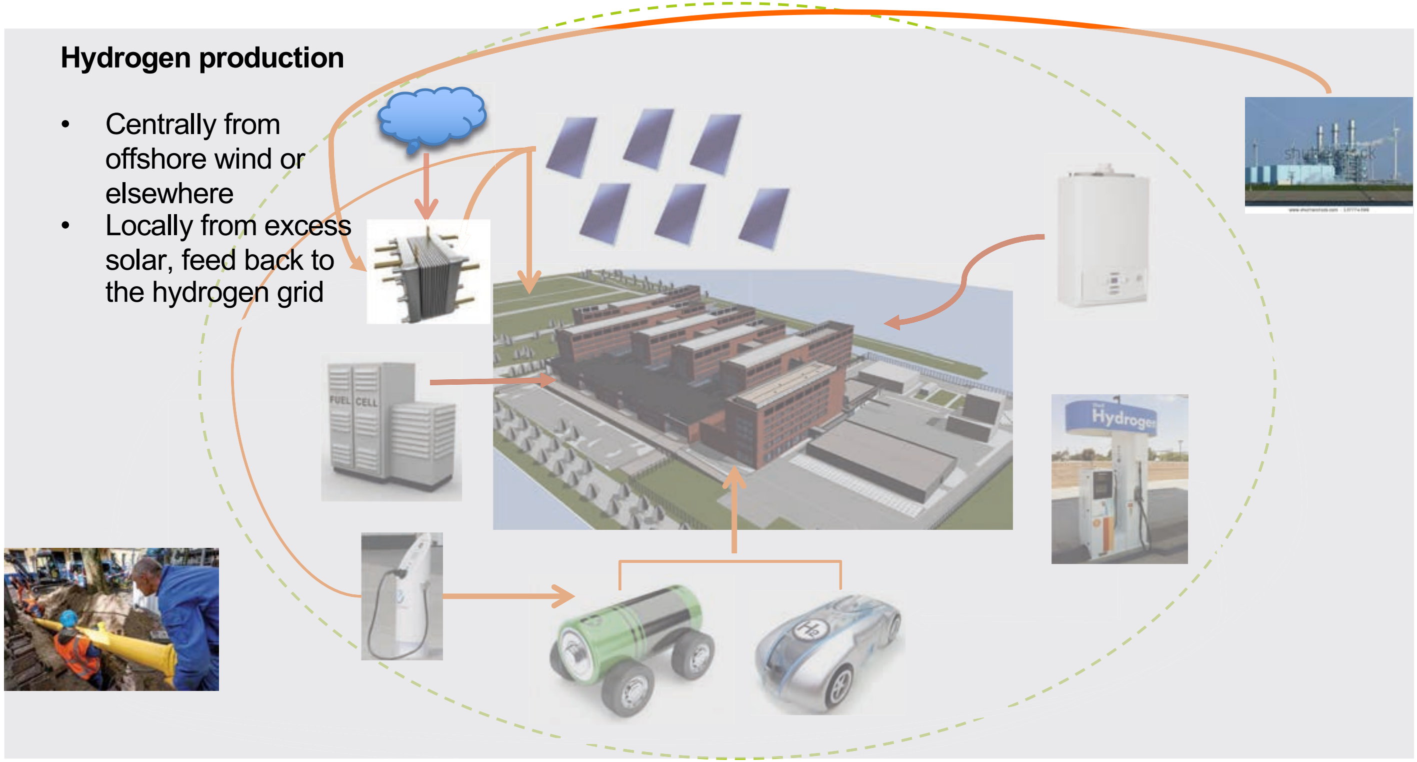
Scenario II: Hydrogen-electric

Hydrogen production

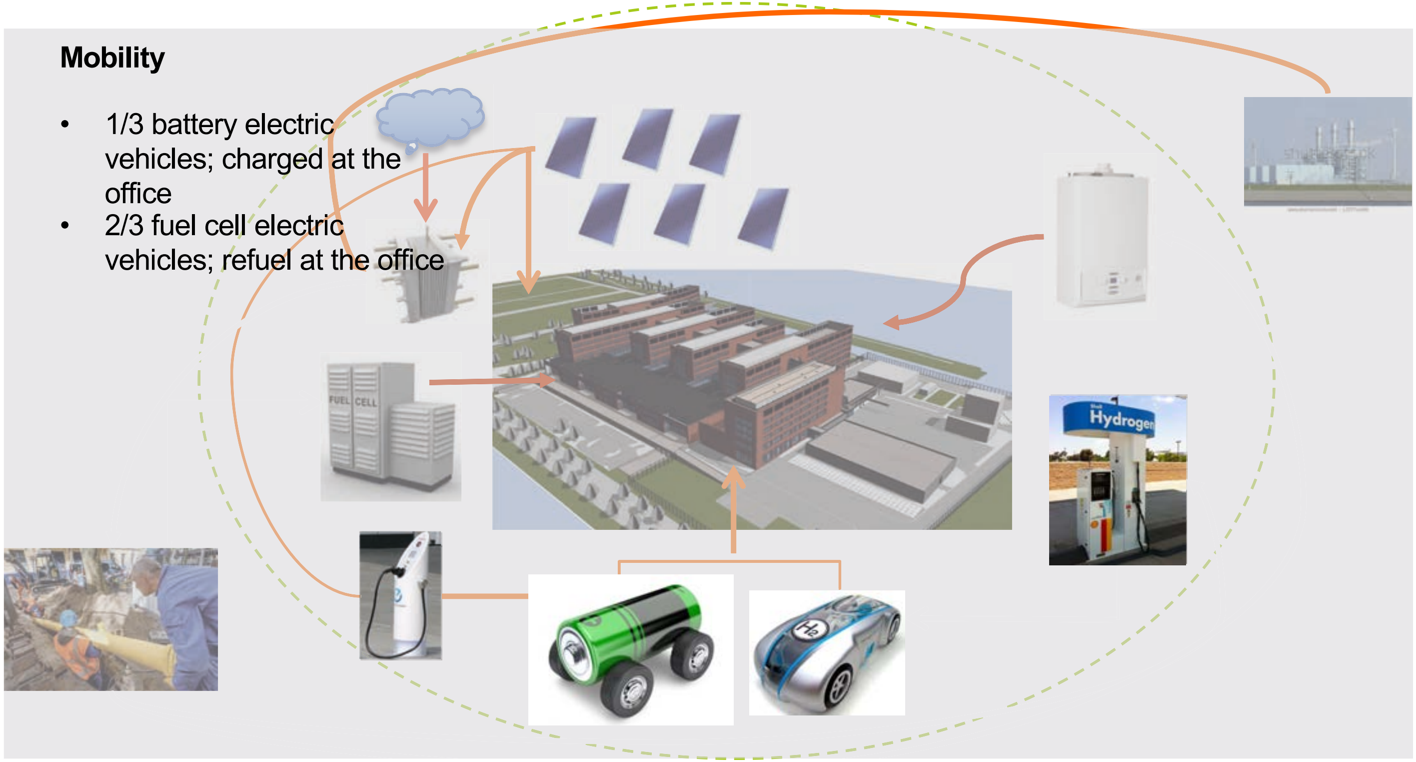
- Centrally from offshore wind or elsewhere
- Locally from excess solar, feed back to the hydrogen grid



Scenario II: Hydrogen-electric

Mobility

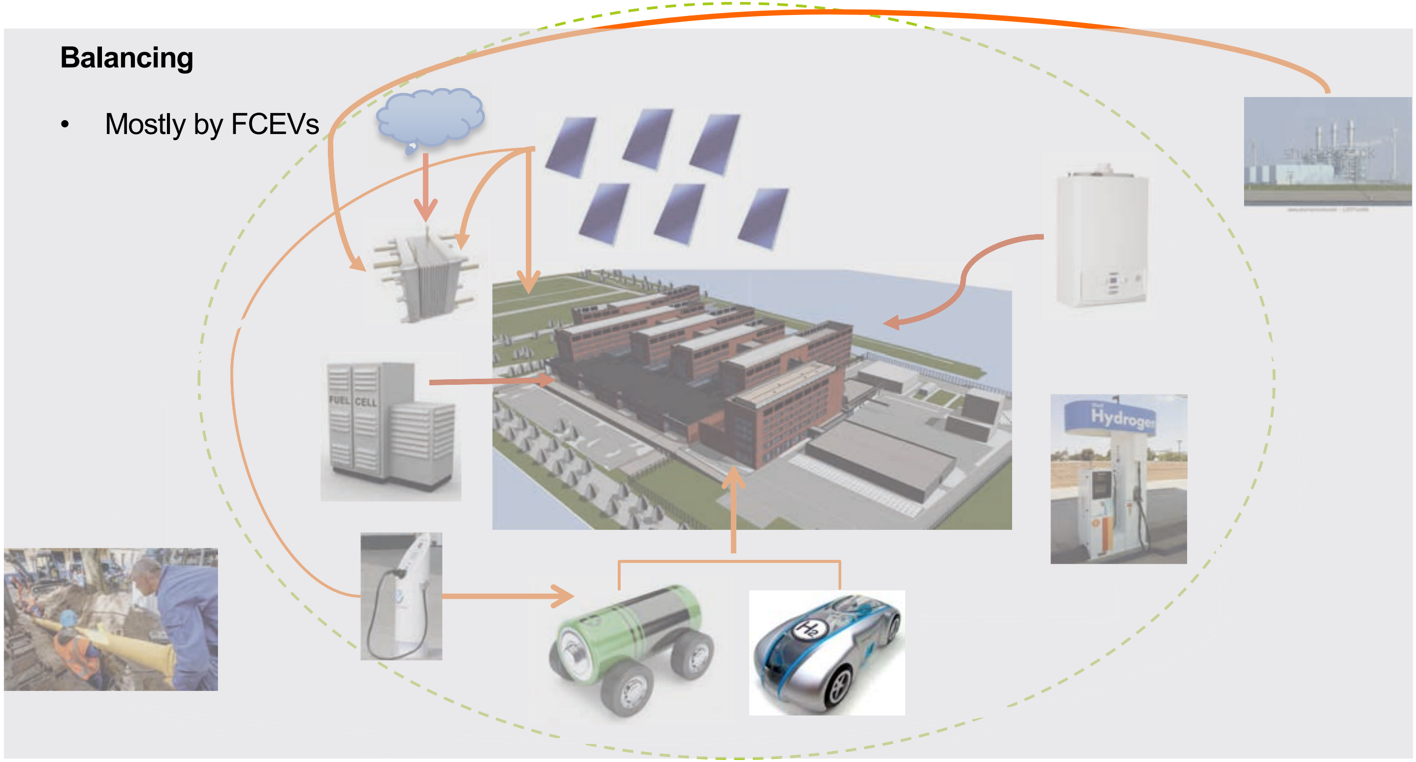
- 1/3 battery electric vehicles; charged at the office
- 2/3 fuel cell electric vehicles; refuel at the office



Scenario II: Hydrogen-electric

Balancing

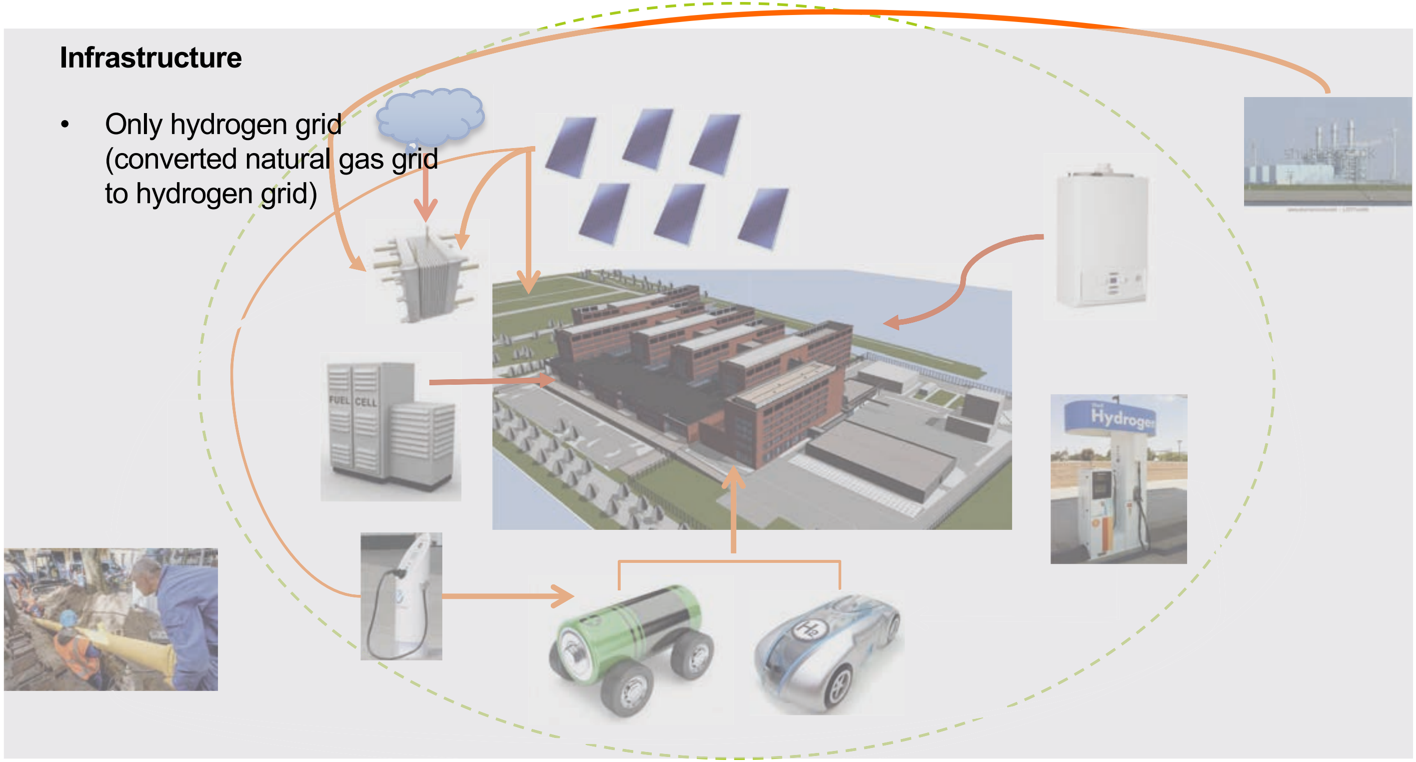
- Mostly by FCEVs



Scenario II: Hydrogen-electric

Infrastructure

- Only hydrogen grid (converted natural gas grid to hydrogen grid)



Scenario III: Combination of I & II

Combining the first and second scenarios using the current electricity and gas capacity

- What is a ‘good’ combination?
- Which components need to be added or removed?
- Do we need other energy resources?
- Which combination is the most cost efficient?

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System's Component Cost: Hydro-Electric vs. All-Electric Case

Hydro-electric		All-electric	
Wind	8.39 MW	Wind	3.786 MW
Storage (salt cavern)	2770k kg H_2	Stationary battery	200 MWh (local)
		Stationary battery	12 MWh (local) 3059 MWh (external)

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(System) Levelized Cost of Energy: Hydro-electric Case

Type of LCOE	Cost [euro/kWh]
$LCOE_{Wind}$	0.030
$LCOE_{Solar}$	0.071
$SLCOE_{H2}$ [kg]	2.550 [euro/kg]
$SLCOE_{H2SLCOE}$ (HHV)	0.065
$SLCOE_{SFC}$	0.12
$SLCOE_{FCEV}$	0.23
$SLCOE_{BEV}$	1.72
$SLCOE_{STCA}$ (weighted average)	0.138

Hydro-Electric 2025 with a 1650 kW SFC

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(System) Levelized Cost of Energy: All-electric Case

Type of LCOE	Cost [euro/kWh]
$LCOE_{Wind}$	0.030
$SLCOE_{Wind}$	0.048
$LCOE_{Solar}$	0.071
$SLCOE_{BESS}$	3.63
$SLCOE_{FCEV}$	0.45
$SLCOE_{BEV}$	0.34
$SLCOE_{STCA}$ (weighted average)	0.57

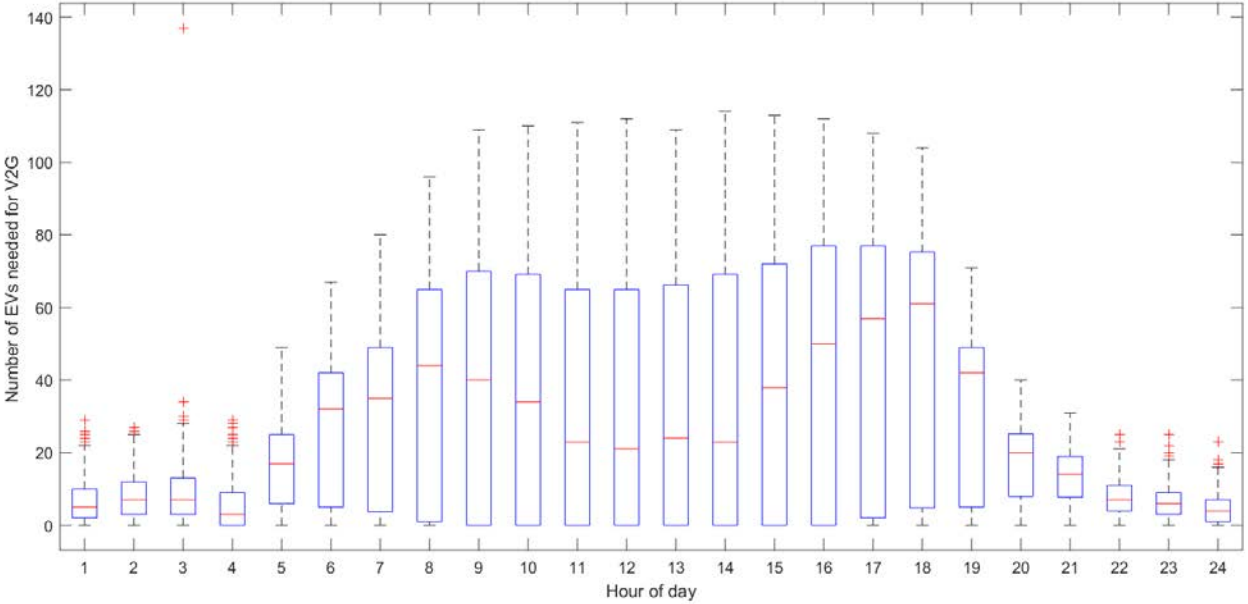
All-Electric 2025 with a 200 MWh local battery

Type of LCOE	Cost [euro/kWh]
$LCOE_{Wind}$	0.030
$SLCOE_{Wind}$	0.063
$LCOE_{Solar}$	0.071
$SLCOE_{BESS}$	0.78
$SLCOE_{FCEV}$	0.40
$SLCOE_{BEV}$	0.36
$SLCOE_{STCA}$ (weighted average)	0.166

All-Electric 2025 with a 12 MWh local battery and outside balancing

EV Requirement for V2G

Number of EVs required for the entire year in the hydrogen-electric case



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Experiments at the Green Village Lab

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V2G @ TU Delft

- Hyundai ix35 FCEV - 10 kW V2G output
- Fuel cell power: 100 kW
- Tank-to-AC-Grid efficiency: 51%
- Range: 500 km
- Developed in cooperation with Hyundai Company in South Korea

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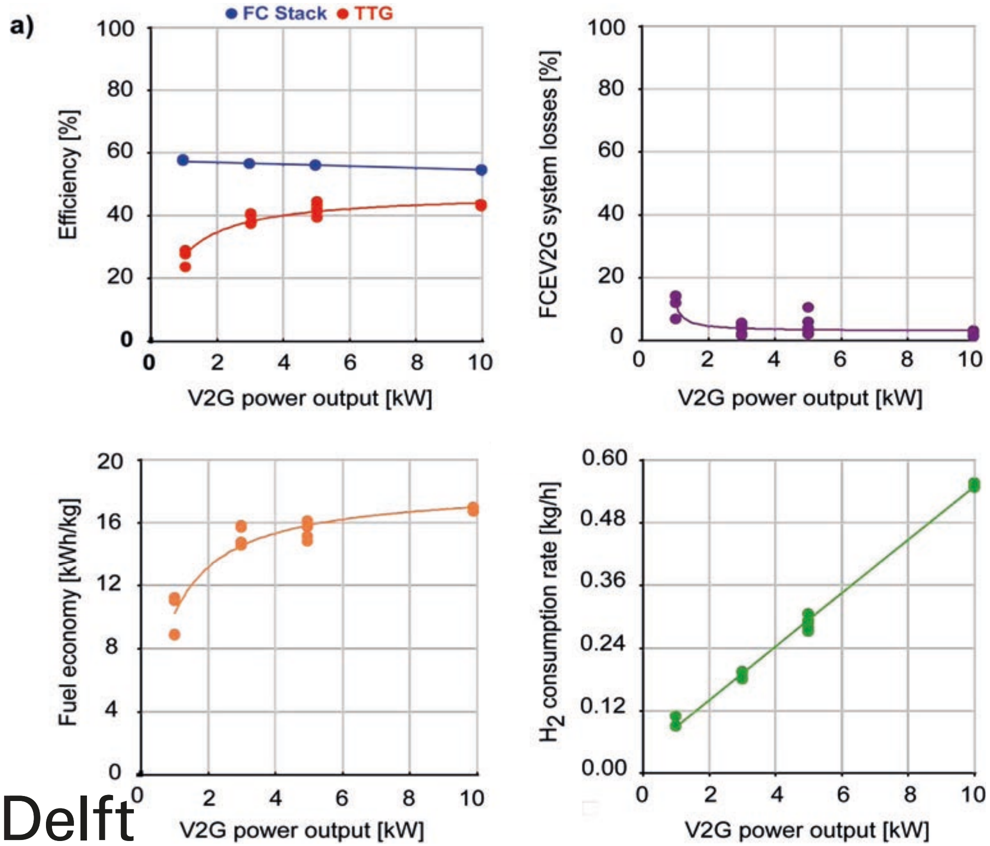
V2G @ TU Delft

- Smart, Hydroelectric – Combined power output 30 kW pack
- Battery pack: 5.3 kWh; FC power: 1 kW
- Range: 65 km/ 45km (hydrogen / electric)
- Max speed: 85 km/h
- Developed by Accenda, TU Delft Science Center

FCEV2G Performance



The Scooter as Power Plant

Item	Specification
Fuel Cell power	1.2 kW
Battery Energy	0.5 kWh
Hydrogen storage	Metal hydride
Max hydrogen stored	90 g
Driving range	Approx. 50 km
Max speed	40 km/h

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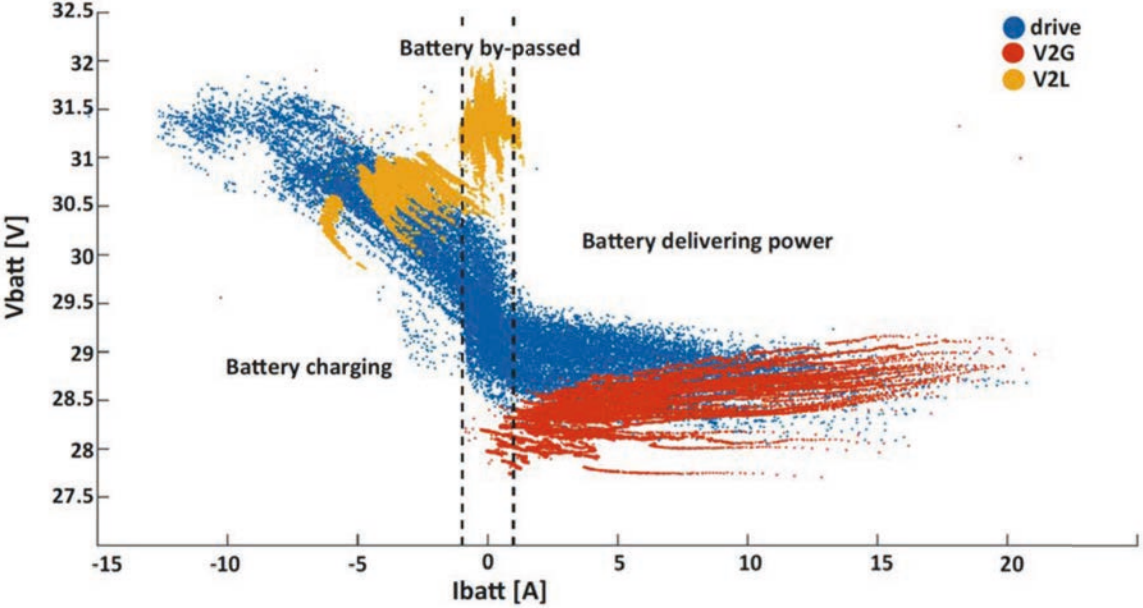
Experimental analysis of behavior in 3 different modes



Thank You!

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1. Oldenbroek V, Hamoen V, Alva S, Robledo C, Verhoef L, Wijk A Van. (2017) Fuel Cell Electric Vehicle-to-Grid: Experimental feasibility and operational performance. 6th Eur. PEFCF & Electrolyser Forum 2017, Luzern, Zwitserland. ISBN: 978-3-905592-22-1.
2. Oldenbroek V., Nordin, L., Wijk, A.J.M. van, (2017). Fuel cell electric vehicle to grid: emergency and balancing power for a 100% renewable hospital. Presentation and paper at 6th Eur. PEFCF & Electrolyser Forum 2017, Luzern, Zwitserland.
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