Options for step wise CO_2 emission reduction using renewable resources

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GLASS SERVICE

17th Conference on Electric Melting of Glass
10 September 2019, Prague, CZ

CONTENT

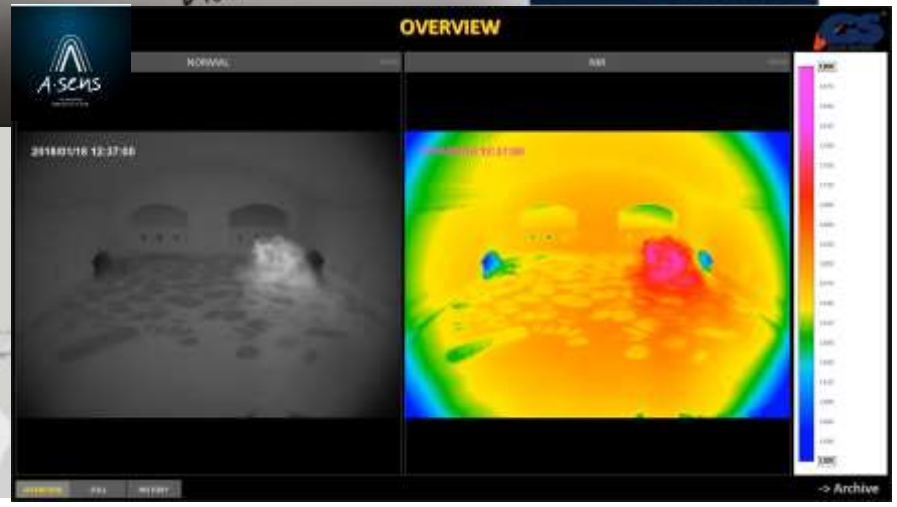
- Introduction GS
- CO_2 emission reduction targets
- Developments in renewable (electric) energy
- Electricity pricing and CO_2 emission reduction
- What about Hydrogen?
- Short history of (all) electric glass melting
- All-electric furnace concepts & largest realized for container glass production
- Concept of GS|H^2EM Horizontal Hybrid Electric Melter
- Conclusions, recommendations & outlook

GS GROUP World Wide

Process Simulation (CFD)
Physical Modeling
Defect analysis
Expert System control
Specialized Engineering
Benchmarking furnaces
-Economically & Ecologically
Raw materials
Burners
Boosting
NIR Furnace Camera’s





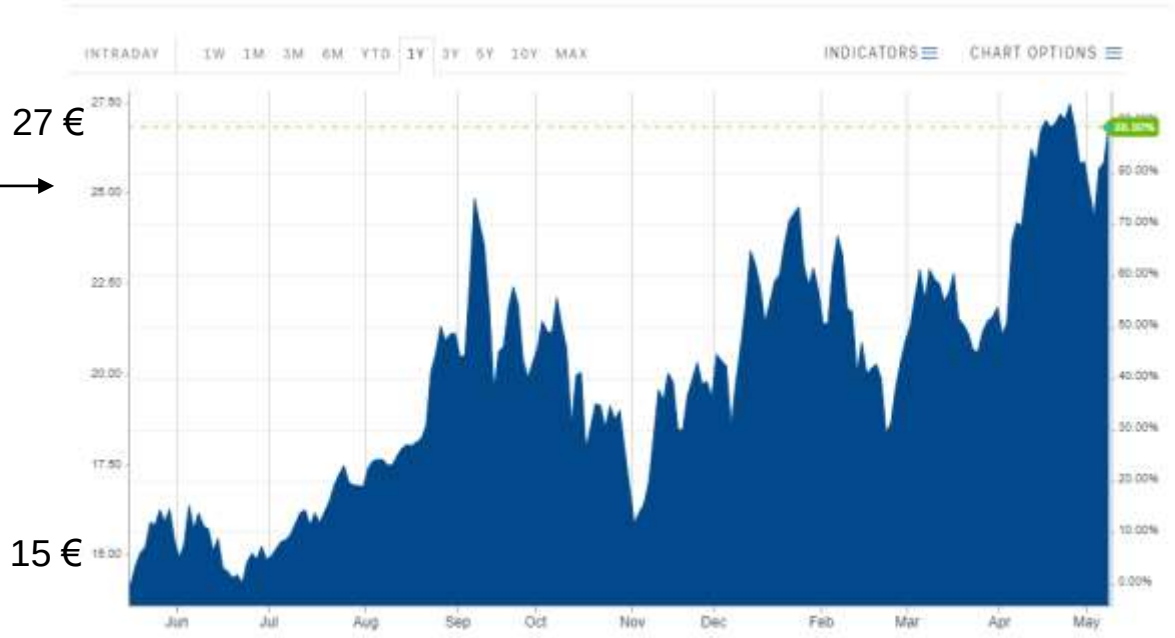


CO_2 reduction is a must to rescue planet earth for our children

- The EU Requires a 43% CO_2 emission reduction by 2030 compared to 2005
- By 2050 the CO_2 emission should be reduced by 80%
- In the Netherlands the Groningen Gas exploration will be stopped by 2030 due to Earthquakes in the region
- It means if you plan your next rebuild now and furnace life is >12 years:

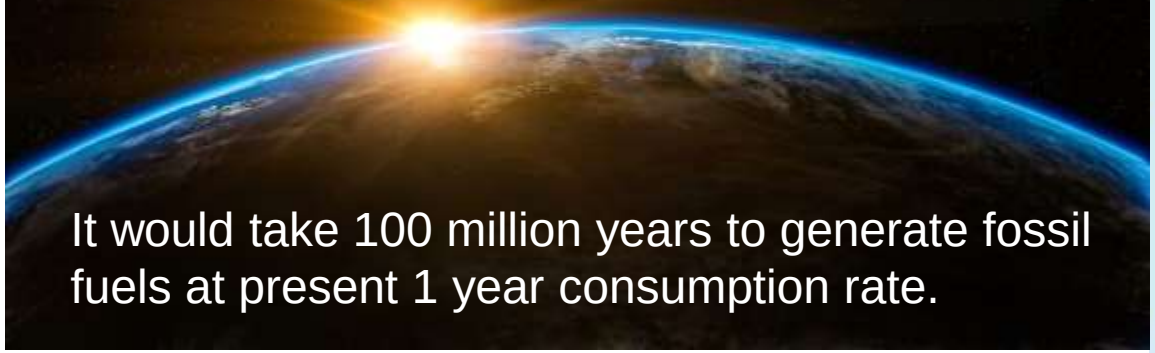
  You should have a plan HOW to reduce CO_2 emission

Actual CO_2
Price 25 €/ton
Emission Trading

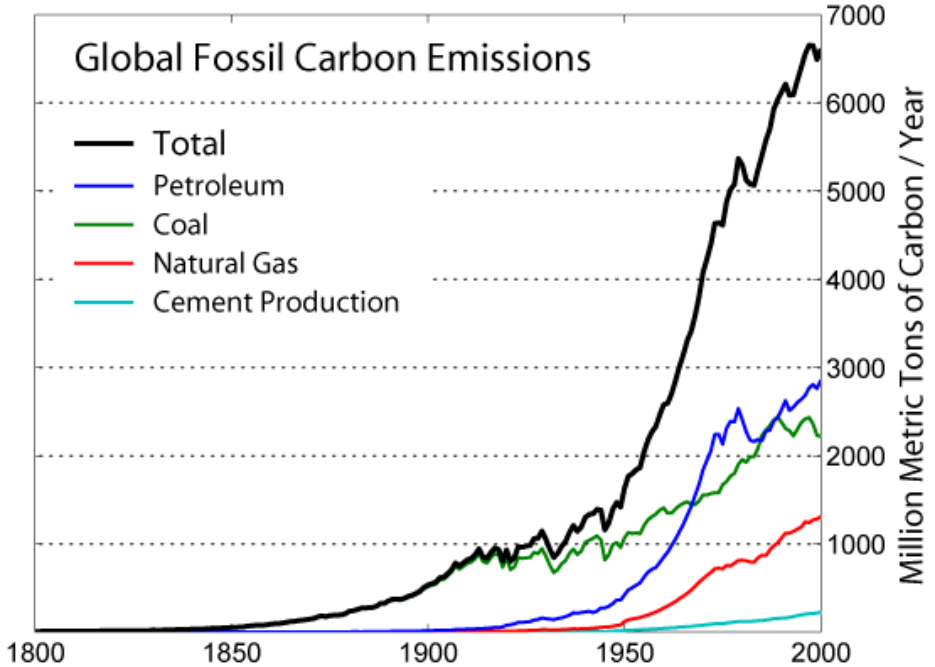


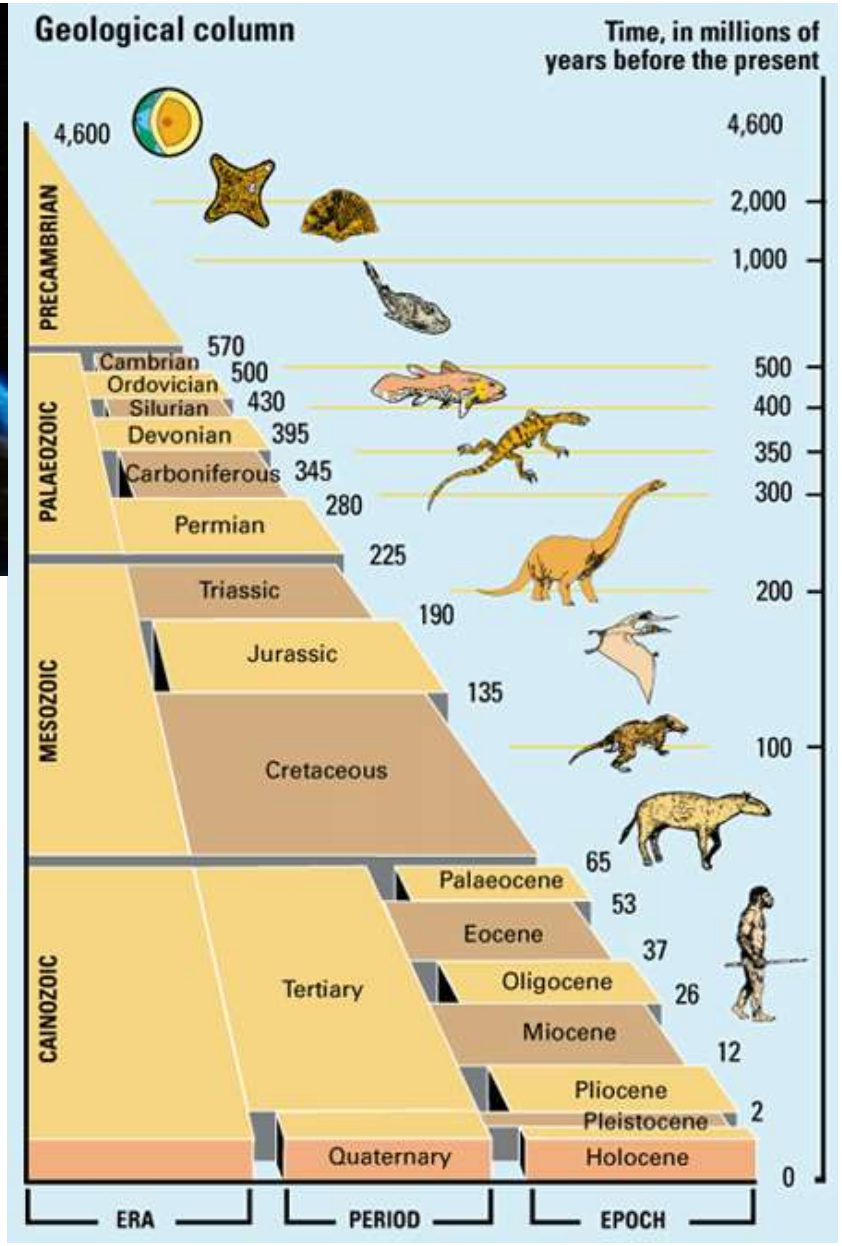
Can fossil fuel be the future?

It took 2.4 billion years for the earth to create fossil fuels from solar energy, that we have burnt in just 170 years. (equivalent to 2 ms / year)



It would take 100 million years to generate fossil fuels at present 1 year consumption rate.



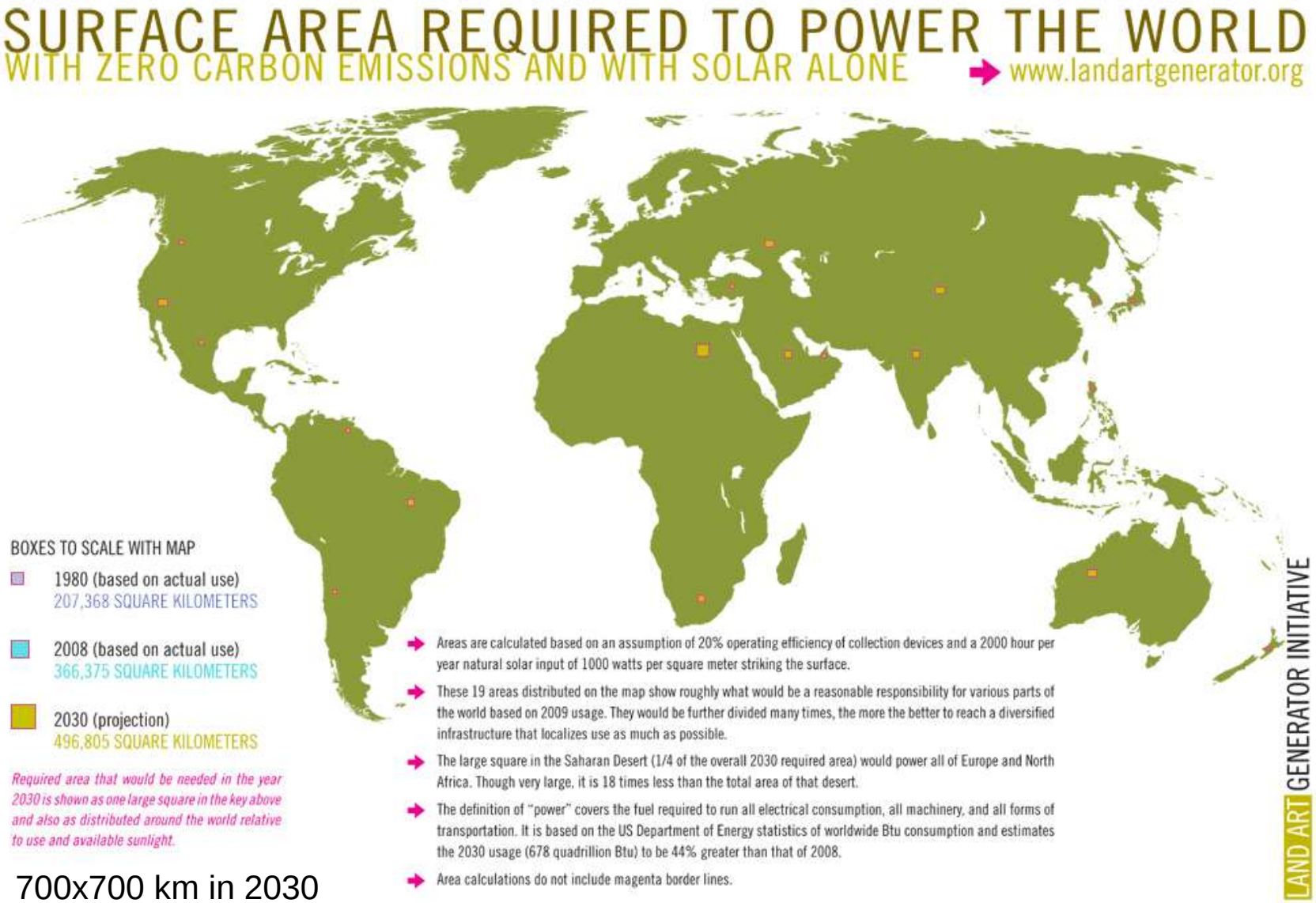


Required surface area to harvest sufficient renewable solar energy. Each hour 430 quintillion (10^{18}) Joules of energy from the Sun hits the Earth.



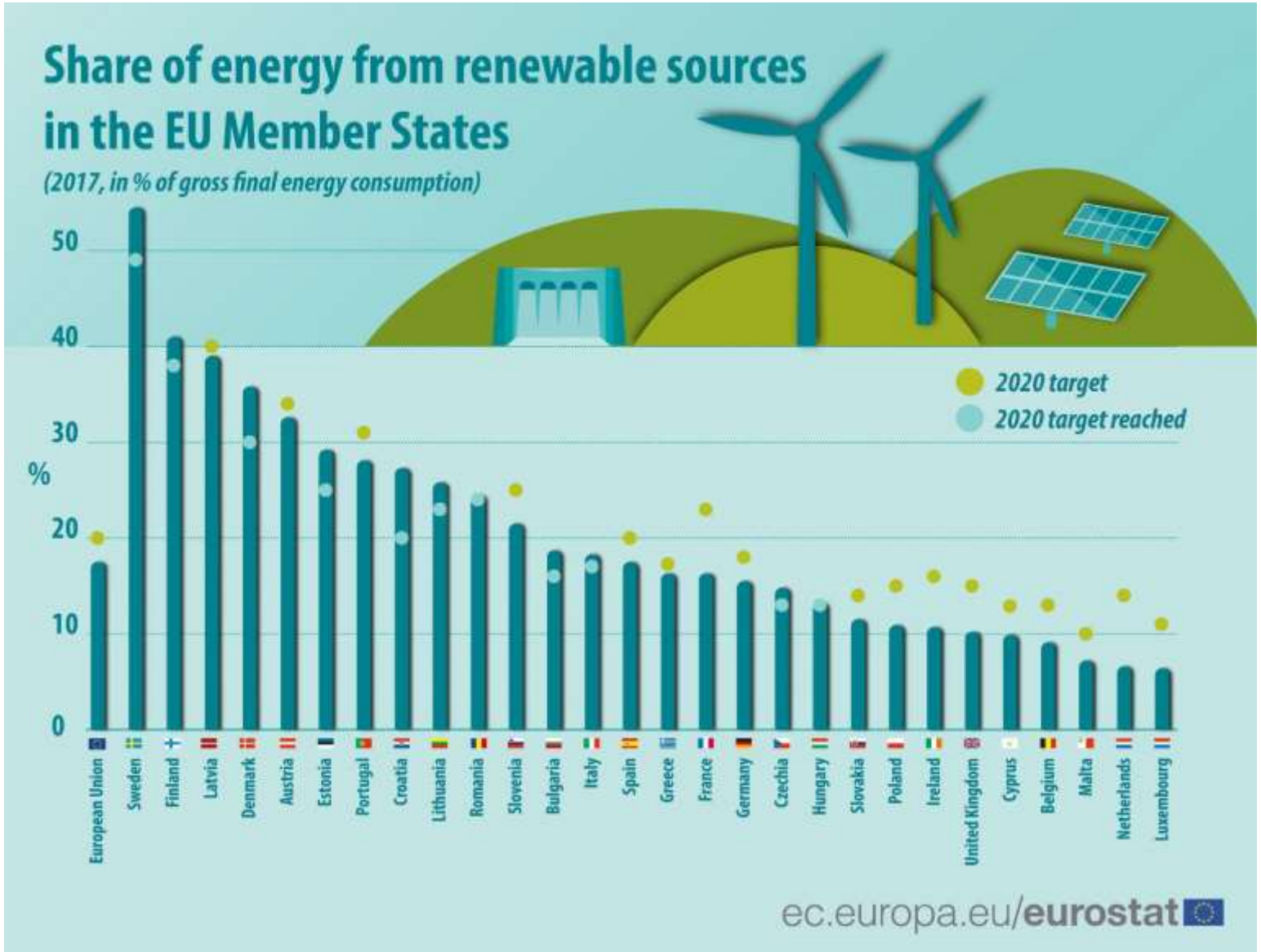
Sea level is rising
8 cm since 1993
200 cm till 2100





700x700 km in 2030
49,116,227 km^2 is total agriculture land 100 times solar

Share of renewable energy on total gross used energy in EU 2017 is already 20%



In Germany share of **Electricity** generation by renewables reached **40%** in 2018

CO_2 emissions per Electric kWh

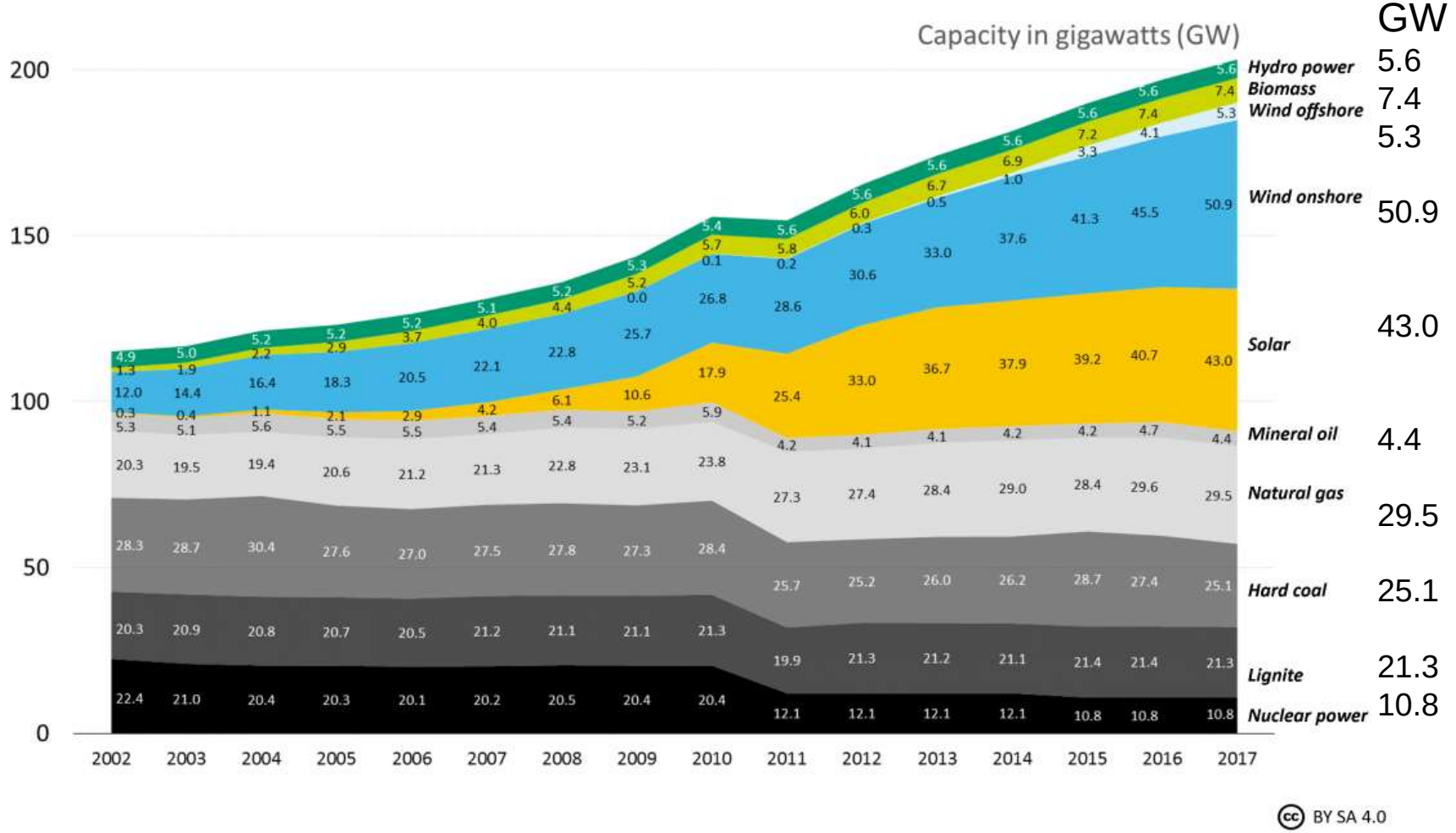
Estonia	948 g CO_2/kWh
Poland	682 g CO_2/kWh
Czechia	**489 g CO_2/kWh**
Netherlands	461 g CO_2/kWh
Germany	426 g CO_2/kWh (40% down from 1990)
USA	420 g CO_2/kWh, 21% Nuclear power
UK	248 g CO_2/kWh
France	67 g CO_2/kWh thanks to Nuclear power
Norway	**30 g CO_2/kWh thanks Renewable Hydro power**
Ontario Canada	18 g CO_2/kWh thanks Nuclear & Hydro power
Orkney Isl (UK)	13 g CO_2/kWh thanks Wind Energy

Installed present renewable energy in Germany.
20% of total energy, 40% of total Electricity

Installed net power generation capacity in Germany 2002 - 2017.

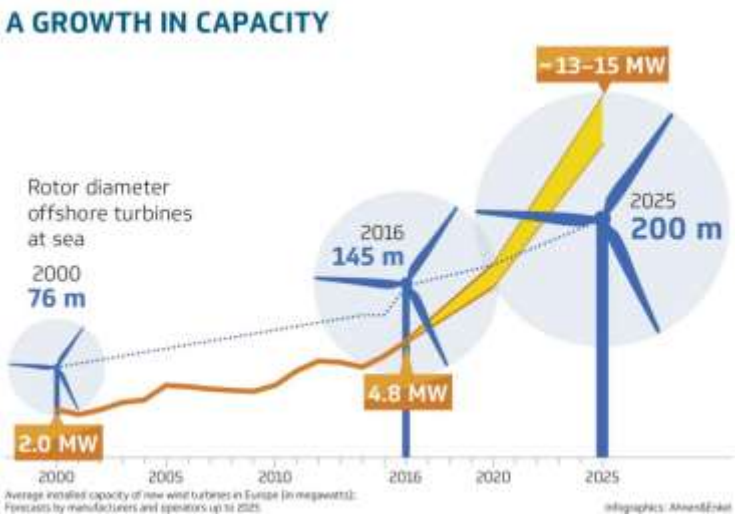
Data: Fraunhofer ISE 2018.

CLEAN ENERGY WIRE



	GW
Hydro power	5.6
Biomass	7.4
Wind offshore	5.3
Wind onshore	50.9
Solar	43.0
Mineral oil	4.4
Natural gas	29.5
Hard coal	25.1
Lignite	21.3
Nuclear power	10.8

BY SA 4.0

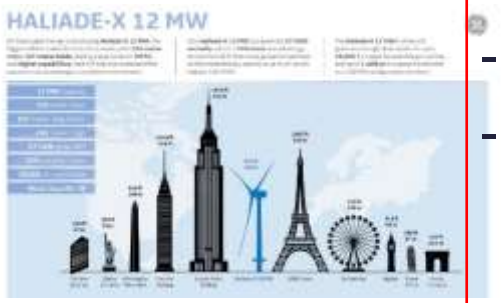


Typical 350 TPD Container glass furnace with 50% cullet uses around 3.5 GJ/ton or 14 MW Fuel & Electric boost
Hybrid Electric it would need 2.5 GJ/ton or about 10 MW



Offshore windmill plans are huge

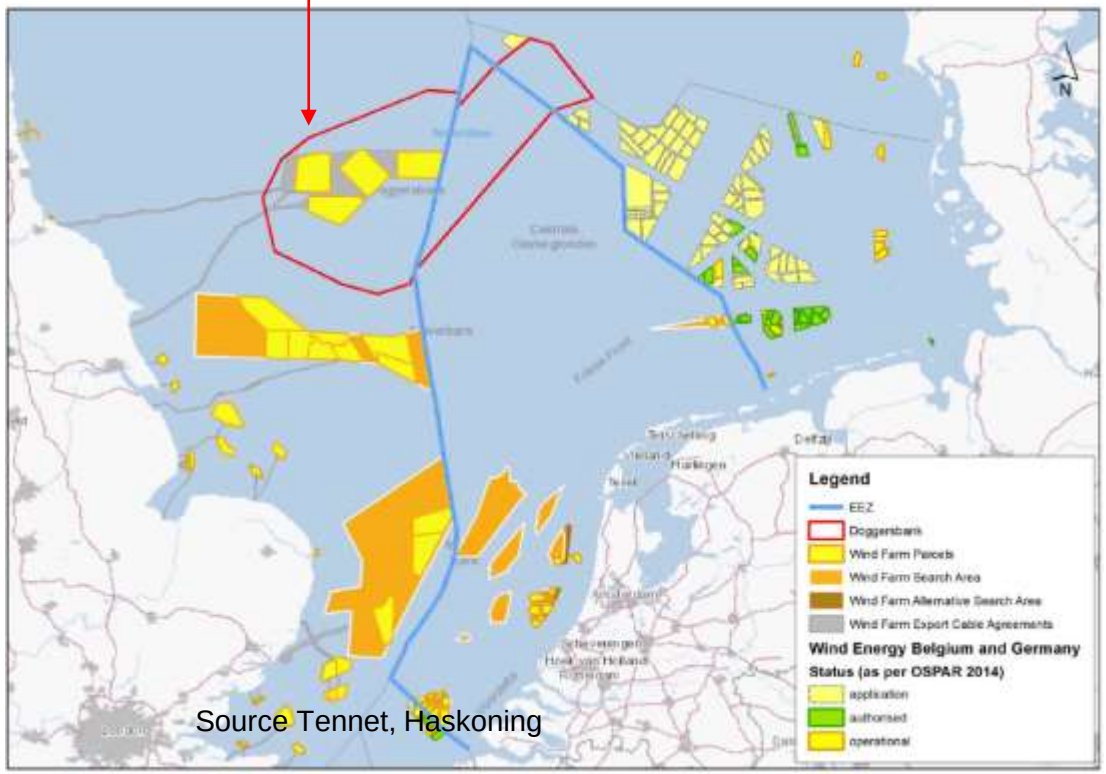
- Dogger Bank plan:
  - 7000 Turbines @ 10 MW each
  - 70 GW total
  - Would cover UK elec. need



Total UK glass industry consumption
= 6.500 GWh/year so 4 days wind is sufficient

Vienna area (existing):
- 700 Turbines @ 2 MW each
- 1.5 GW total
- Covers Vienna electricity need





Source Tennet, Haskoning



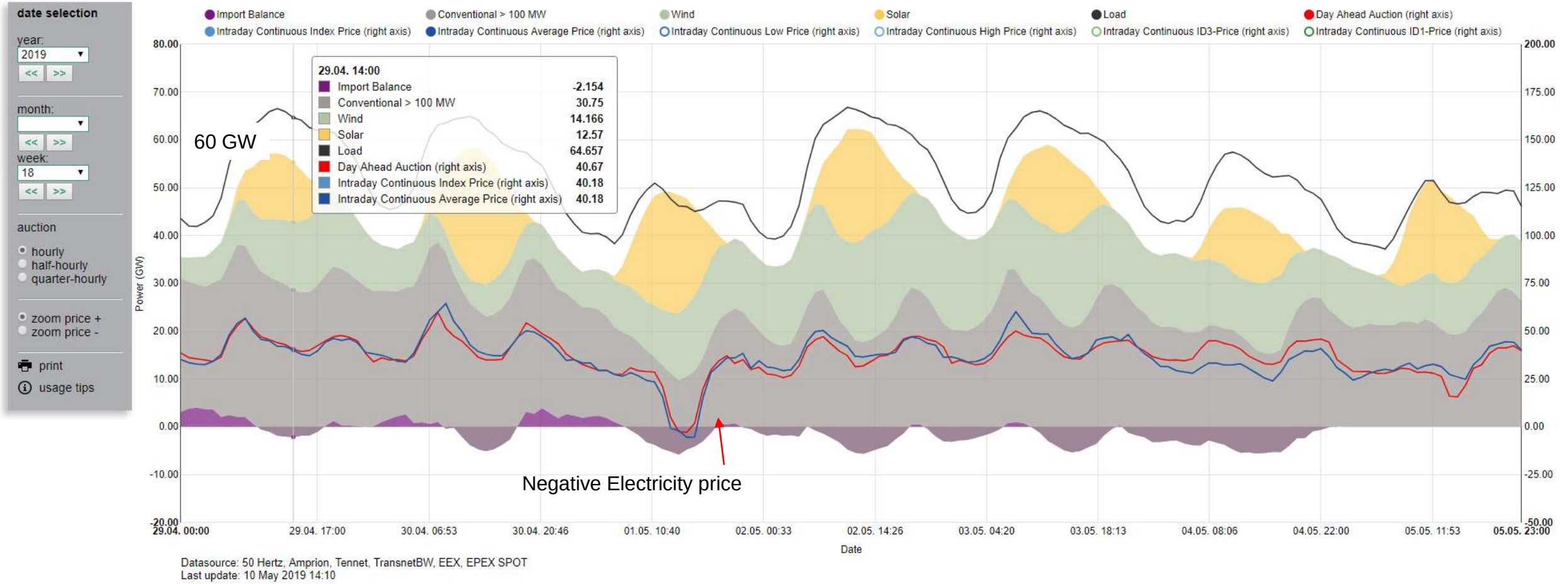
New life of Gas Platform:
1. Gather all windmill power
2. Increase voltage to
3. Transfer Electricity to shore
4. Produce Hydrogen
5. Store Hydrogen in Caves
6. Transport Hydrogen to shore

Removing of 600 Platforms costs billions Euro
Converting them to Renewable is cost effective

Present offshore active 20 GW
Price 0.05 €/kWh

Prepare for energy costs and heating value fluctuations with smarter model based furnace control

Electricity production and spot prices in Germany in week 18 2019

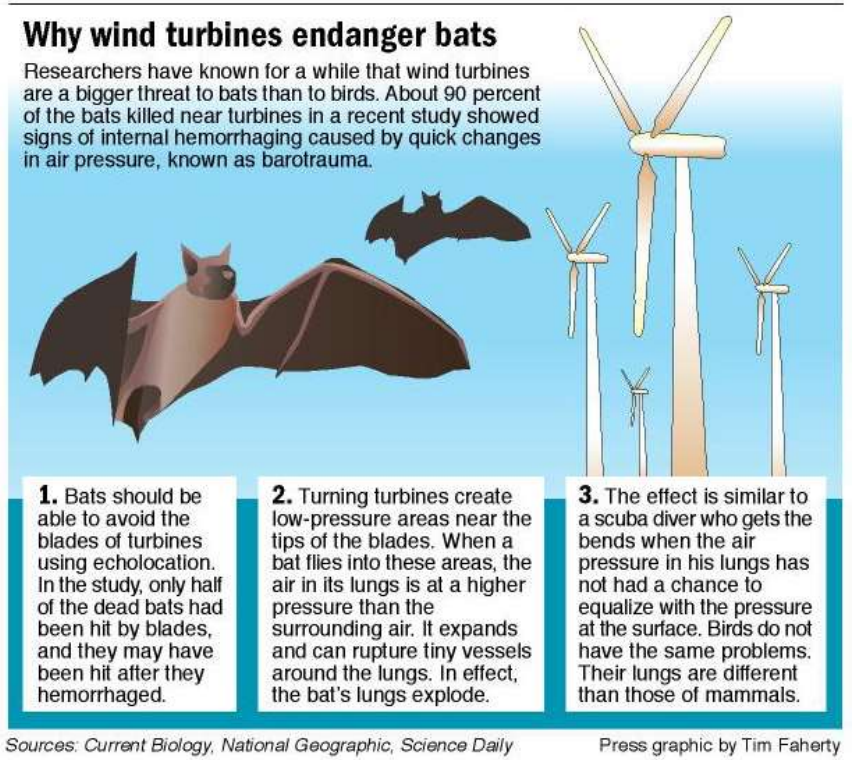


Source Fraunhofer

Daily variation of generated wind and solar energy and consequently fluctuating electricity price

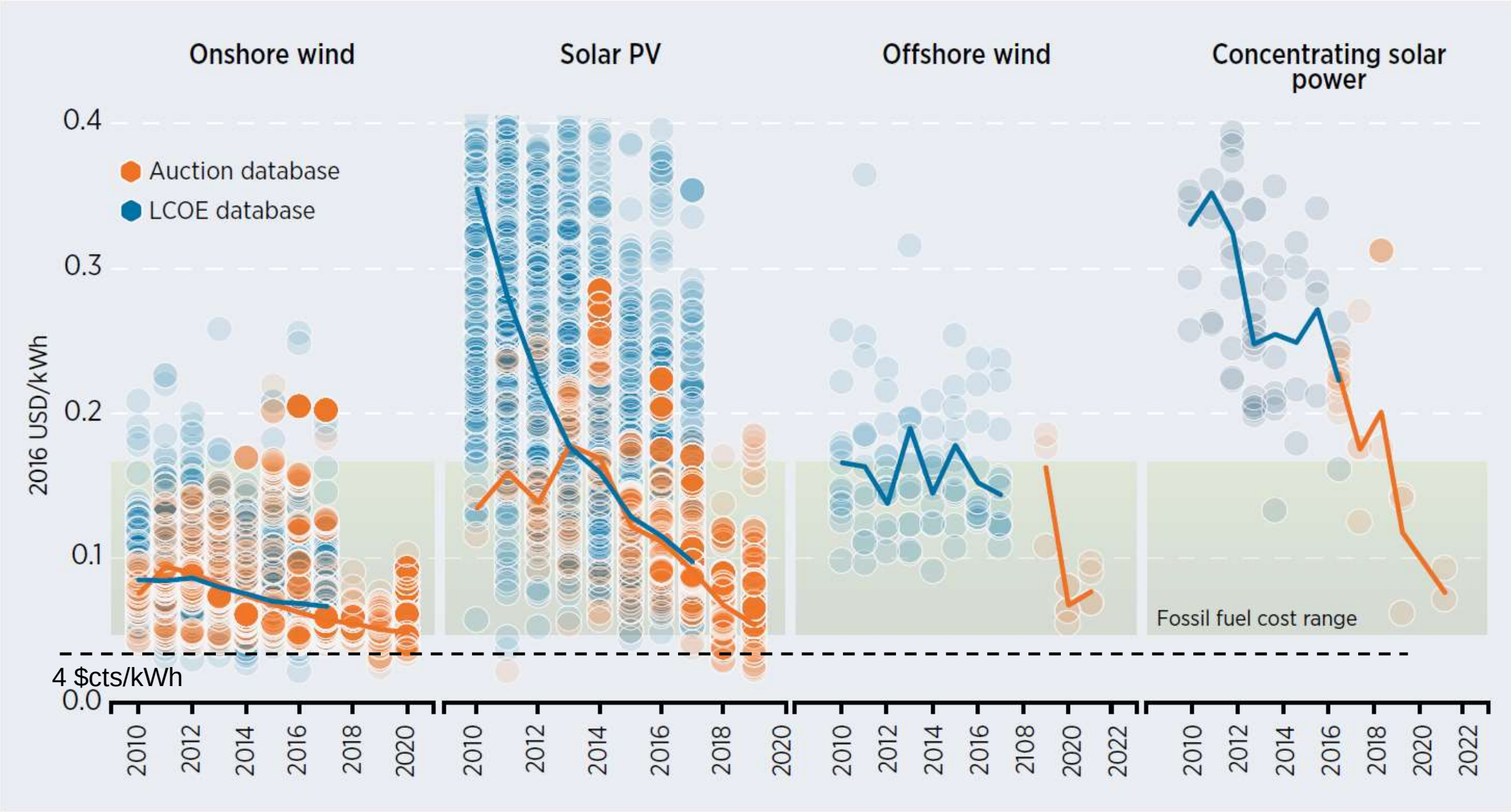
Why people resist on renewable energy

- 1. It destroys our beautiful Horizon
  - Yeah, smoky chimneys and cooling towers are beautiful
- 2. Windmills kill birds
  - Number 1. are predators eg. cats, 2. High rise buildings & pol
- 3. It kills jobs
  - Per invested Million € renewables create 5-10 times more job
- 4. We have enough fossil fuels
  - Nope, max 50 till 100 years, than it is gone
- 5. Global warming does not exist (fake news)
  - Who knows for sure, but it is highly likely and anyway => 4.
- 6. What to do when there is no sun or wind
  - Diversify: water, sun, wind geographically spread and Hydrogen & Bio
- 7. Costs & just because it is new
  - Prices dropping fast & yes humans do not like changes



Netopýřsi

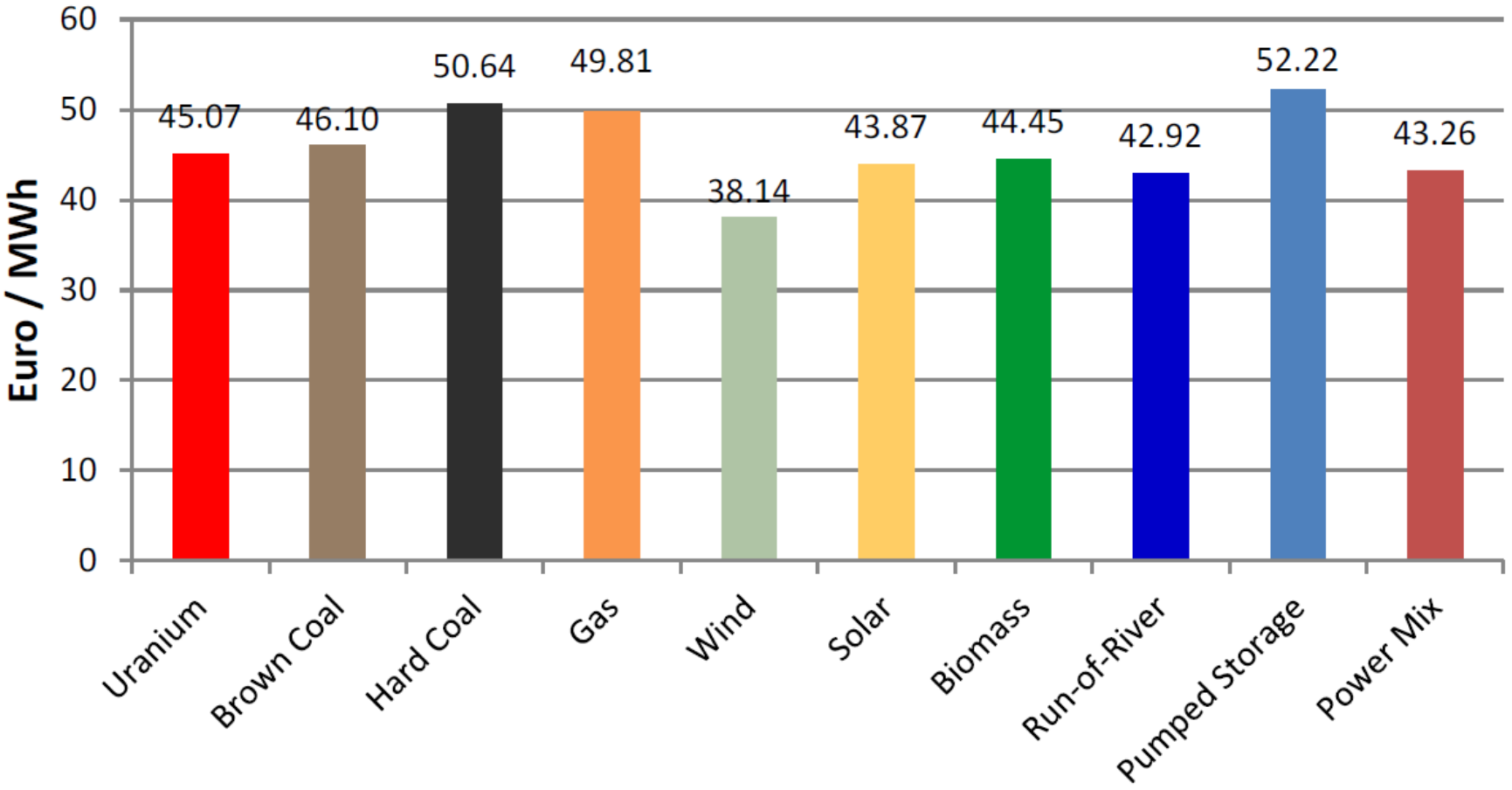
Electricity costs from renewables are close to fossil fuel costs



Source: IRENA Renewable Cost Database and Auctions Database.

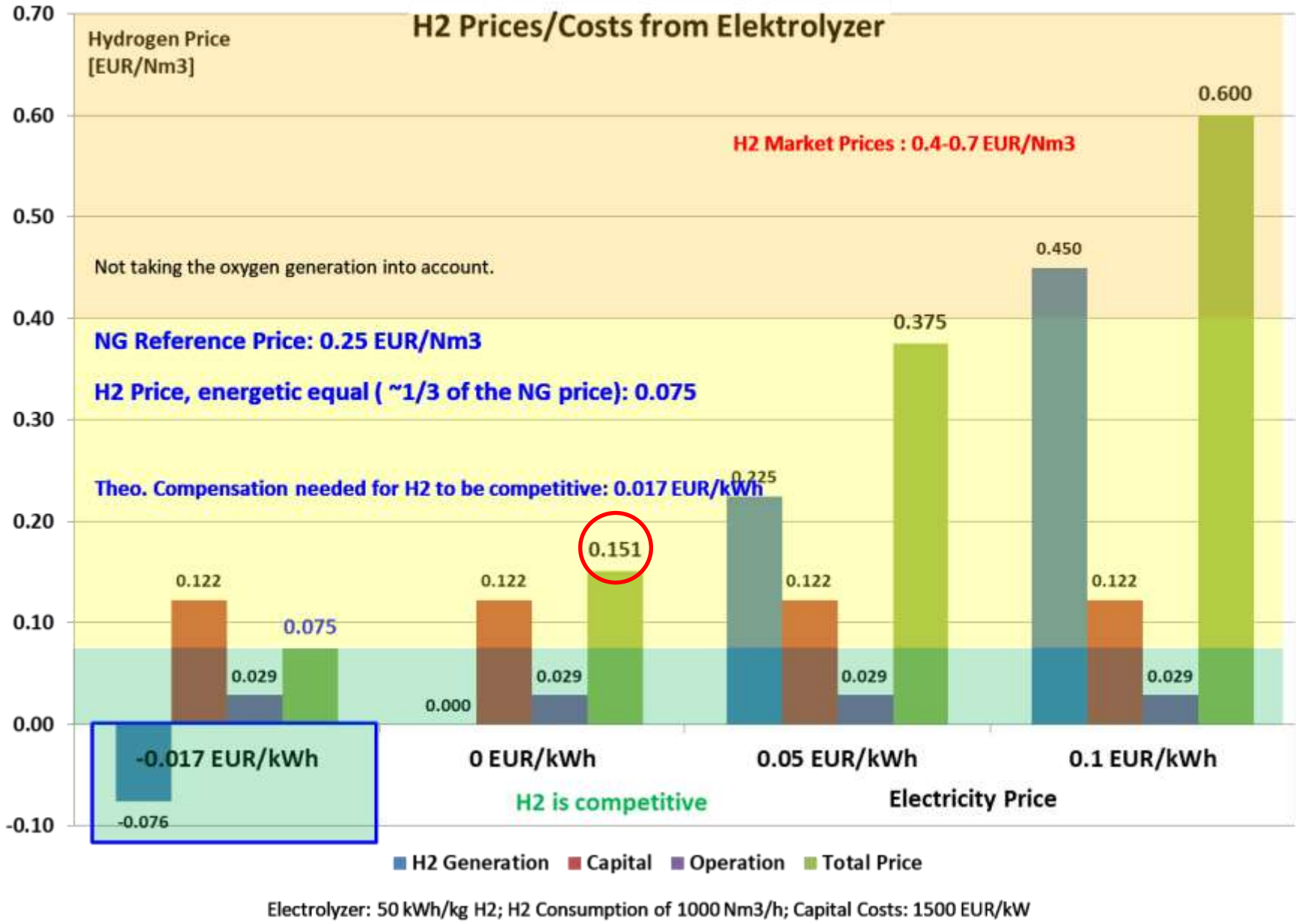
Electricity costs from renewables in Germany are below fossil fuel costs < 0.045 € /kWh (before Tax)

Day Ahead market values, weighted by volume
Year 2018



Source
Fraunhofer

(When) Will Hydrogen be an alternative?

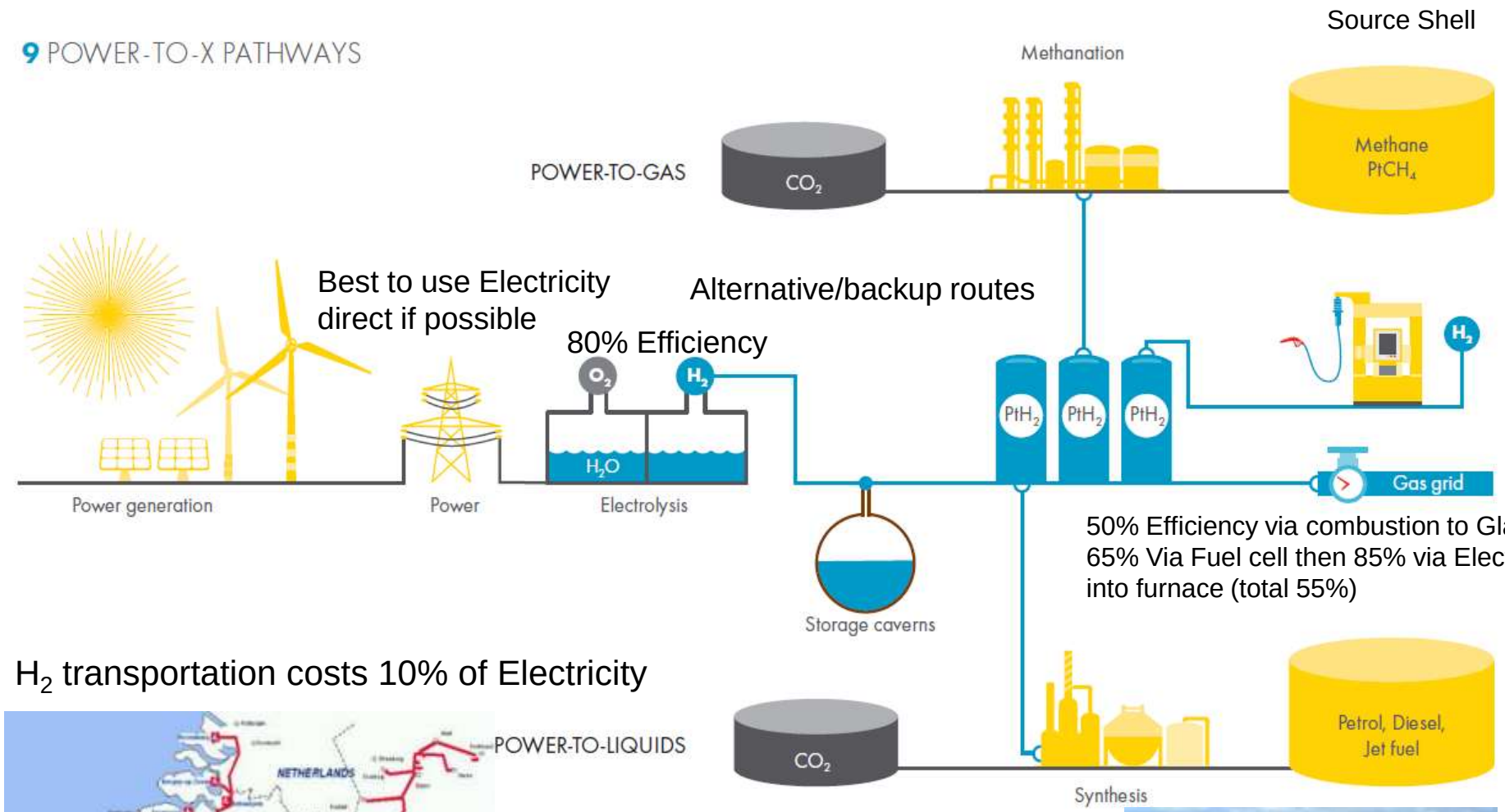


Electrolyzer: 50 kWh/kg H2; H2 Consumption of 1000 Nm3/h; Capital Costs: 1500 EUR/kW

Power to pathways using H_2

Buffering peaks and dips

Source Shell



H_2 transportation costs 10% of Electricity



Existing H_2 gas pipe network 950 km
Source Air Liquide
Or add H_2 into natural gas till 10%

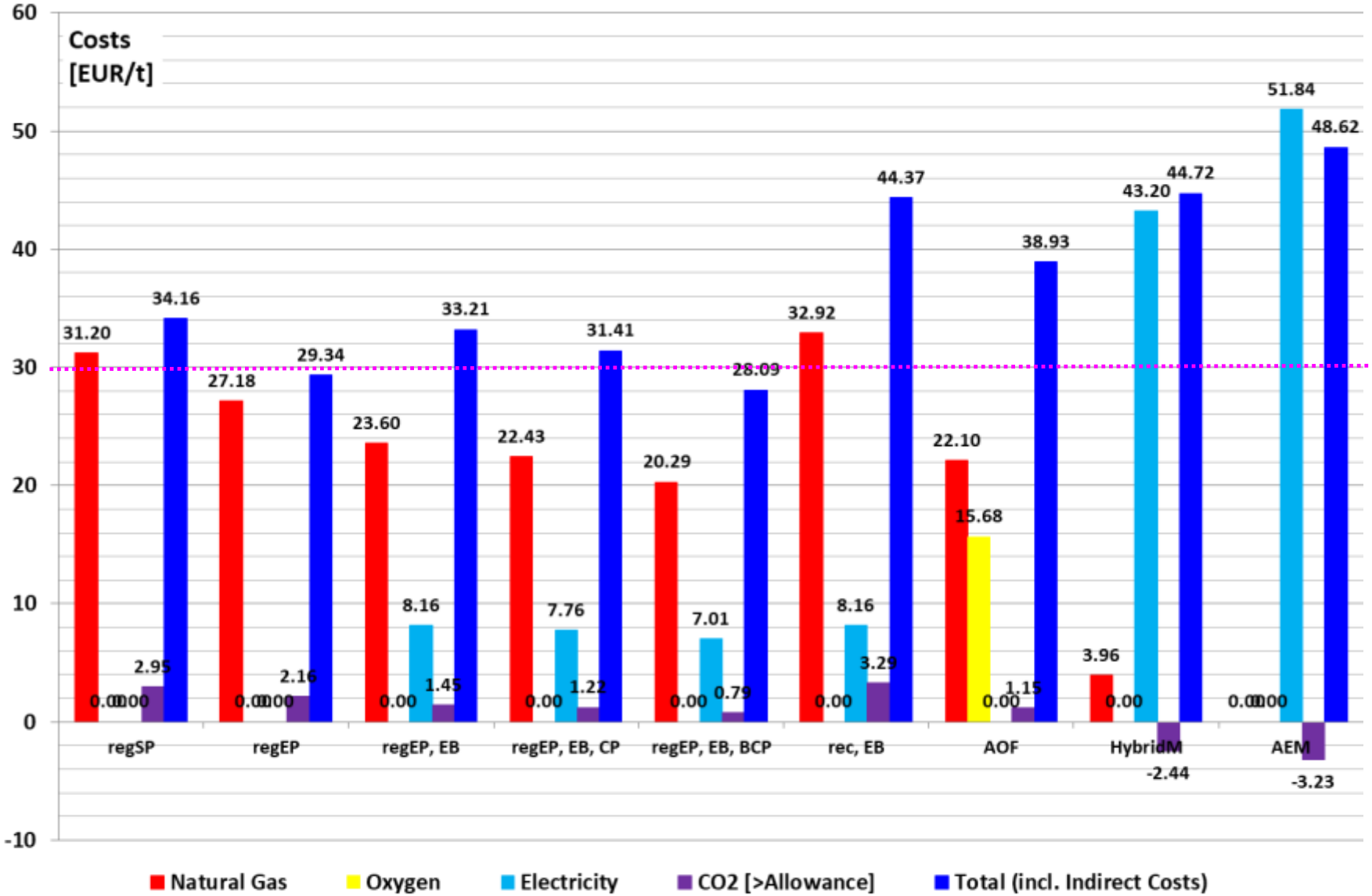


H_2 Ship Transport
Similar to LNG
Electric Engine
H_2 powered

Furnace definition for following financial calculations

- Furnace melting container green glass 300 TPD
- Cullet 50%
- Combustion natural gas (price 0.3 €/Nm^3)
- Electricity sources vary from German energy mix to windmill
- Electricity pricing vary from 4 till 10 € cents per kWh
- CO_2 Emission costs above allowance of 0.2 ton per ton glass vary costs from 25 (present) till 50 and 100 € per ton
- H_2 costs estimate 0.1, 0.2 till 0.4 €/Nm3

Melting Costs #1 Comparison, electricity 0.08 €/kWh



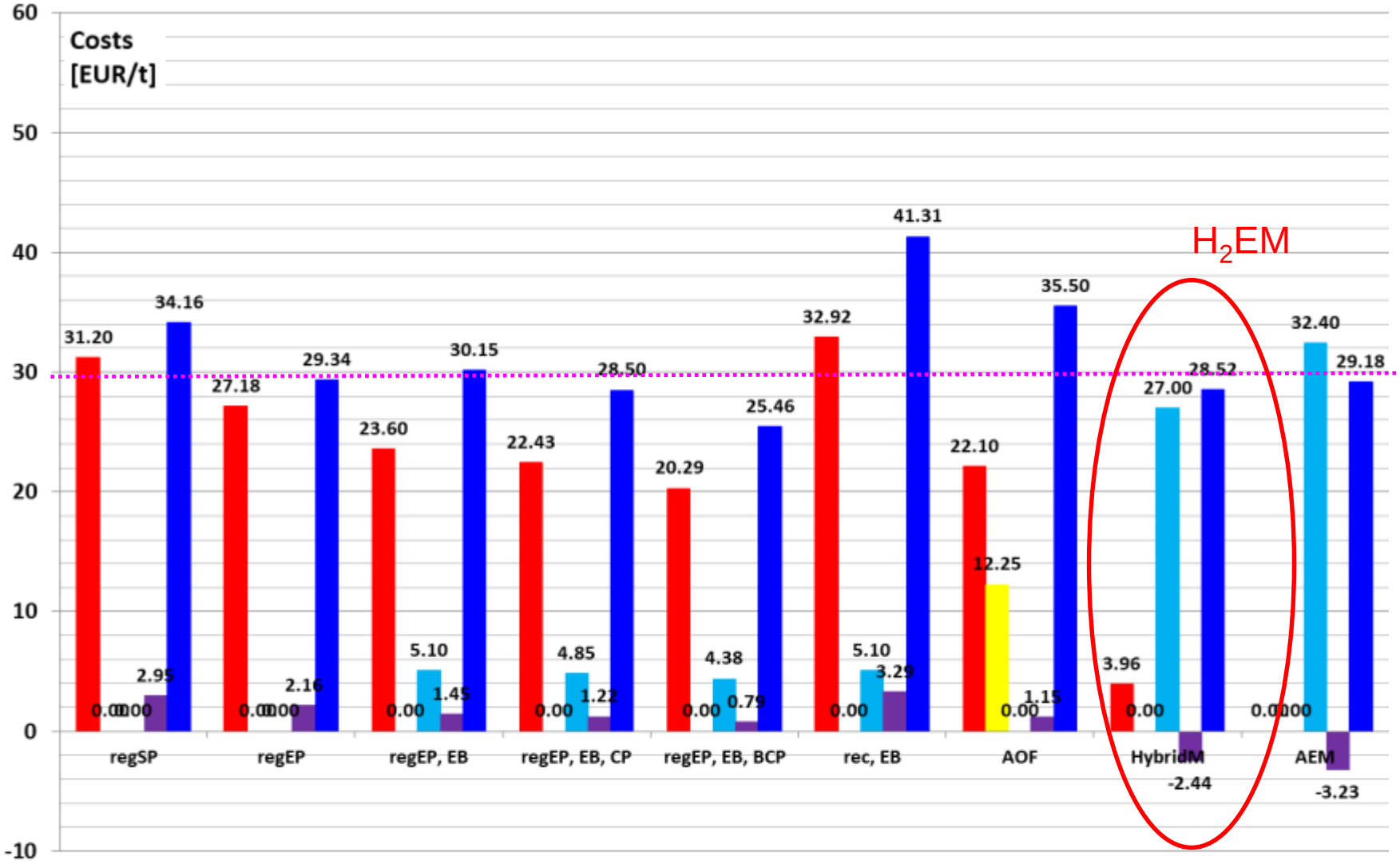
~30 EUR/t

300 TPD
50% cullet

NG Price: 0.25 EUR/Nm3; Electricity Price: 0.08 EUR/kWh; Oxygen Price: 0.084 EUR/Nm3
CO2 Allowance: 0.209 t/t; CO2 Costs (>Allowance): 25 EUR/t

Without Investment costs

Melting Costs #2 Comparison, electricity 0.05 €/kWh



H_2EM

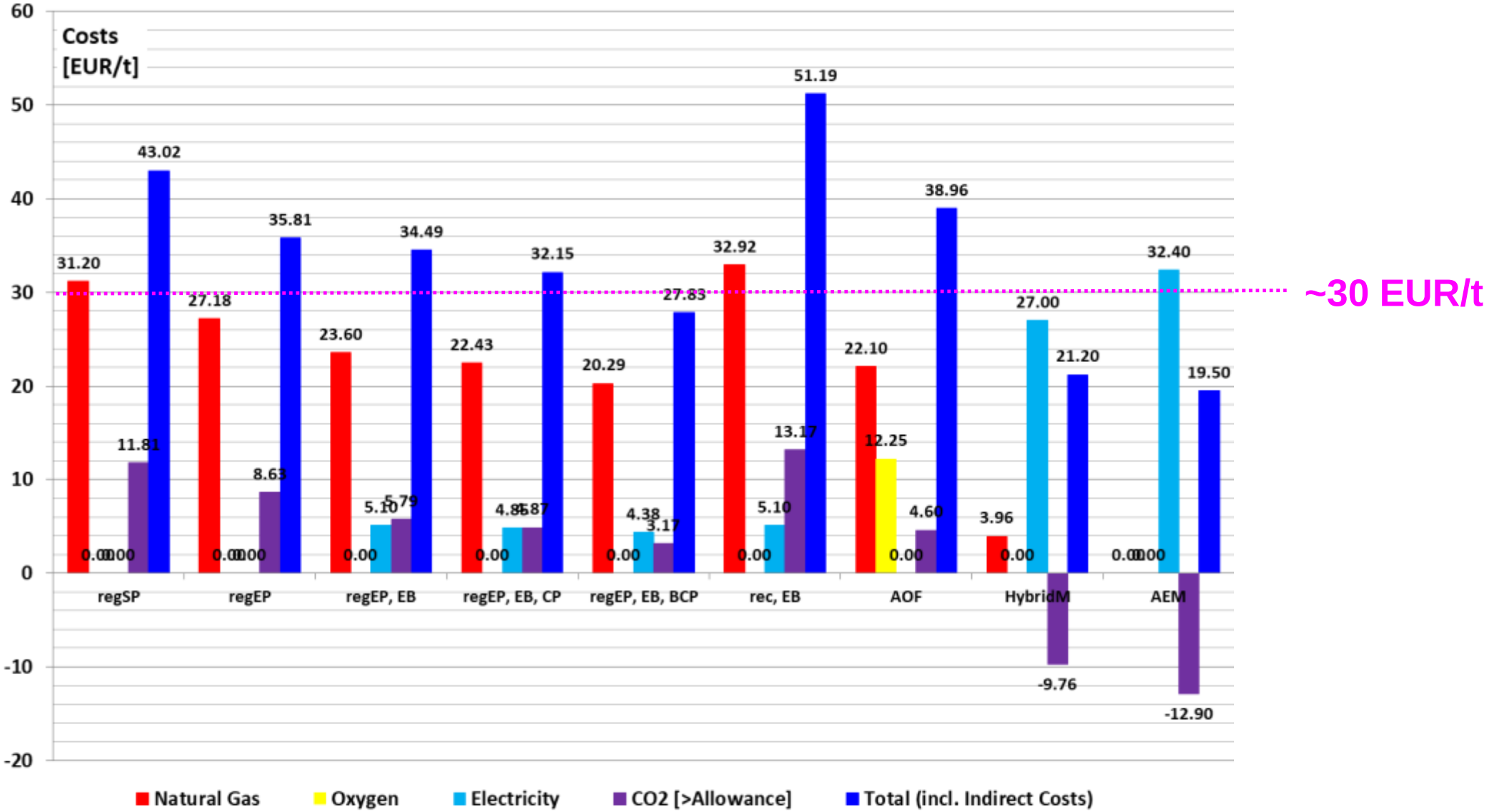
~30 EUR/t

300 TPD
50% cullet

NG Price: 0.25 EUR/Nm3; Electricity Price: 0.05 EUR/kWh; Oxygen Price: 0.066 EUR/Nm3
CO2 Allowance: 0.209 t/t; CO2 Costs (>Allowance): 25 EUR/t

Without Investment costs

Melting Costs #3 Comparison, CO_2 100 EUR/ton

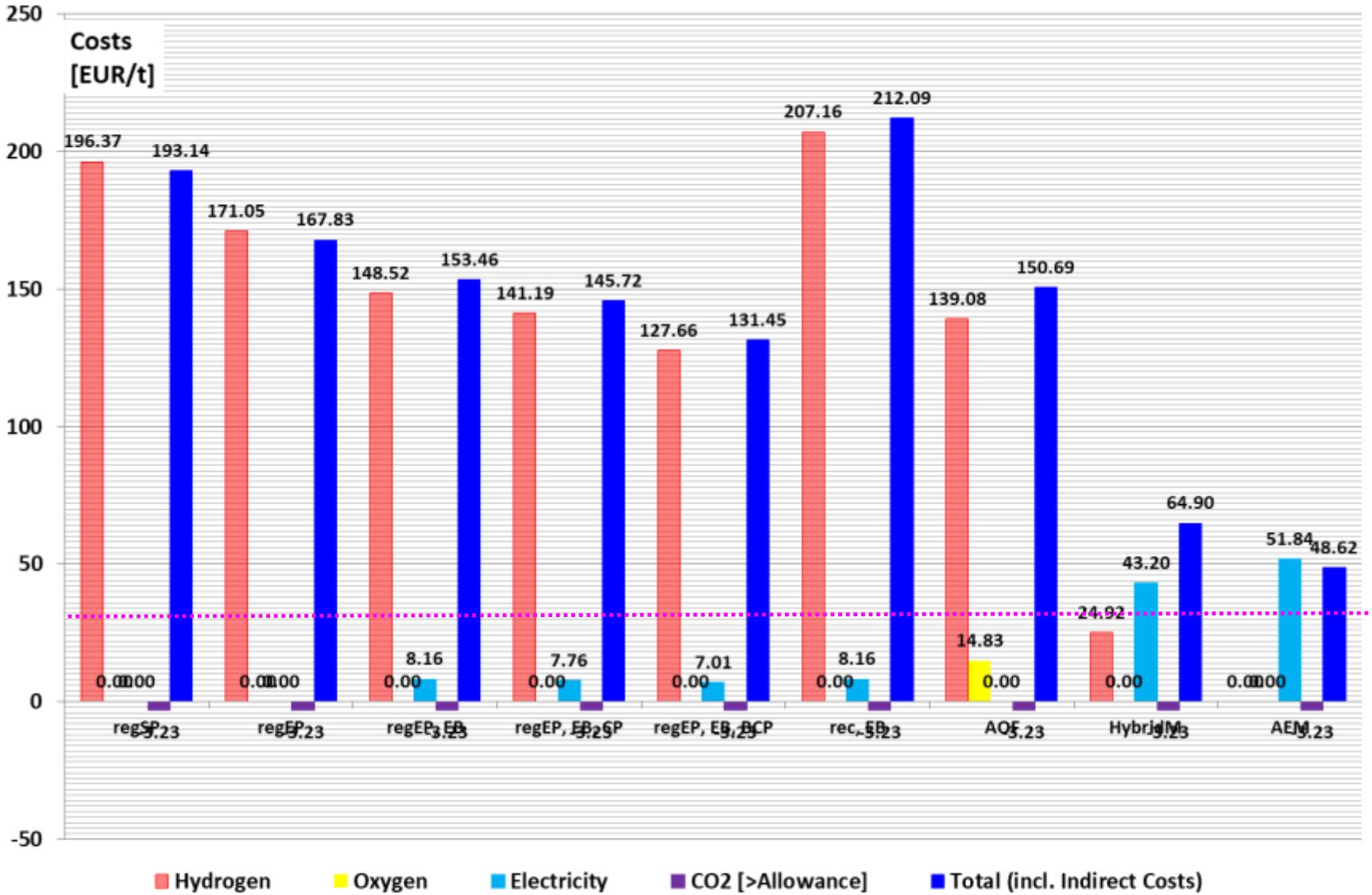


300 TPD
50% cullet

NG Price: 0.25 EUR/Nm3; Electricity Price: 0.05 EUR/kWh; Oxygen Price: 0.066 EUR/Nm3
CO2 Allowance: 0.209 t/t; CO2 Costs (>Allowance): 100 EUR/t

Without Investment costs

Melting Costs #4 Comparison, Hydrogen gas 0.4 EUR/Nm³

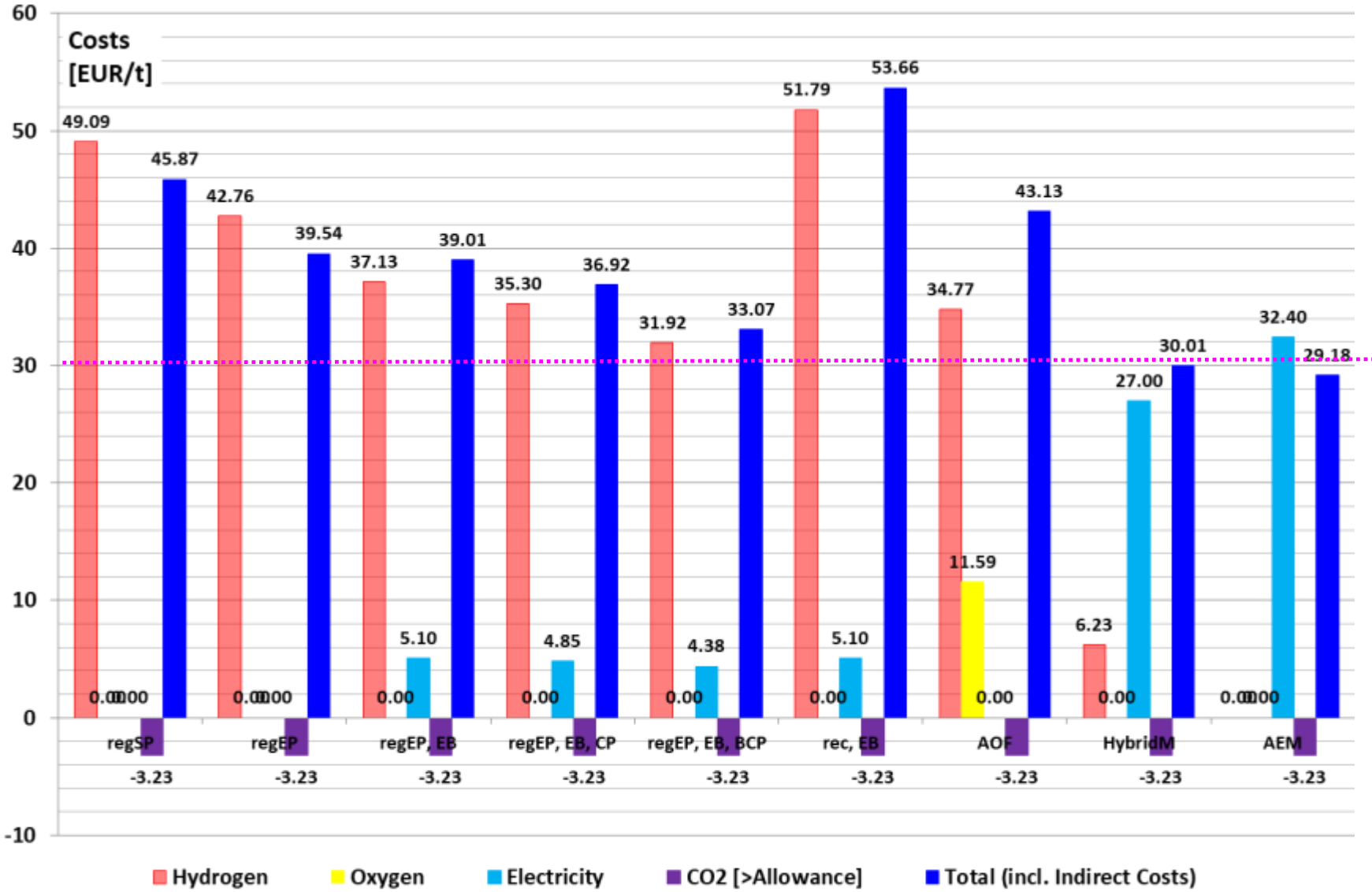


300 TPD
50% cullet

H2 Price: 0.4 EUR/Nm3; Electricity Price: 0.08 EUR/kWh; Oxygen Price: 0.084 EUR/Nm3
CO2 Allowance: 0.209 t/t; CO2 Costs (>Allowance): 25 EUR/t

Without Investment costs

Melting Costs #5 Comparison, Hydrogen gas, 0.1 EUR/Nm³

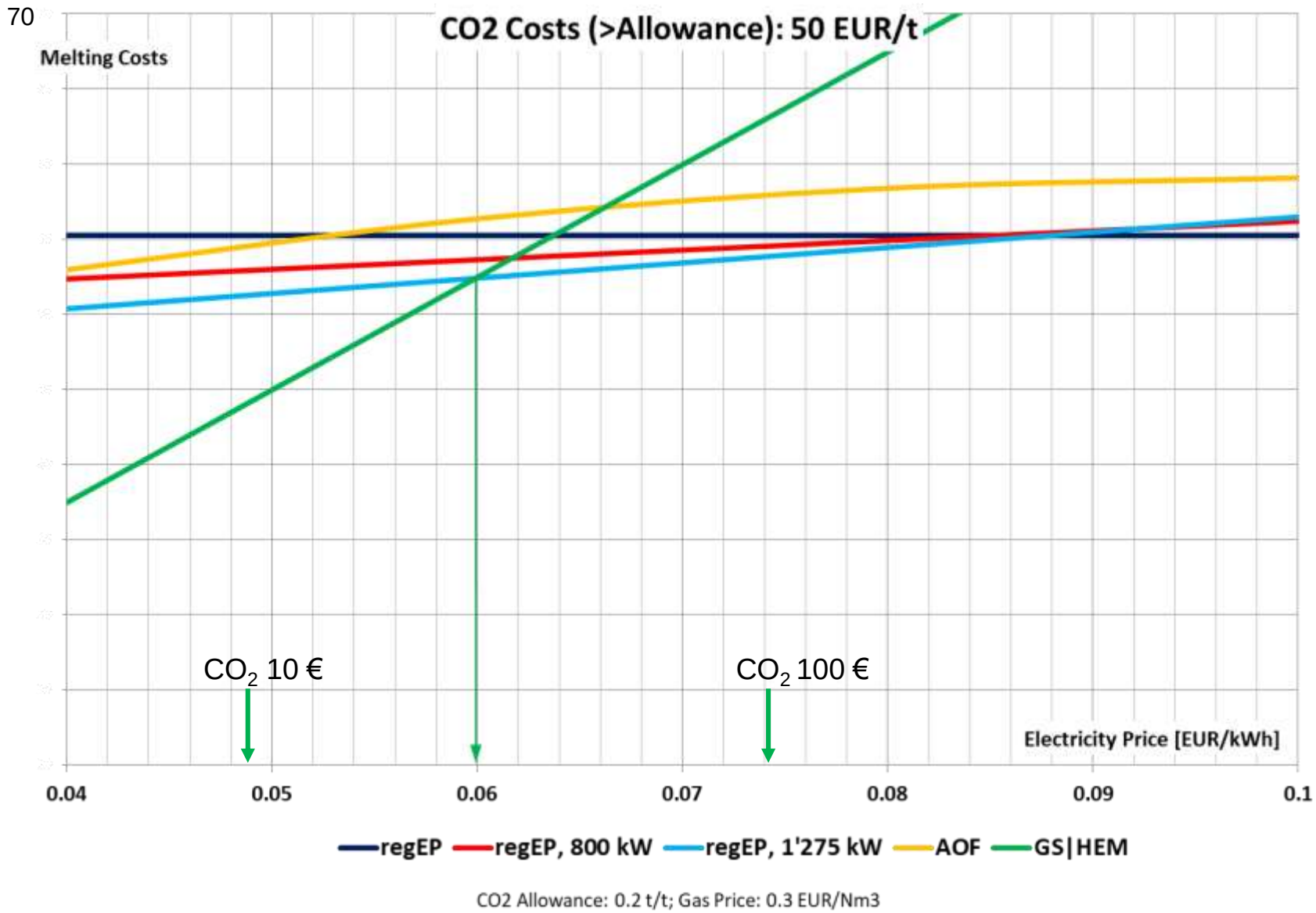


300 TPD
50% cullet

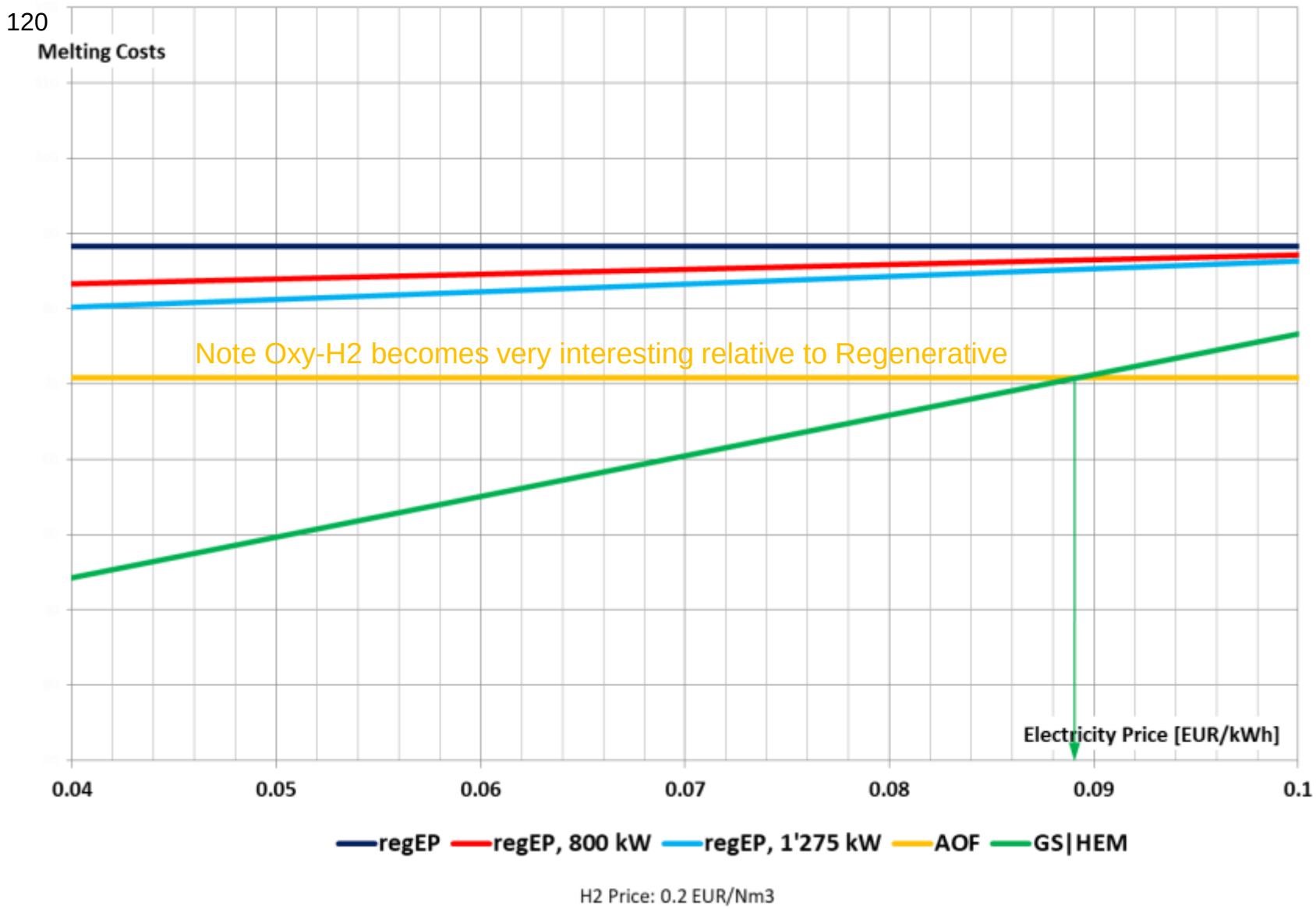
H2 Price: 0.1 EUR/Nm3; Electricity Price: 0.05 EUR/kWh; Oxygen Price: 0.066 EUR/Nm3
CO2 Allowance: 0.209 t/t; CO2 Costs (>Allowance): 25 EUR/t

Without Investment costs

Hybrid breakeven point as function of Electricity price



Hybrid breakeven point as function of Electricity price
Using Hydrogen combustion instead of NG



H2 Price: 0.2 EUR/Nm3

Prof. Stanek (CZ) wrote in 1977 in his book: "Electric Melting of Glass"

- The melting of glass by passage of **electric** current through the melt, becoming an ever more **favored** mode of production, this method has a **high thermal efficiency**, is easy to control, yields homogeneous glass possessing the required properties and also economizes raw materials that **volatilize** readily and are therefore economically attractive.

Sometimes a new player opens the market

- The construction of electric melting furnaces is **simpler** than that of the hitherto exclusively used flame-fired furnaces and as a consequence **less expensive** to build. A greater amount of glass is produced by unit volume.
- Only he expected growing NUCLEAR power to bring down electricity pricing….

1st electric glass melting in 1905

- The first furnace in which 300 kW electric current passed from (unsuitable) graphite electrodes to produce windows glass was a Sauvageon's design
- First successful furnaces producing 30 TPD green and amber bottles was designed by

  E. Cornelius in Kungelo (Sweden) 1925

  Using pure Iron blocks C< 0.03%
- Specific energy consumption

  was 0.73 kWh/kg
- But iron electrodes

  limited in glass colours and life

  Lifetime was 17 months

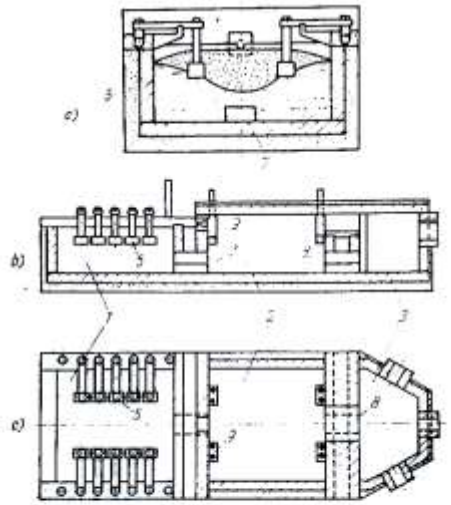
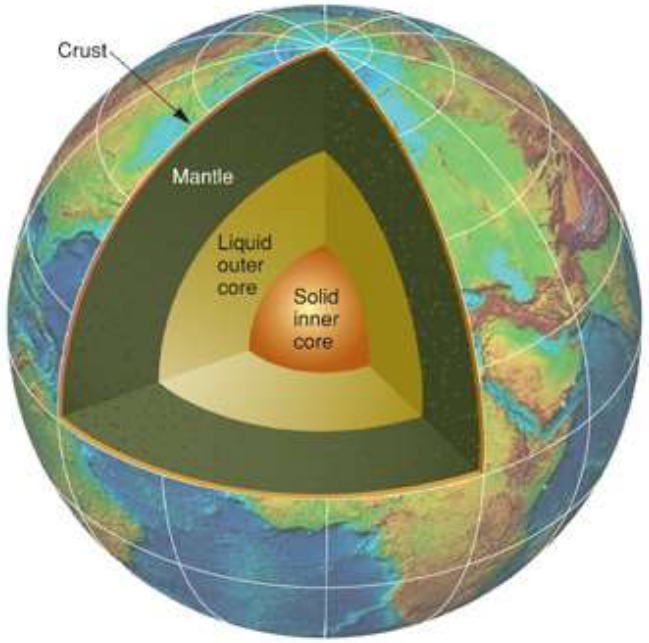
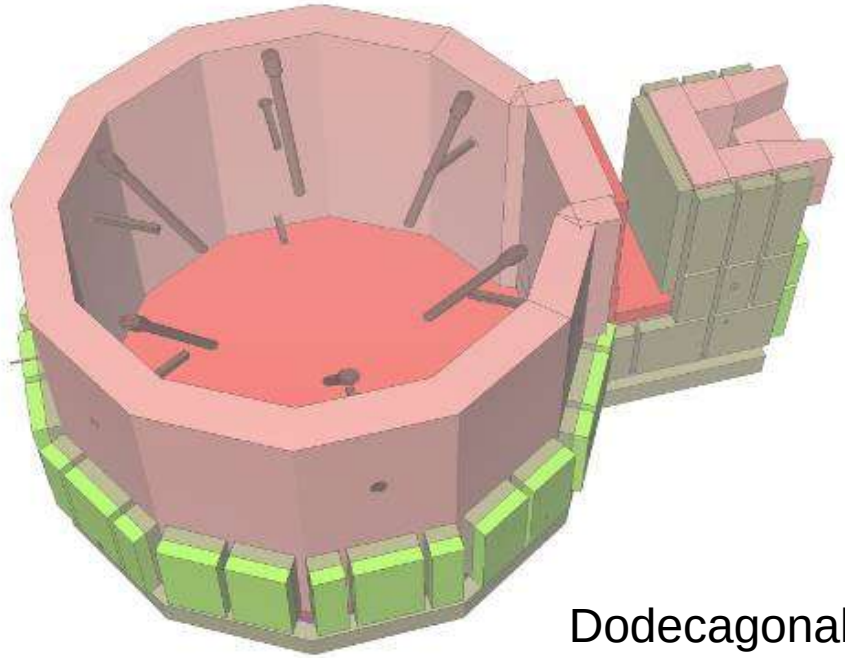


FIG. 4.3 Three-zone Cornelius furnace melting container glass
a) transverse section; b) longitudinal section; c) plan;
1 — Melting chamber; 2 — Refining chamber, 3 — Working chamber; 4 — Batch; 5 — Electrodes in melting chamber; 6 — Electrode holders; 7 — Throat linking the melting and the refining chambers; 8 — Throat linking the refining and the working chambers; 9 — Electrodes in the refining chamber

Why most All-Electric melters are Hexa or Polygonal?

- Simply the main heat loss of an (cold) electric melter is the sidewalls. There is no crown and the bottom surface can be well insulated.
- An All-Electric melting furnace is more a volume melter than a surface melter
- The most thermal efficient melter would be a sphere, but that is difficult to build, so hexagonal or polygonal is a close approach.
- Round or Hexagonal furnaces makes sense for small melters < 80 TPD

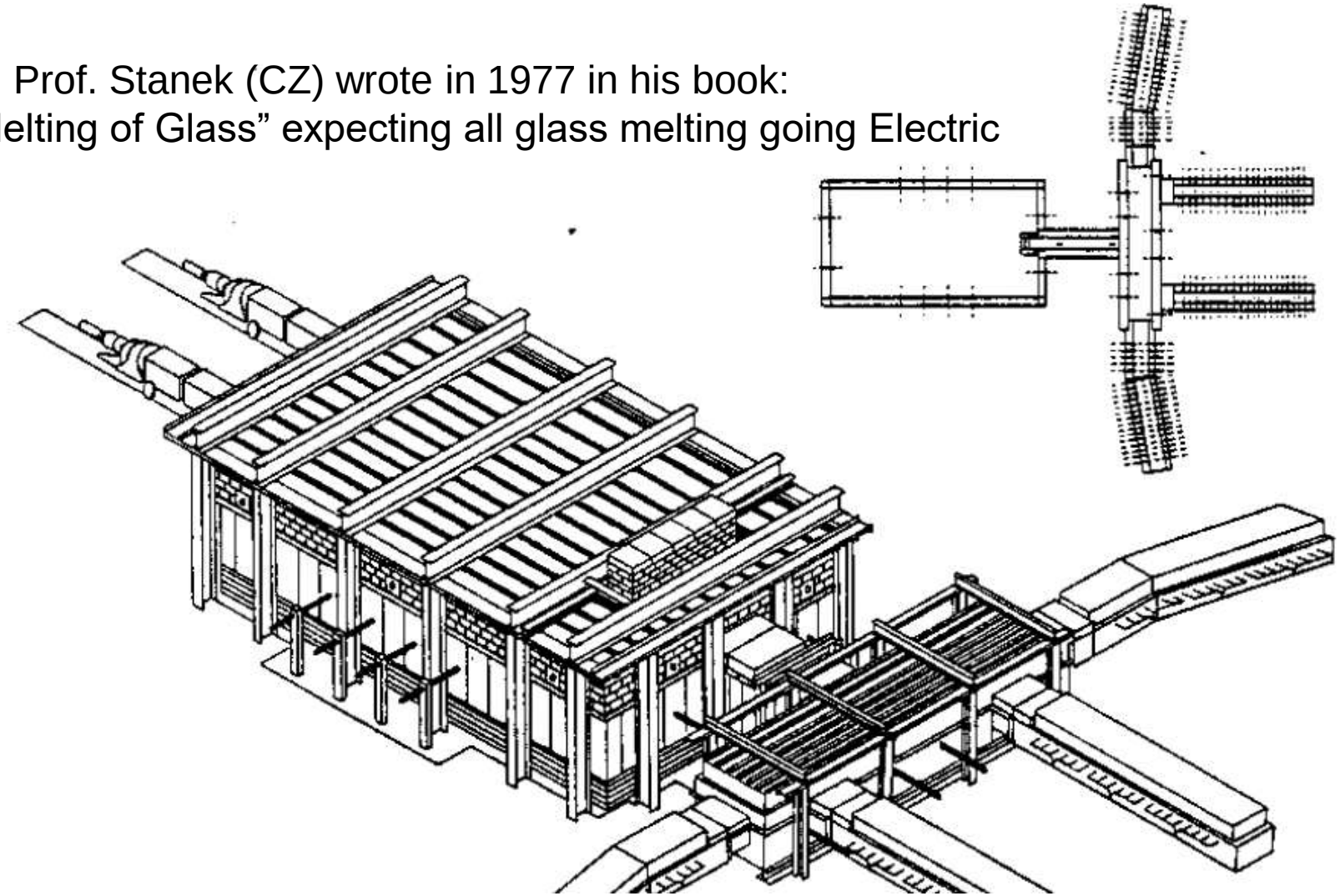




Dodecagonal

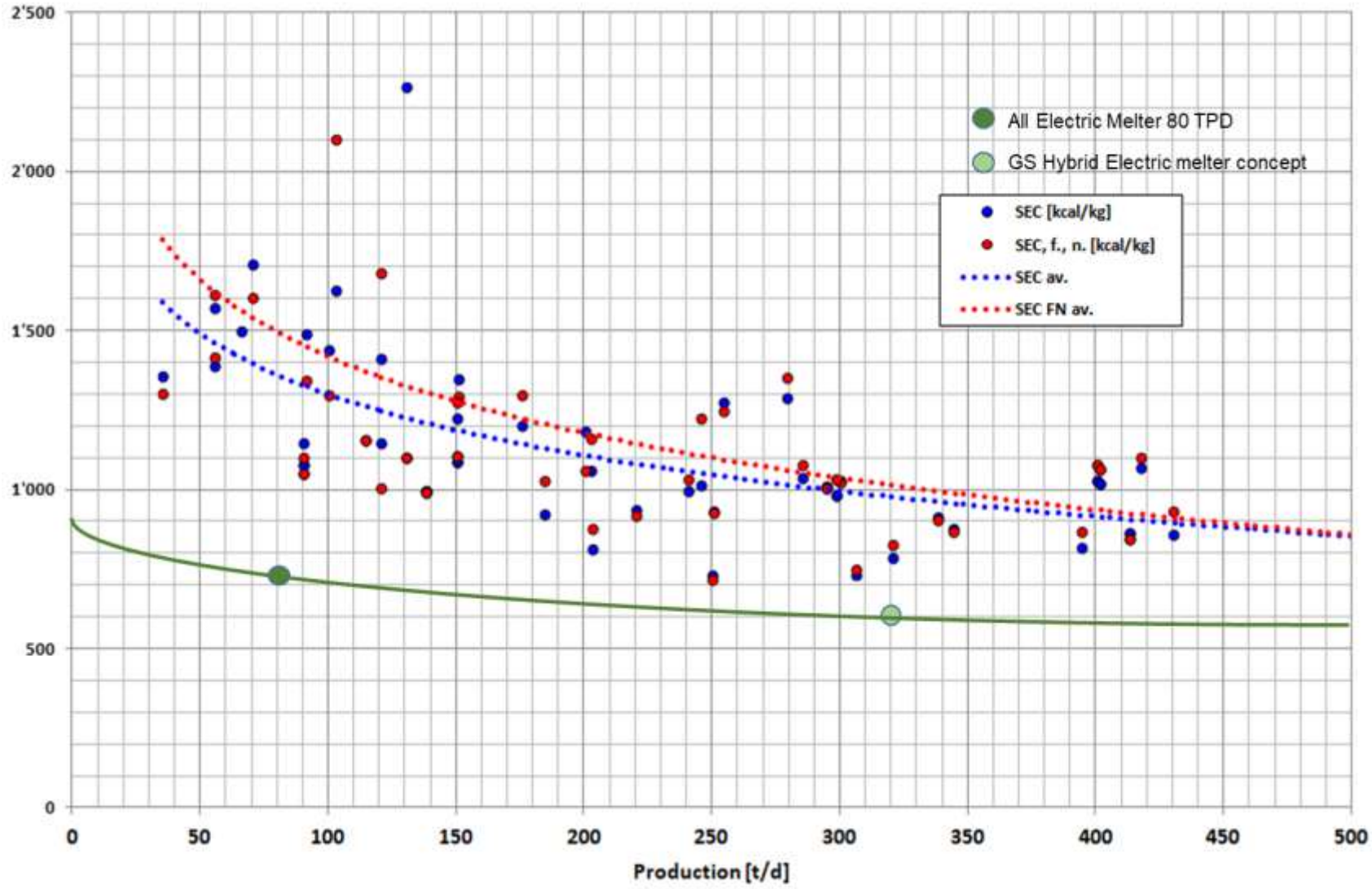
20 Continuous All electric Horizontal Melter for container glass at 140 TPD operated in USA around 1980

Prof. Stanek (CZ) wrote in 1977 in his book:
“Electric Melting of Glass” expecting all glass melting going Electric



There were more than 20 (warm top) Electric melters in the USA after the 1970s oil crisis
First electric glass melting is from 1905 at 0.73 kWh/kg

Electric melting has ±double thermal efficiency compared to fossil fuel typical 85% vs 45%



Advantages of All Electric melting versus fossil

- No emissions & no dust, so no filter investment and no costs for cleaning (no NO_x, SO_x, low CO_2)
- No chimney, no complaints from neighbors
- Lower investment, small furnace volume (up to 4 tpd/m^2) and no or simple crown and no regenerator or flue gas channels
- Less maintenance on cleaning of regenerators etc.
- No or minimum volatilization (lower raw materials costs)
- Smaller repair costs, and shorter furnace repair time
- Efficiency depends less on furnace size and capacity

Disadvantages of electric melting versus fossil

- Less pull flexibility for cold top
- Shorter furnace lifetime (proven till 8 years for smaller furnaces 50 till 80 TPD)
- Less experience of operators
- Depending on electric availability (net stability)
- Proven melting only with up to 55% cullet
- Limited experience with producing reduced colored container glass (=> Hybrid)

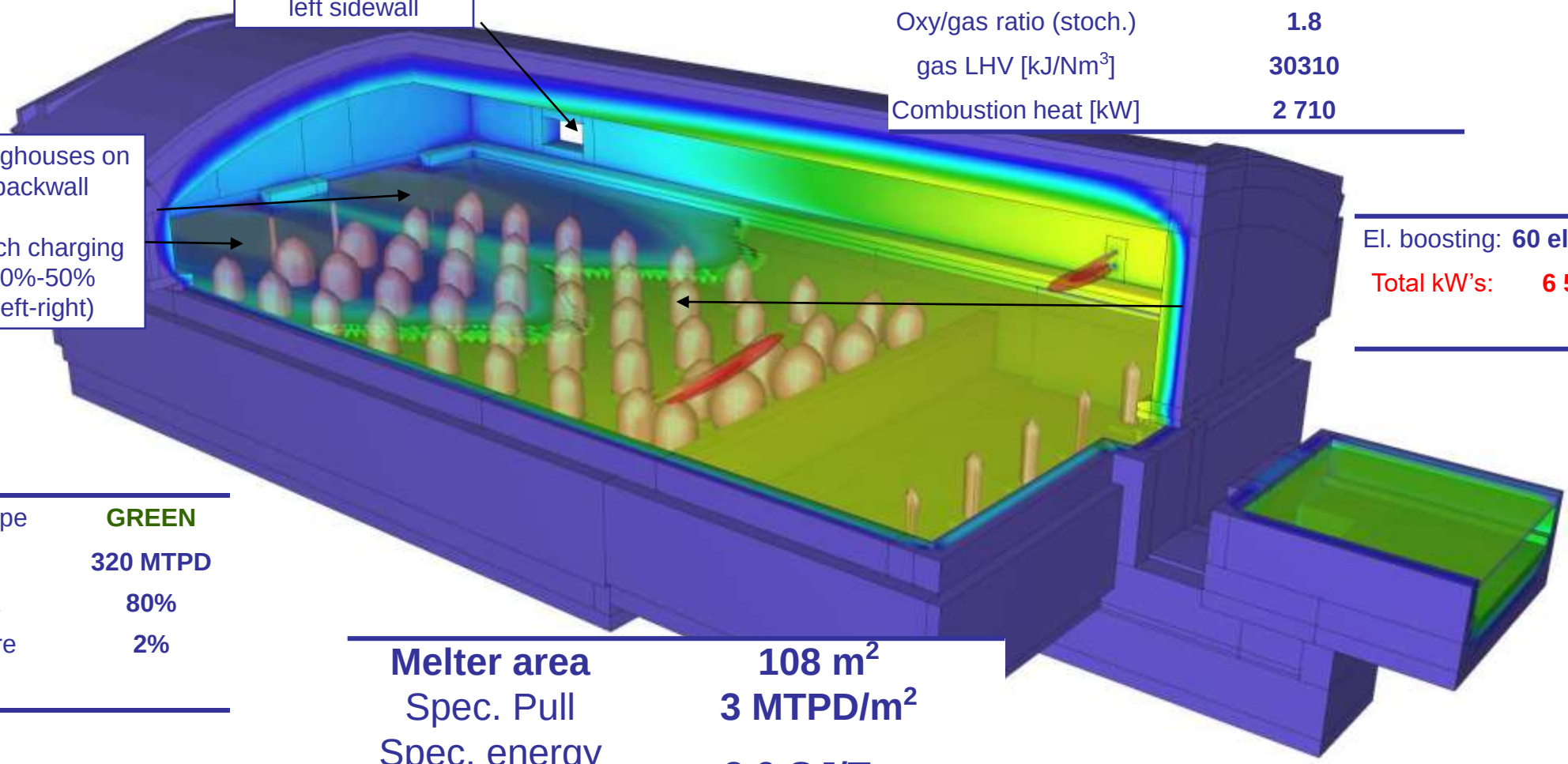
Horizontal Hybrid Electric Melter – GS|H²EM CH_4

Total gas [Nm^3/h]	**314 (157 on the each side)**
Total oxygen [Nm^3/h]	**565**
Oxy/gas ratio (stoch.)	**1.8**
gas LHV [kJ/Nm^3]	**30310**
Combustion heat [kW]	**2 710**

1 exhaust of **0.5 m²** left sidewall

2 doghouses on backwall

Batch charging 50%-50% (left-right)



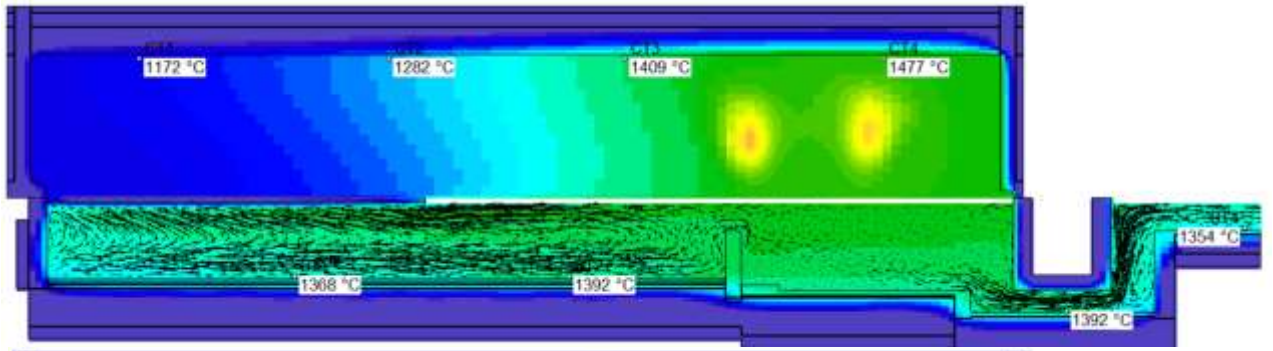
El. boosting: **60 electrodes**

Total kW's: **6 560kW**

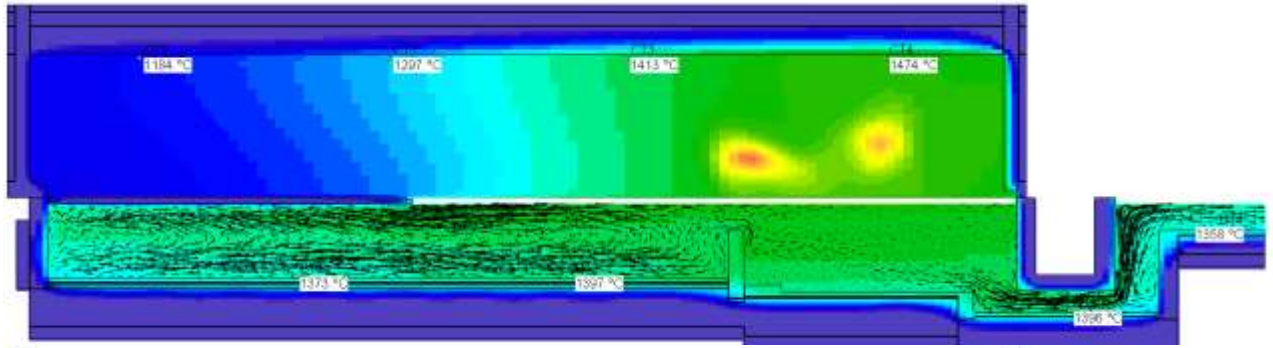
Glass type	**GREEN**
Pull	**320 MTPD**
Cullet	**80%**
Moisture	**2%**

Melter area	**108 m²**
Spec. Pull	**3 MTPD/m²**
Spec. energy consumption	**2.6 GJ/Ton**

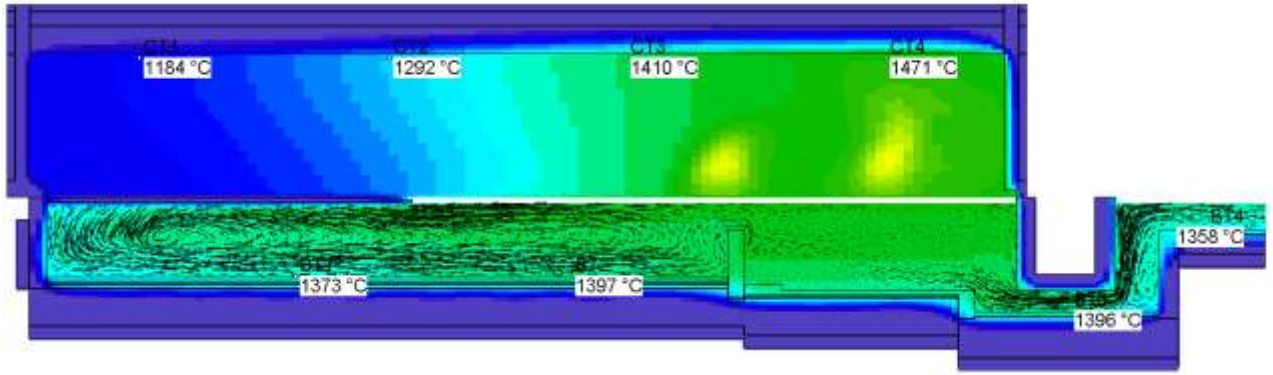
Comparison - Central Cut
Natural gas firing versus Hydrogen firing



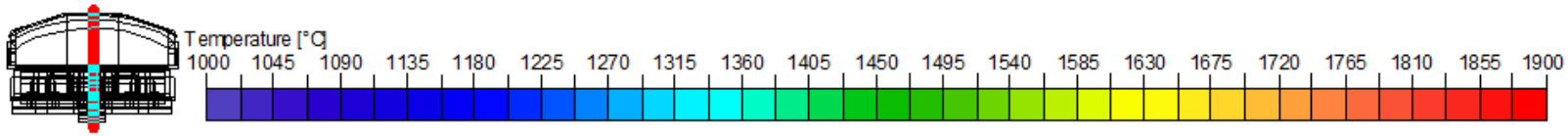
Case_CH_4



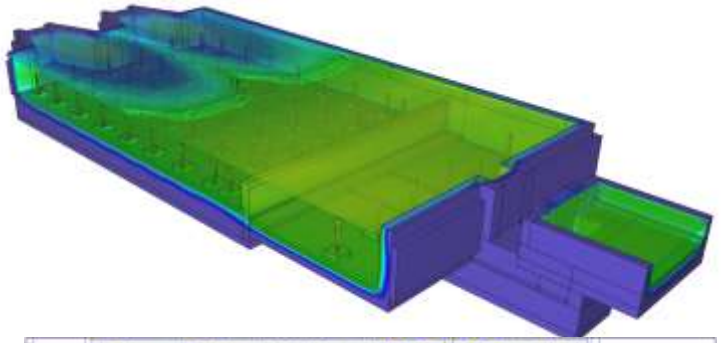
Case2_H_2

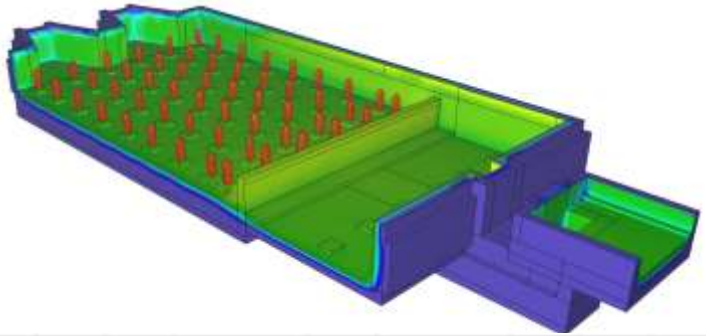


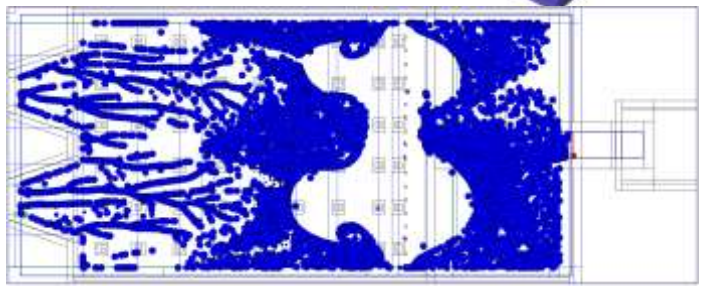
Case2_H_2
Adapter burner

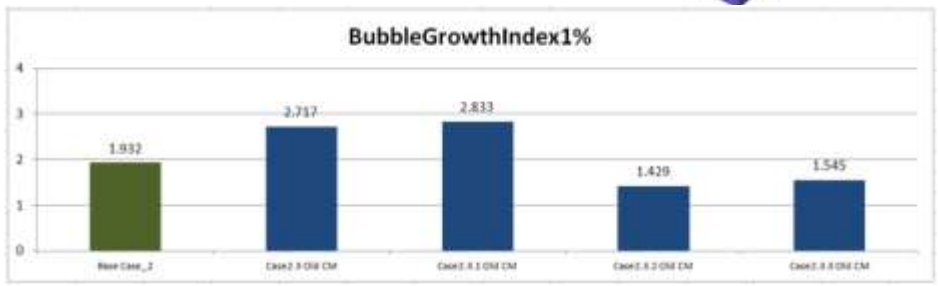


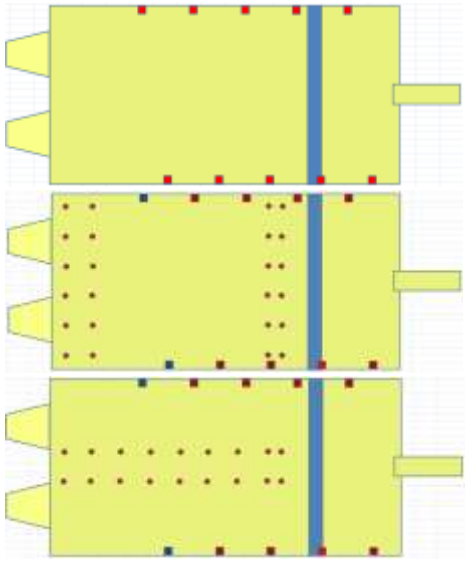
Optimizing electric heating configurations with CFD

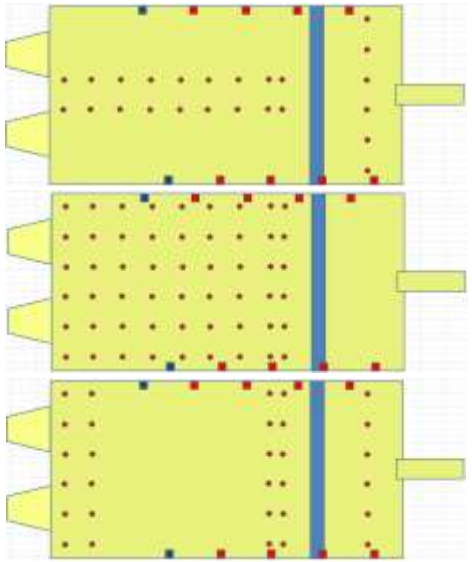


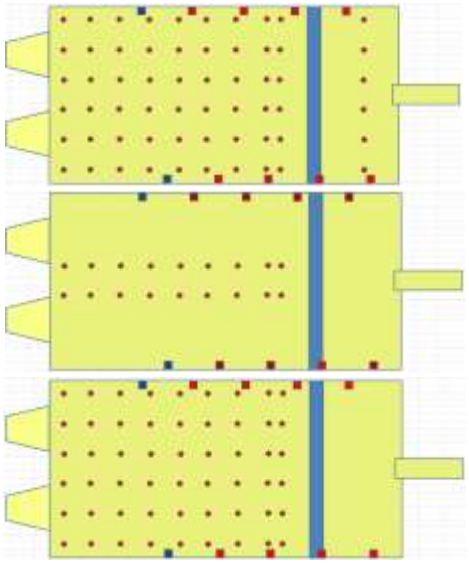




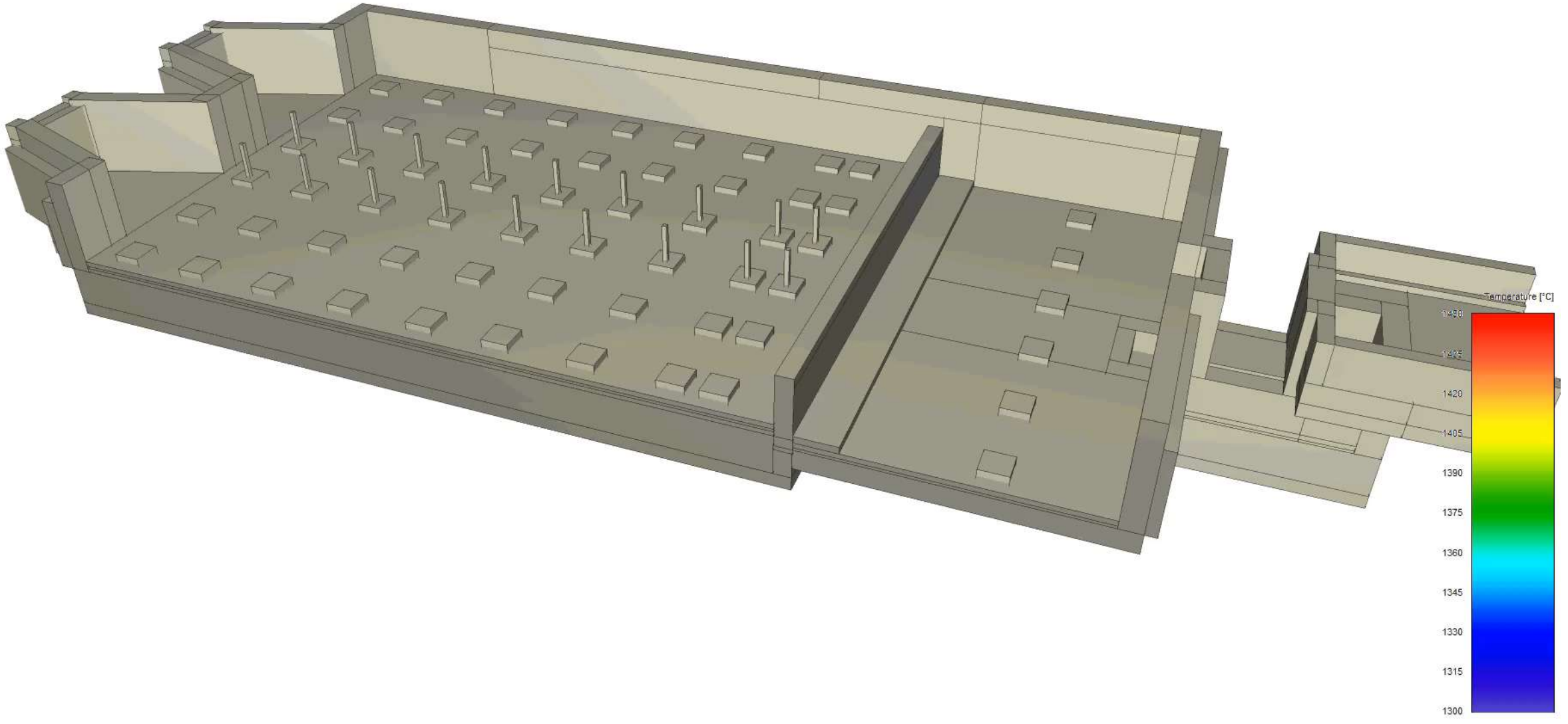




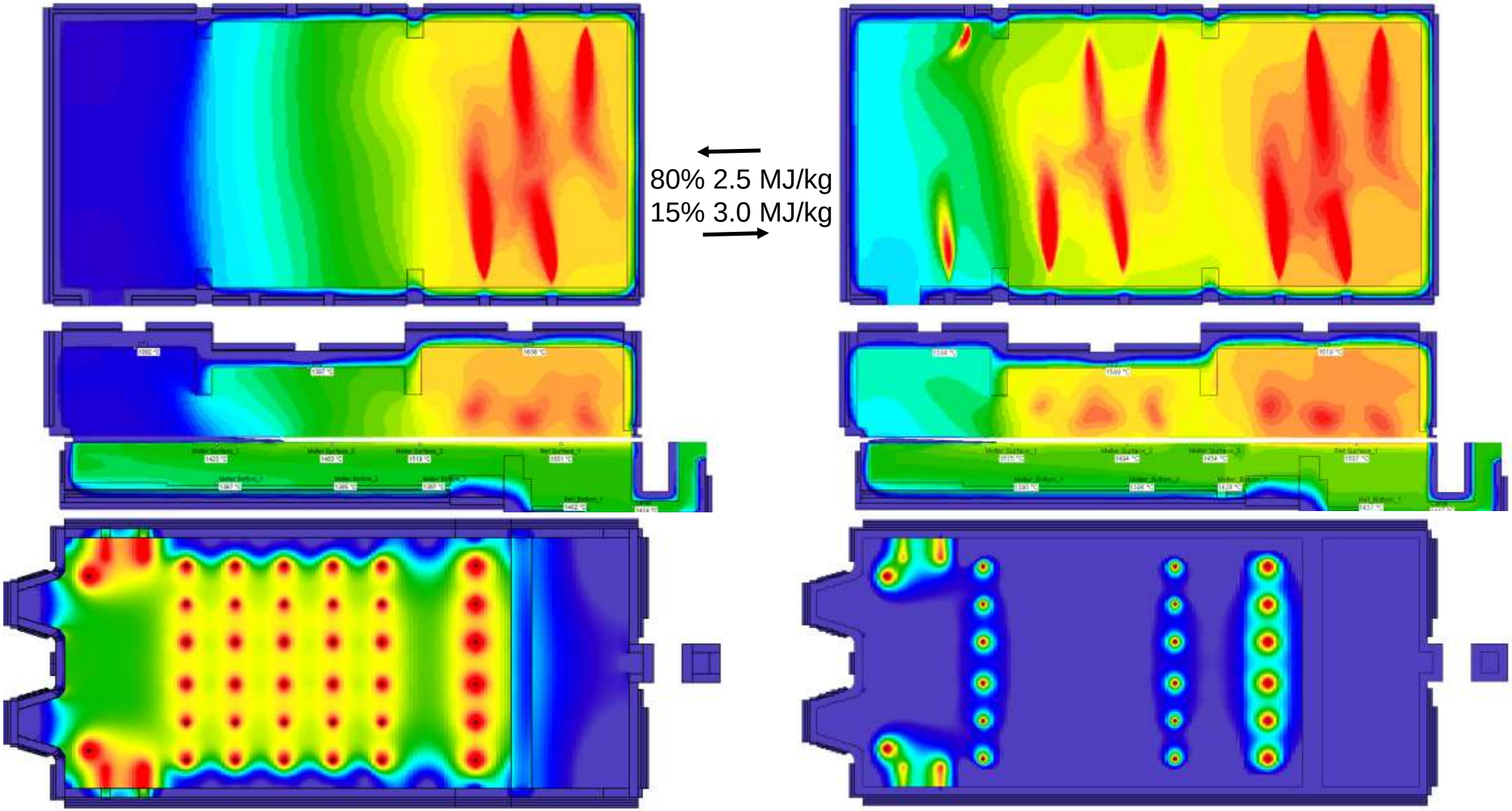




Checking best quality via quality tracers
Center Electrodes showing good mixing and optimal “space utilization”



More details worked out 350 tpd H²EM concept working in 80% Electric Mode (L) and 15% Electric Mode (R)



GS *Expert System III* MPC control autmomatic furnace following electricity price variation or availability

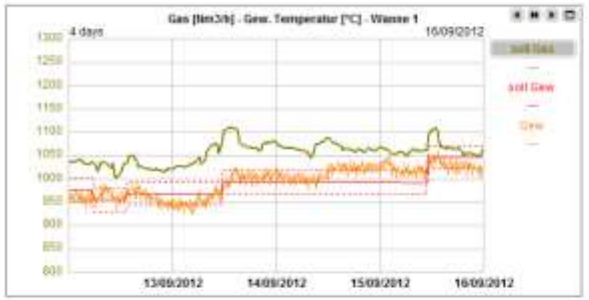
ESIII^{TM} Energy Management System controls the total electric energy consumption of the entire plant within preset limits by varying the electric boosting to both furnaces depending on the actual electric energy demand in the rest of the plant (e.g. compressors on/off, machines, offices, lighting, etc.). During the day the plant energy demand is higher and thus the electric boosting is reduced, and compensated by gas firing to maintain the glass bottom temperatures at the desired setpoint. Electric boosting energy supply can also be transferred from one furnace to the other, depending on actual need (e.g. furnace pull).

Fluctuations in gas heat value can be compensated by rapid corrections in gas setpoint, if CV-meter is installed.

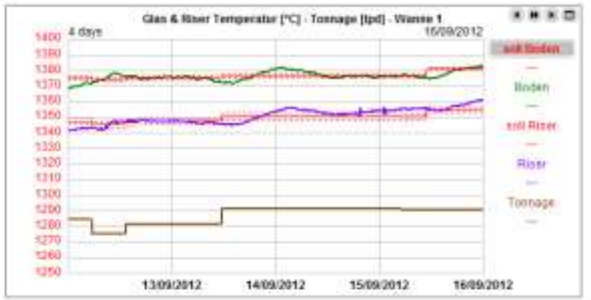


Plant Electric Energy

Electric Boosting F#1 & F#2

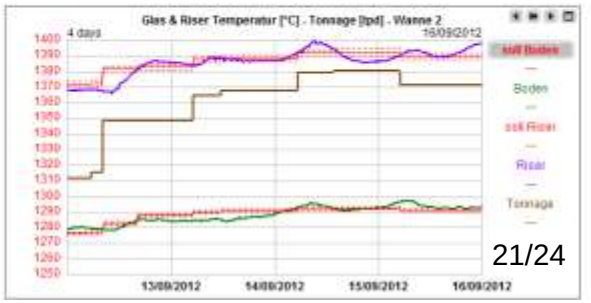












ESIII™ Specific Energy Cost Optimization and Automatic Evaluation Calculation

Specific Energy

Sample 1 - Base sample. Historic period of manual furnace control (From - To)
Sample 2 - Historic period of ESIII furnace control (From - To)
Sample 3 - Recent period of ESIII furnace control (Last x days)

Select time samples		
Sample 1	16.09.2018	15.11.2018
Sample 2	15.11.2018	24.12.2018
Sample 3	100	

Aging compesation		
On	*Nominal Date*	*Aging Coef.*
	01.03.2018	1.00%

Cullet compensation		
On	*Nominal Cullet*	*Cullet Coef.*
	50%	0.25%

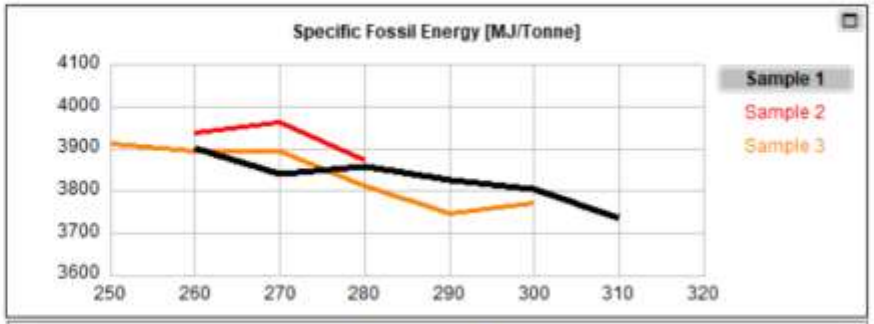
Energy Prices [EUR/ ...	
Electricity	0.09120
Gas	0.02681

Update now.

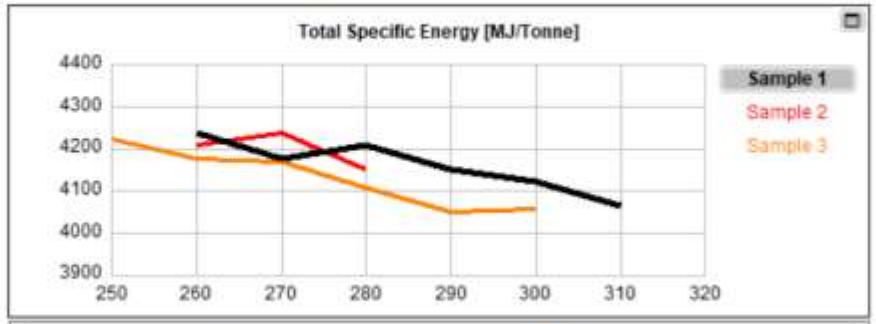
-3.8%

Approximate cost savings for comparable tonnages

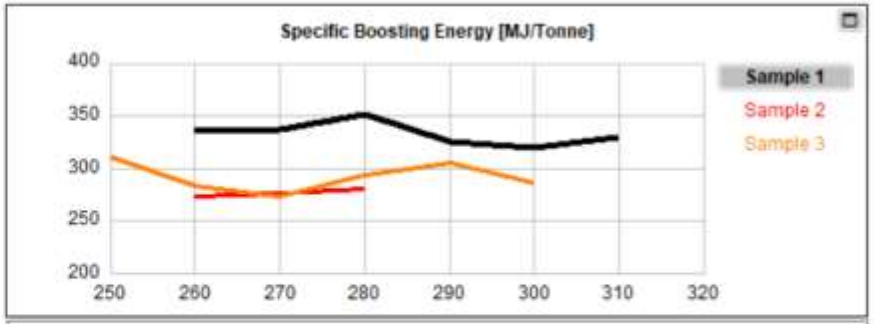
Calculated from comparison of Sample 3 to Sample 1



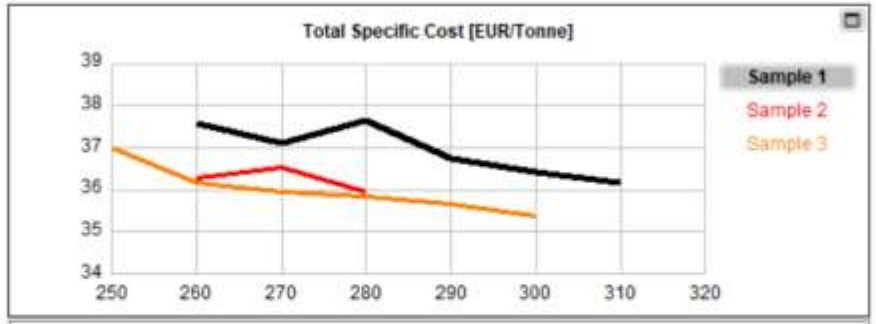
Specific Fuel Energy in comparison to Sample 1 [%]								
Pull group	250	260	270	280	290	300	310	320
Sample 2	---	0.8	3.2	0.3	---	---	---	---
Sample 3	---	-0.2	1.5	-1.2	-2.1	-0.9	---	---



Total Specific Energy in comparison to Sample 1 [%]								
Pull group	250	260	270	280	290	300	310	320
Sample 2	---	-0.7	1.5	-1.4	---	---	---	---
Sample 3	---	-1.5	-0.2	-2.5	-2.4	-1.6	---	---



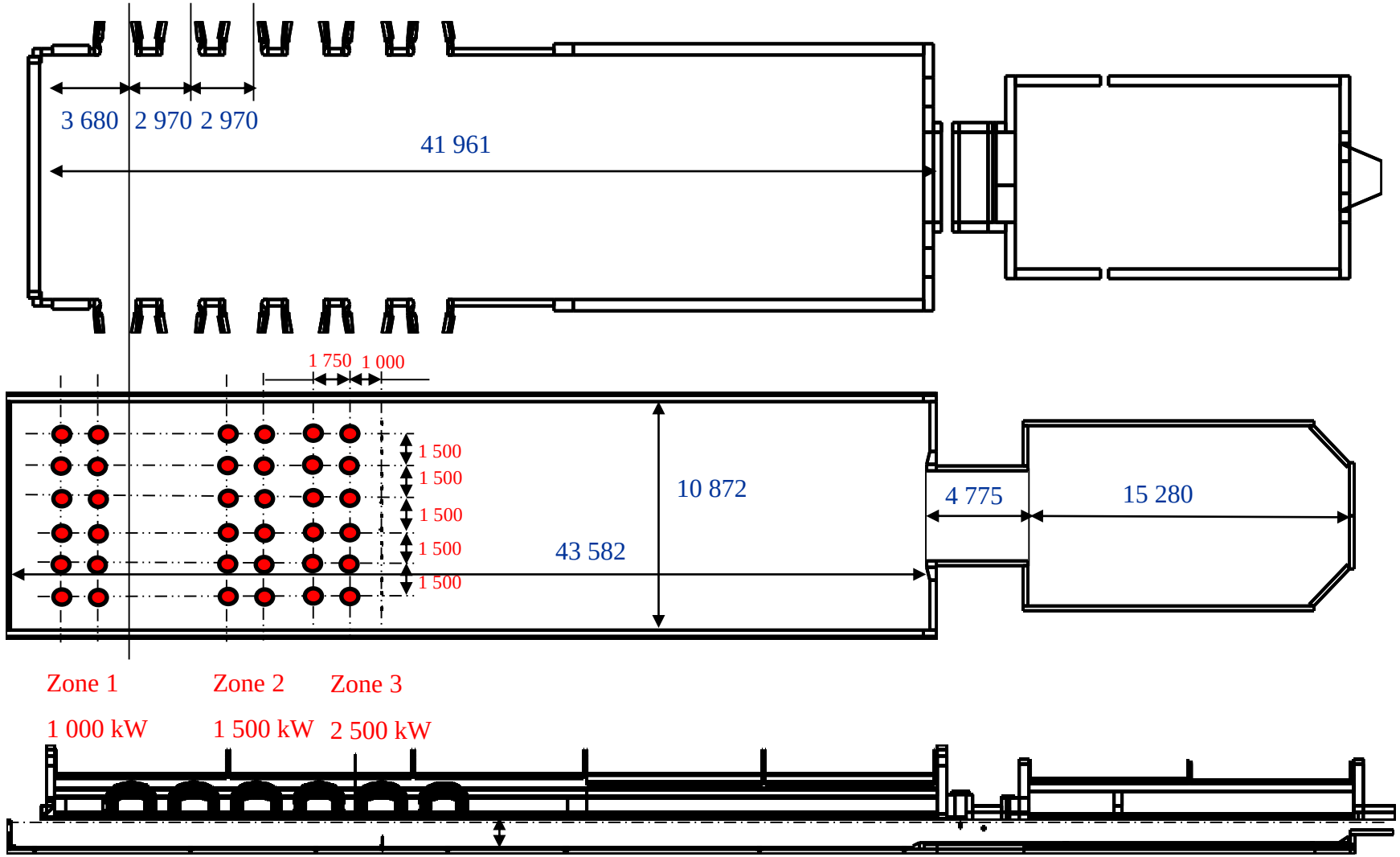
Specific Boosting Energy in comparison to Sample 1 [%]								
Pull Group	250	260	270	280	290	300	310	320
Sample 2	---	-18.4	-17.6	-20.2	---	---	---	---
Sample 3	---	-15.6	-18.8	-16.6	-6.1	-10.3	---	---



Total Specific Cost per Ton in comparison to Sample 1 [%]								
Pull group	250	260	270	280	290	300	310	320
Sample 2	---	-3.5	-1.6	-4.5	---	---	---	---
Sample 3	---	-3.7	-3.2	-4.9	-3.0	-3.0	---	---

The Expert System Department devised procedures for calculating specific energy cost within automated task.

Example Hybrid (super boost) Float

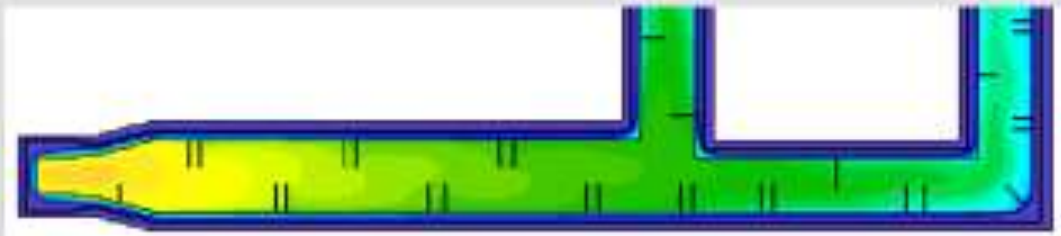


Forehearth conversion from Gas firing to Electric can reduce fuel consumption 60-80% (example from JM)

Front End (Channel/forehearth) CO_2 emissions

Front end (working end, channel, forehearth …) energy use can be a significant percentage of melter energy for some operations. Non-preheated air/NG combustion is typical.

- Oxygen/NG firing can reduce NG usage and CO_2 emissions by 60+% if do not account for oxygen generation electricity emissions
- Electric forehearths can eliminate CO_2 emissions and provide more uniform heating in bulk glass (if not account for electricity generation)





in 1

project to develop system and install 2003-5. Installations have proven 60+% decrease in NG usage and related CO2 emissions

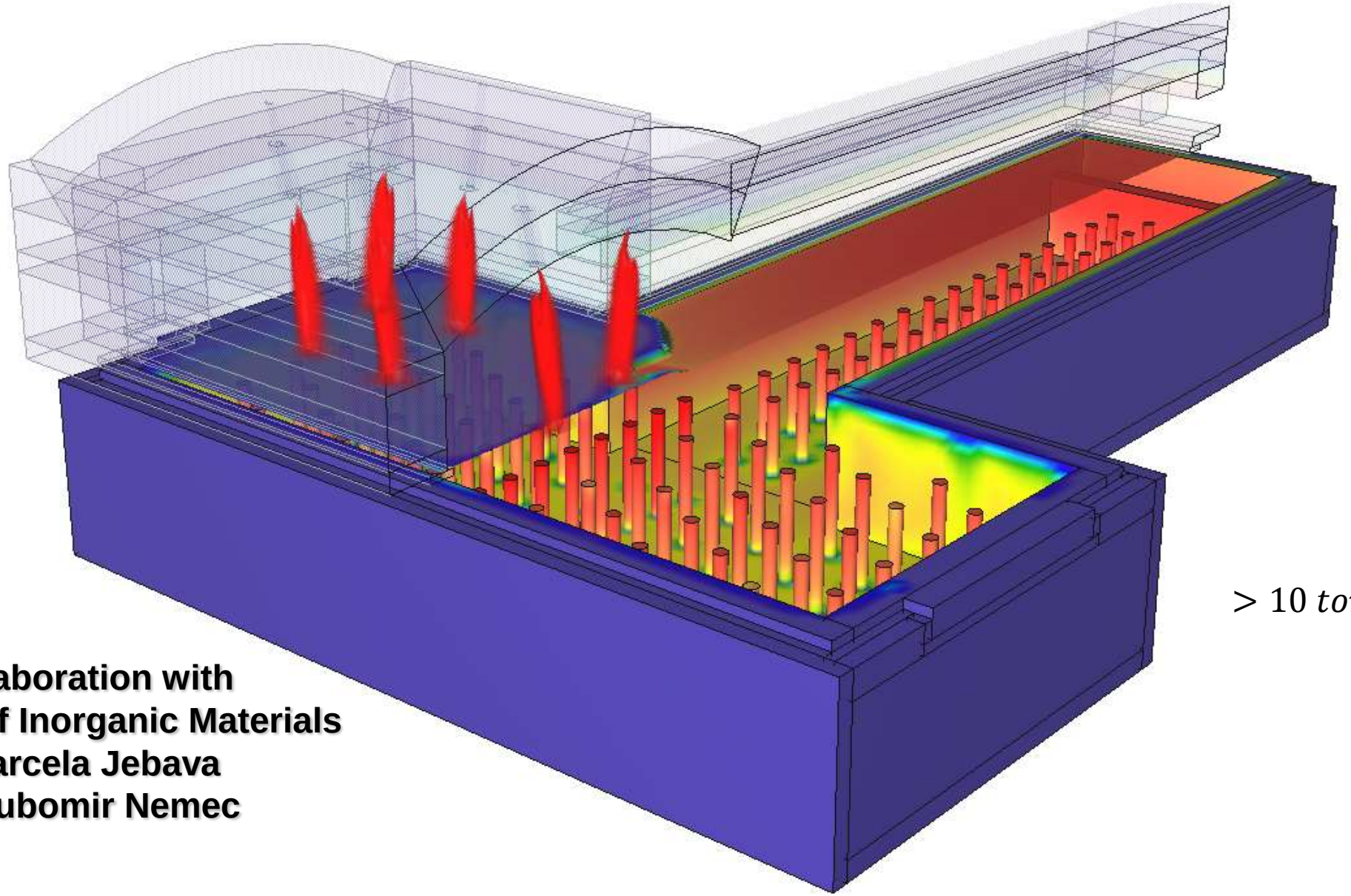
Johns Manville

John Manville
Aaron Huber
Presented on
GS Seminar 2019

Recommendations & conclusions
Steps to reduce your CO_2

1. Improve furnace efficiency by cullet increase, batch& cullet preheat, furnace design, combustion system (eg Oxy-fuel, Optimelt or Heat-Oxy) or regenerator sizing
2. Install more electric boosting (depending on electricity price and source)
3. Install MPC to balance fluctuating dynamic energy prices and availability
4. Install Super boosting or convert to Horizontal Hybrid Electric melter GS H^2EM (already in operation in EU)
5. Make combustion system able to use (partial) Hydrogen combustion
6. Depending on Natural gas, CO_2 emission prices the commercial breakeven point to go more Electric is below 0.08 €/kWh. (also lowers investment, NOx, dust, space, filter etc)

The future may be **T furnace** (not Tesla)



$> 10\ tons/(day \cdot m^2)$

In collaboration with
Laboratory of Inorganic Materials
Dr. Marcela Jebava
Prof. Lubomir Nemec

THANK YOU FOR ATTENTION !

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