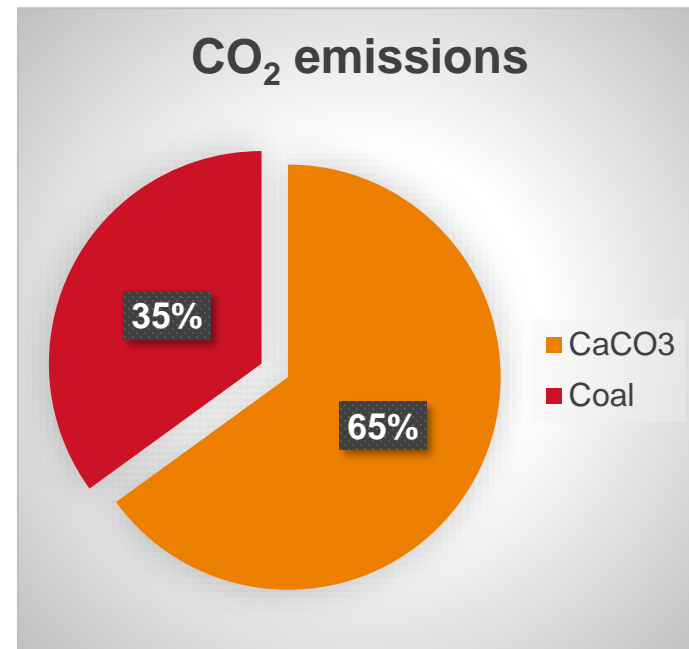
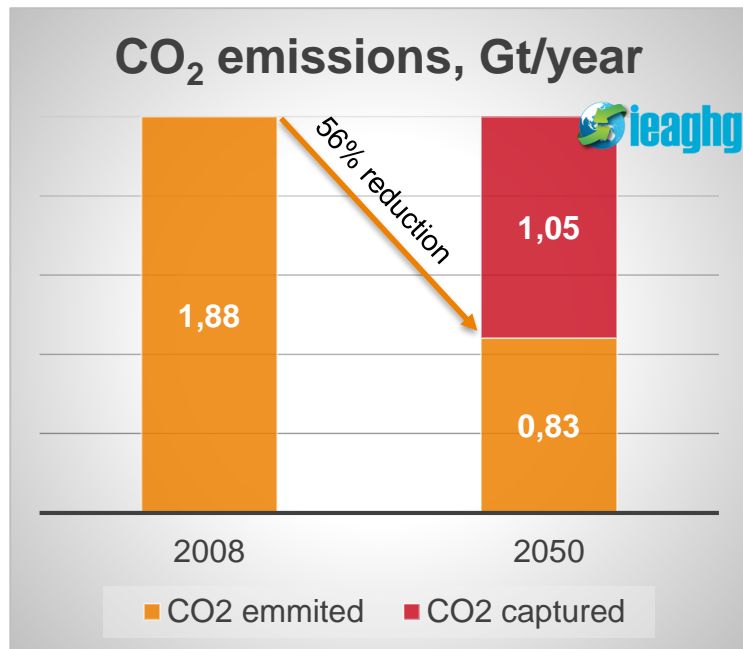


# CO<sub>2</sub> UTILIZATION BY ETHANOL PRODUCTION IN THE CEMENT INDUSTRY

Juliana Monteiro (TNO), Peter van Os (TNO), Earl Goetheer (TNO), Helmut Hoppe (VDZ)

**TNO** innovation  
for life

# THE CEMENT INDUSTRY



# THE CEMCAP CONTEXT (1/3)

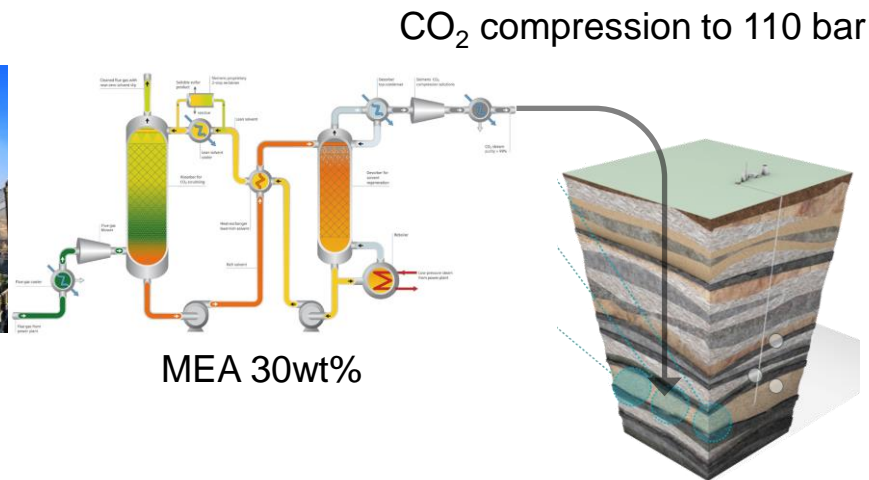
## › WP3: CEMCAP Framework

- Reference case: Best Available Technique (BAT) standard
- Representative size for a European cement plant
- Cement production of 1.36 Mt per year
- Heat and mass balances available



# THE CEMCAP CONTEXT (2/3)

- › WP4: Comparative capture process analysis, D4.2
- › Economic Key Performance Indicators



# THE CEMCAP CONTEXT (3/3)

## › WP5: Post-capture CO<sub>2</sub> management (CCUS)

1. CCS: Geological sequestration: option to be defined (TNO)
2. CCS: Mineralization to MgCO<sub>3</sub> (ETH Zurich)
3. CCU: CO<sub>2</sub> hydrogenation to ethanol (TNO)
4. CCU: CO<sub>2</sub> polymerization to Poly(propylene carbonate) (TNO)
5. CCU: food-grade CO<sub>2</sub> (TNO)

Suitable



# ETHANOL



# WHY ETHANOL?

- › Fuel → large market 110 billion liters per year
- › Potential for CO<sub>2</sub> utilization = 166 Mton CO<sub>2</sub> per year
- › 195 BAT cement plants
- › Market has potential to increase: drop-in fuel



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## Alternative Fuels Data Center

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Find and compare alternative fuel vehicles (AFVs), engines, and hybrid systems. Some of the light-duty AFVs in this tool may count toward vehicle-acquisition requirements for [federal fleets](#) and [state and alternative fuel provider fleets](#) regulated by the Energy Policy Act (EPACT).

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# WHY ETHANOL?

- › Community already looking into methanol and methane



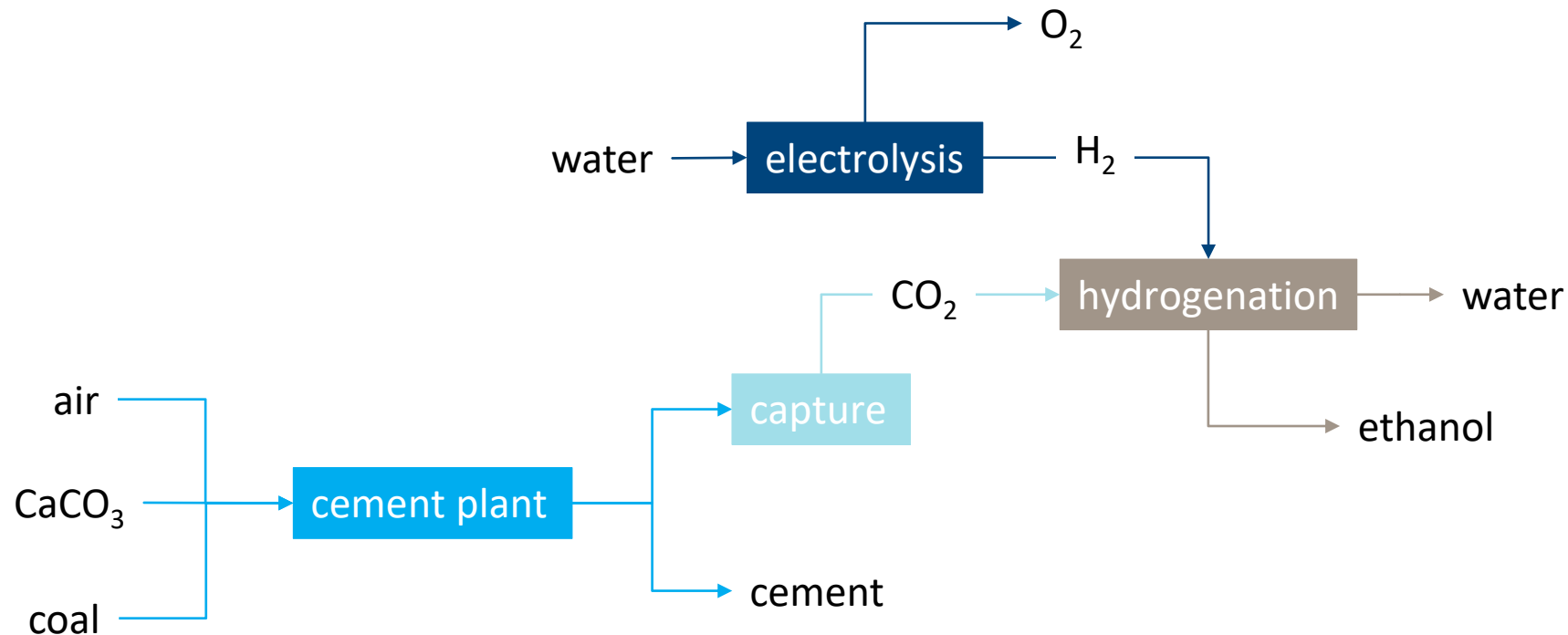
- › Ethanol has a higher price



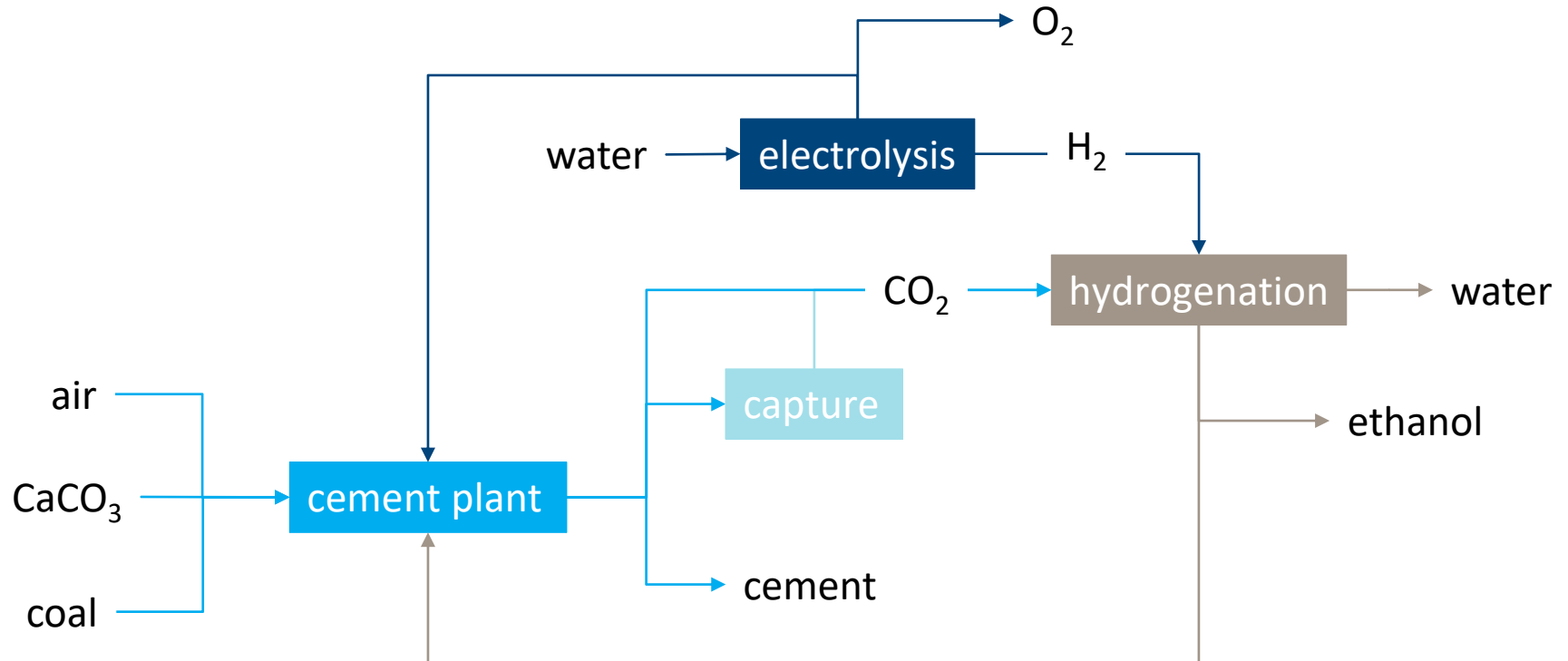
# INTEGRATION

The image features a light blue background with several dark silhouettes of hands reaching in from the edges. These hands are positioned around a cluster of interlocking gears of various sizes. The word 'INTEGRATION' is written in large, bold, white capital letters across the center of the image, partially overlapping the gears and hands.

# PROCESSES



# INTEGRATED PROCESSES



## COMPARING FUELS

	Coal	Ethanol
Calorific value, kJ/kg	27150	29700
C content, %wt	69	52
Calorific value, kJ/kgC	39450	59925

Burning ethanol  
generates  
40% less CO<sub>2</sub>

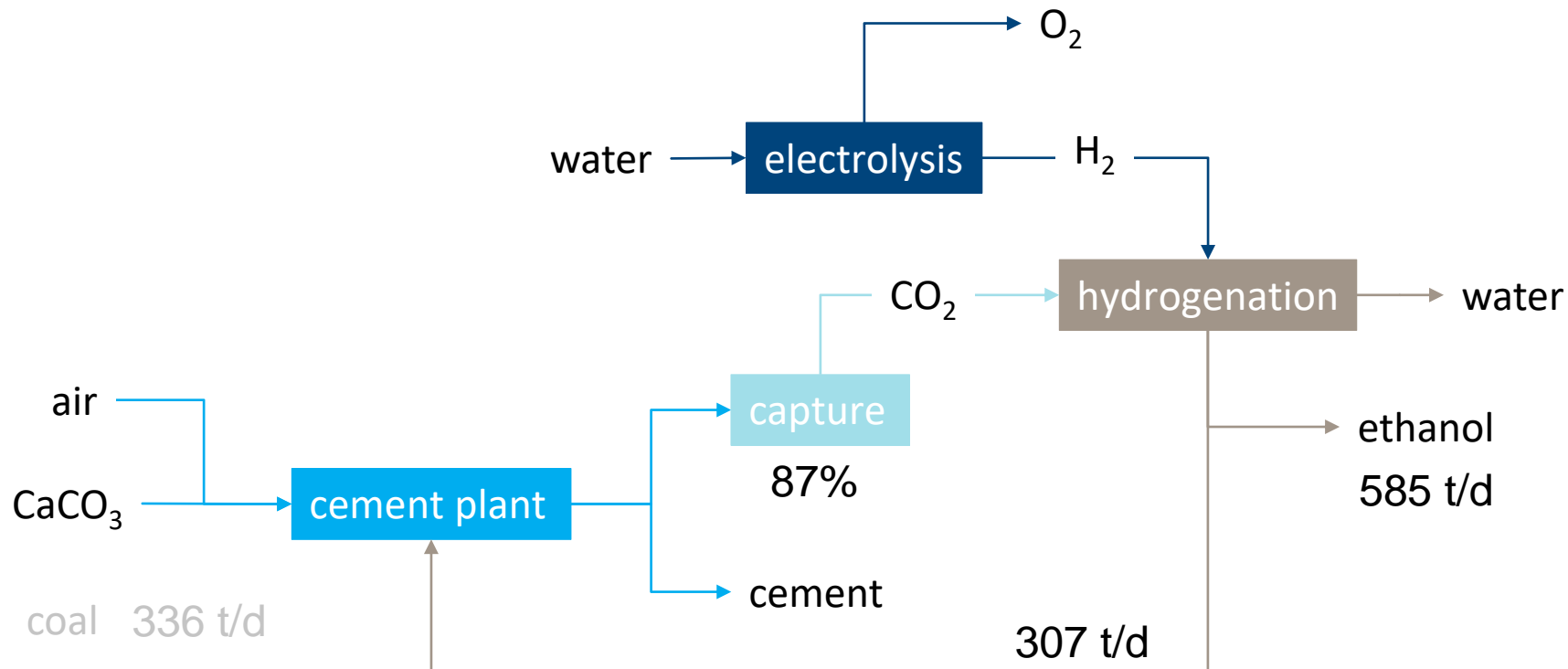
# INTEGRATION

- › Various possibilities
- › What about feasibility?

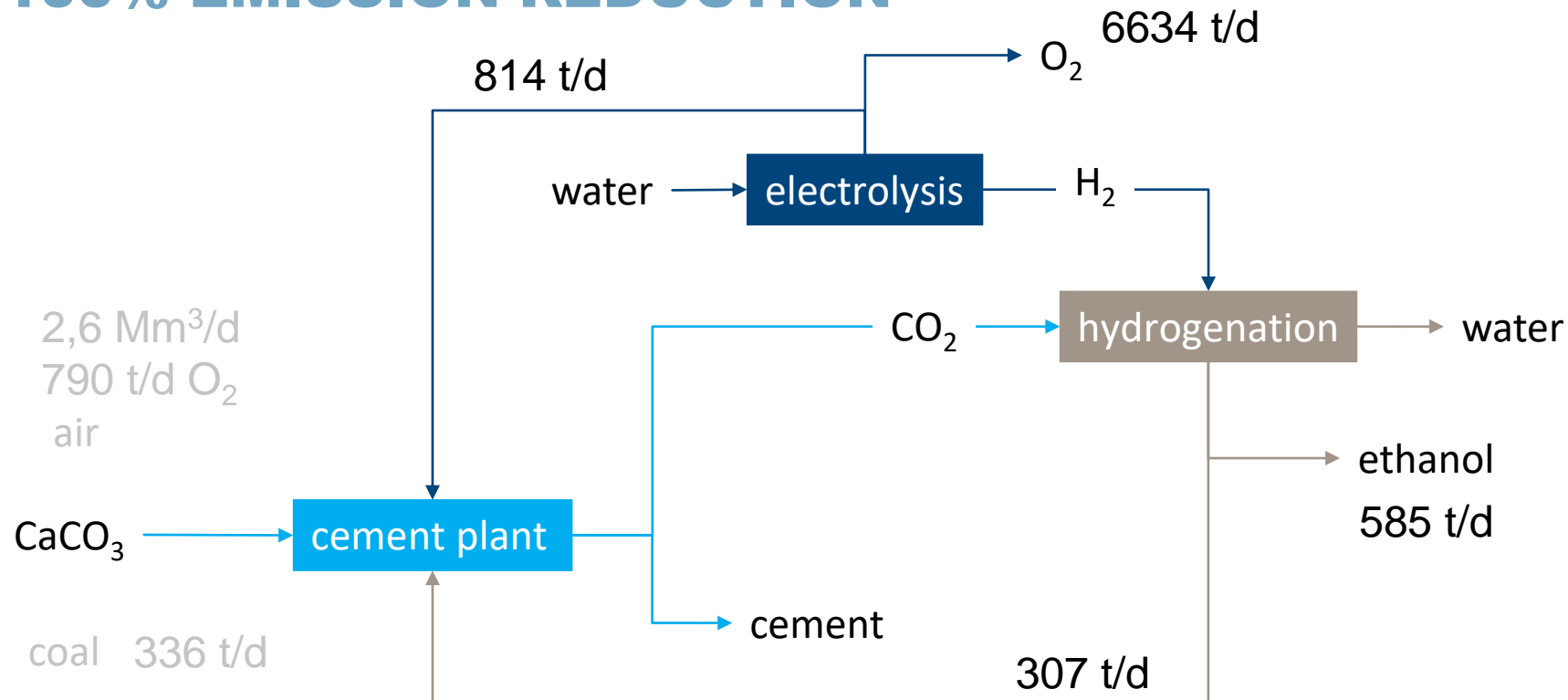


# HEAT AND MASS BALANCES

# 90% EMISSION REDUCTION

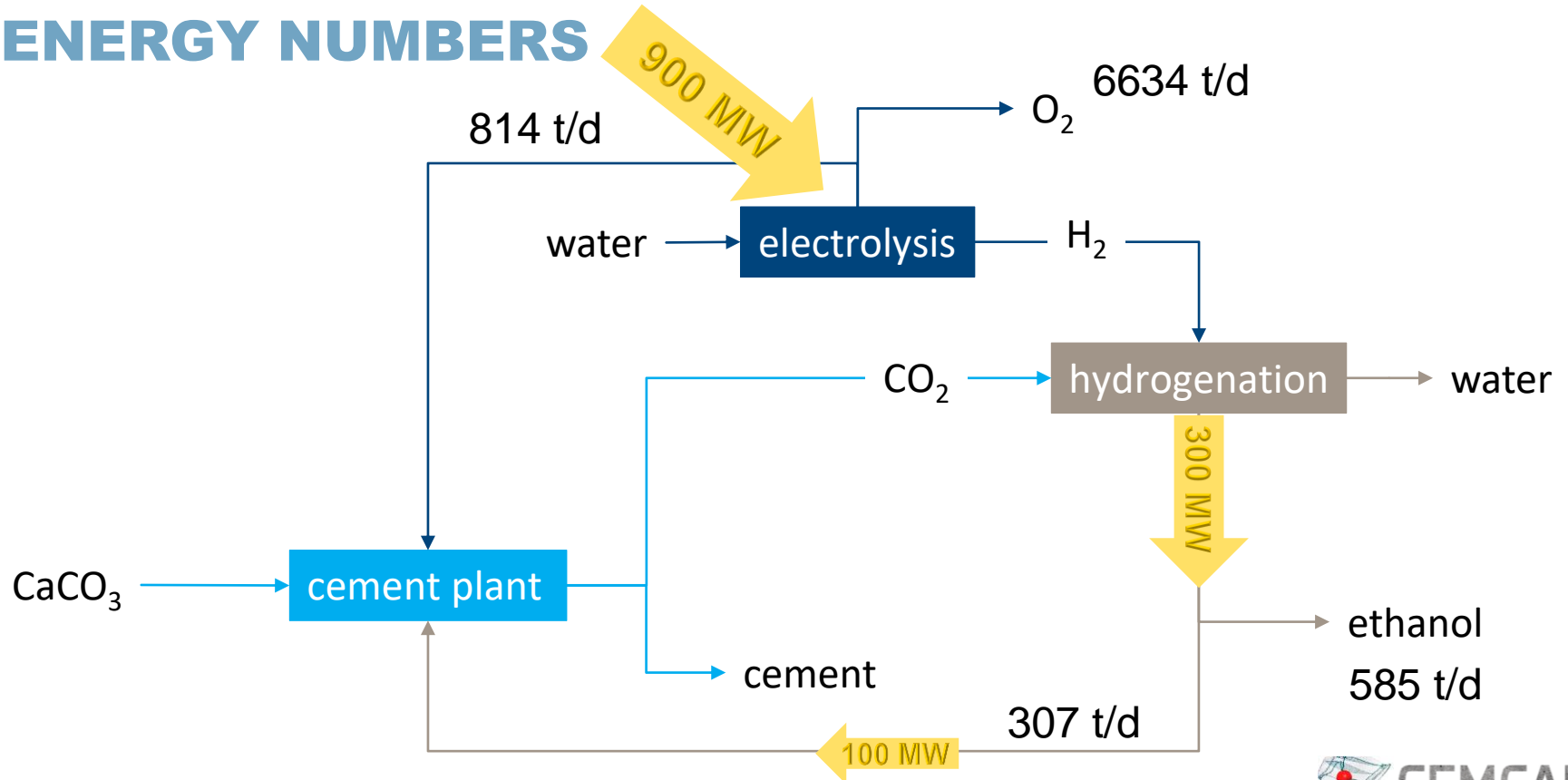


# 100% EMISSION REDUCTION

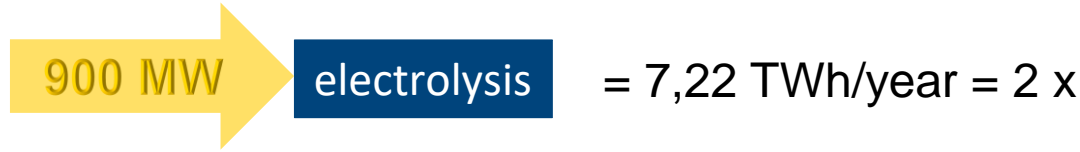




# ENERGY NUMBERS



# WIND FARM SCALE

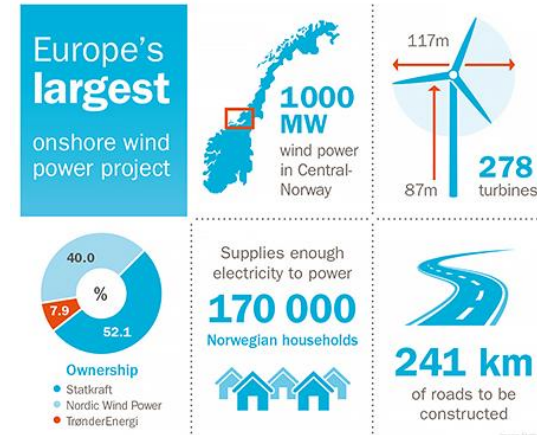


3 x Manhattan

½ Trondheim

22000+ soccer fields

Fosen Vind = 3,4 TWh/year



<http://www.fosenvind.no/om-fosen-vind/>

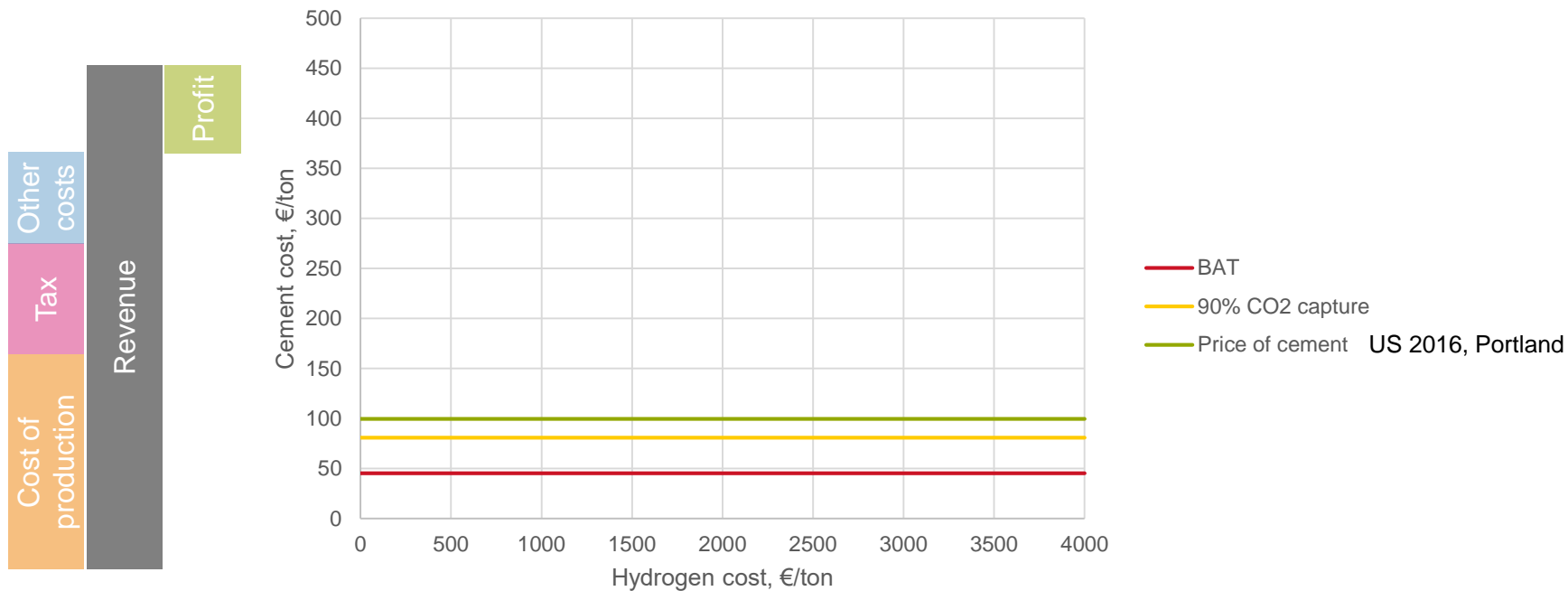
# ECONOMICS

<b>Cement €/ton</b>	<b>No capture</b>	<b>90% CCS</b>	<b>90% CCU</b>
Raw meal	3,68	3,68	3,68
Fuel	6,92	6,92	0,00
Electricity	5,64	9,69	7,00
Steam	0,00	14,19	16,00
Cooling water	0,00	0,65	1,00
Hydrogen	0,00	0,00	457,46
Other	0,80	2,32	3,00
<b>Variable OPEX</b>	<b>17,04</b>	<b>37,45</b>	<b>488,14</b>
<b>Fixed OPEX</b>	<b>13,33</b>	<b>19,64</b>	<b>25,00</b>
<b>CAPEX</b>	<b>14,99</b>	<b>23,60</b>	<b>50,00</b>
<b>Ethanol revenue</b>	<b>0,00</b>	<b>0,00</b>	<b>91,00</b>
<b>Cost of cement</b>	<b>45,36</b>	<b>80,69</b>	<b>472,14</b>

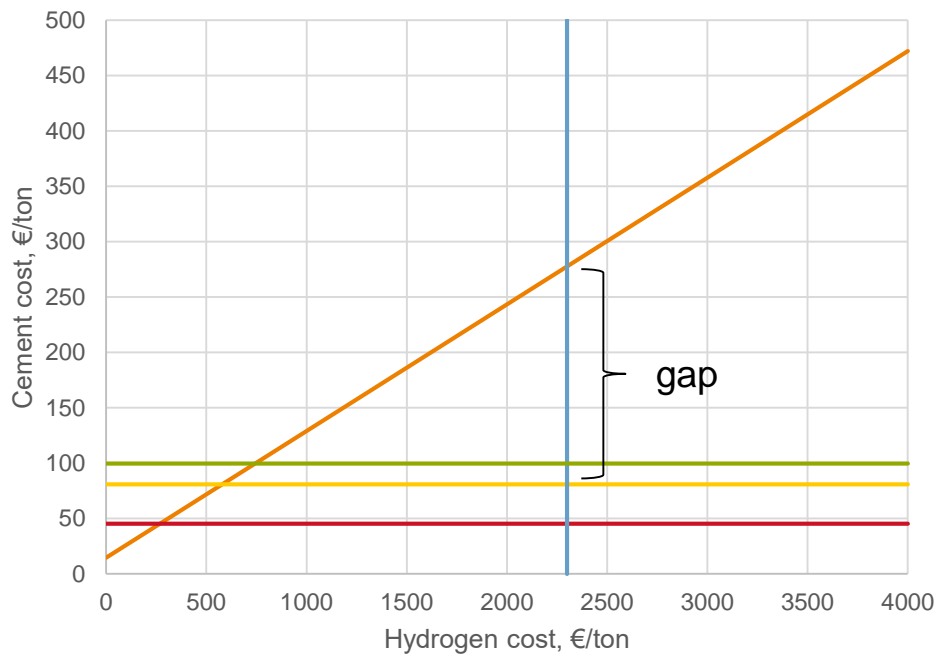
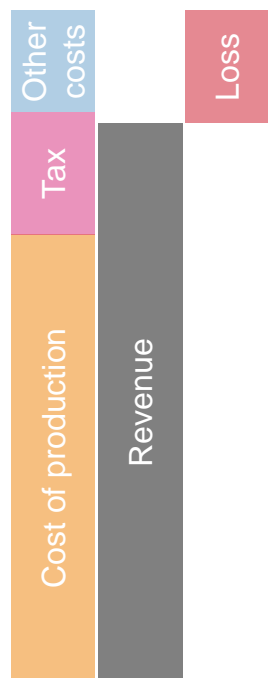
hydrogen  
4000 €/ton



# ECONOMIC SCENARIOS



# ECONOMIC SCENARIOS



- Ethanol
- BAT
- 90% CO2 capture
- 2020 DoE target
- Price of cement

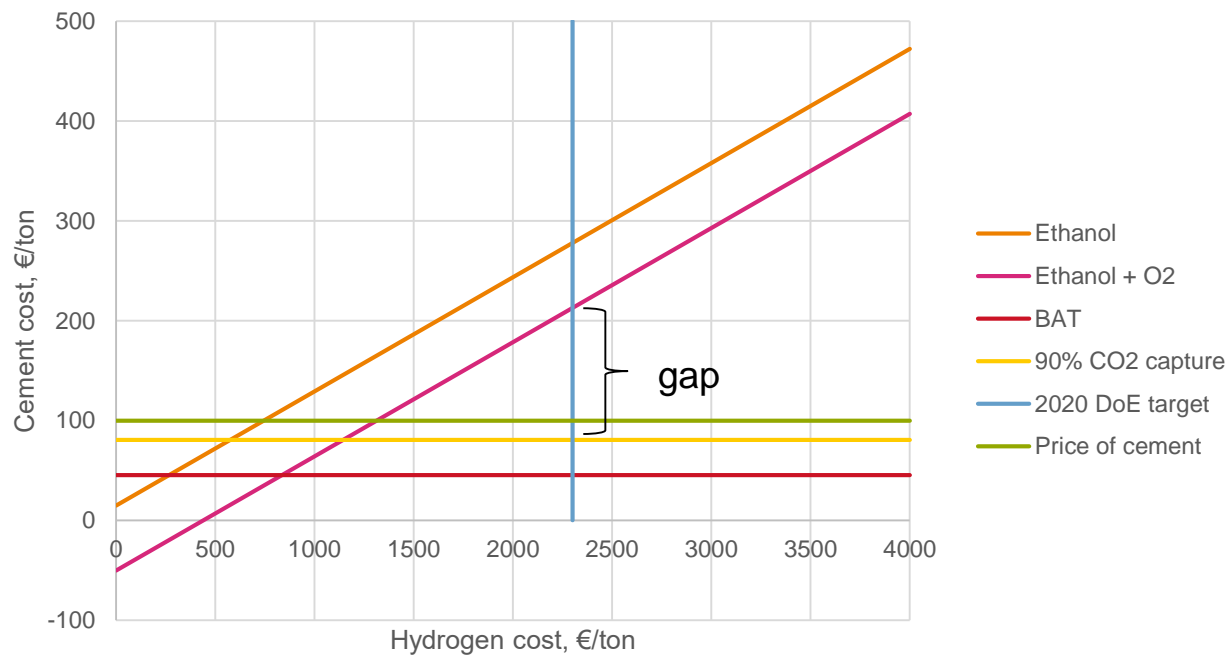


# #1 INCREASE REVENUE – SELLING OXYGEN

- › 6634 ton/day = 0,55% of global market
- › Hydrogen future (2050?) → oxygen may have little to no value
- › Oxygen price = €40/ton → cost of on-site production



# ECONOMIC SCENARIOS



## #2 DECREASE COSTS

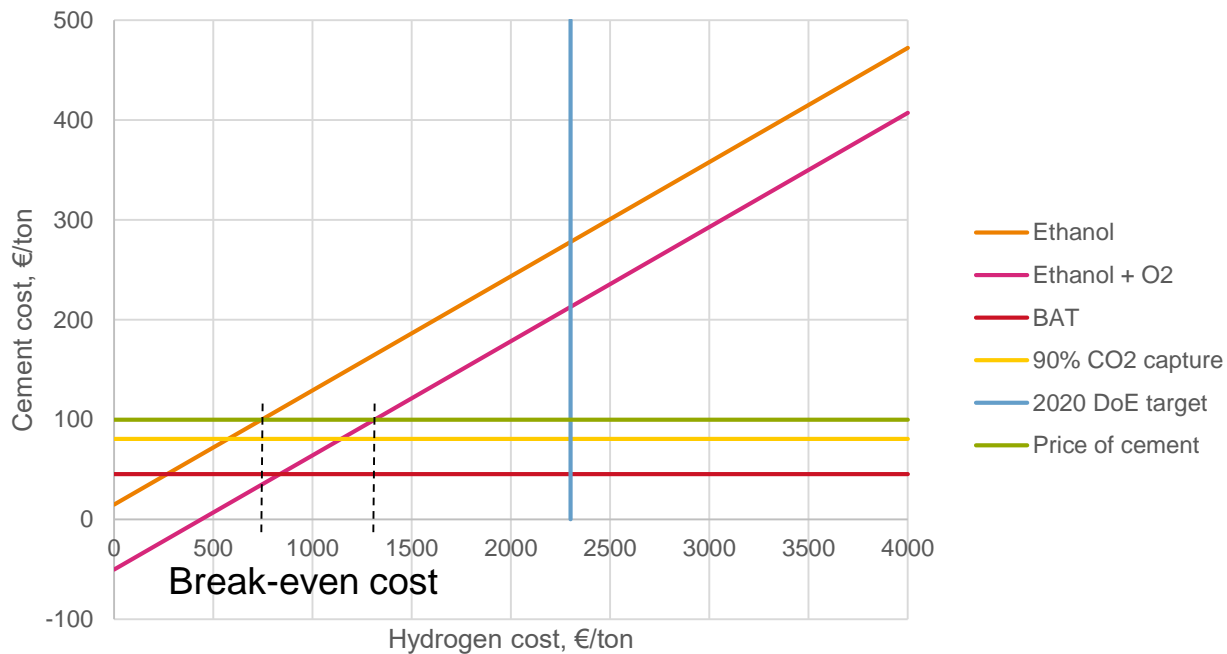
- › Lower or no **tax** on “green” cement
  
- › Lower **hydrogen cost**
  - Cheaper electricity
  
  - Improvements on hydrolysis
  
  - Alternative technologies, e.g., photocatalytic: 1600 – 10400 USD/ton

Pinaud, B. A., Benck, J. D., Seitz, L. C., Forman, A. J., Chen, Z., Deutsch, T. G., ... Jaramillo, T. F. (2013). Technical and economic feasibility of centralized facilities for solar hydrogen production via photocatalysis and photoelectrochemistry. *Energy & Environmental Science*, 6(7), 1983–2002.  
<https://doi.org/10.1039/C3EE40831K>





# ECONOMIC SCENARIOS



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[www.sintef.no/cemcap](http://www.sintef.no/cemcap)

Twitter: @CEMCAP\_CO2



A nighttime photograph of a city street. On the left is a brick building with lit windows. On the right is a modern building with a curved facade and lit windows. A long-exposure shot of a car's headlights and taillights creates a bright green and white light trail that curves across the middle of the image. The overall scene is illuminated by city lights.

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ATTENTION**

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