MÖGLICHKEITEN DER CO2 EINSPARUNG DURCH EINSATZ ELEKTRISCHER UND HYBRIDER SCHMELZÖFEN

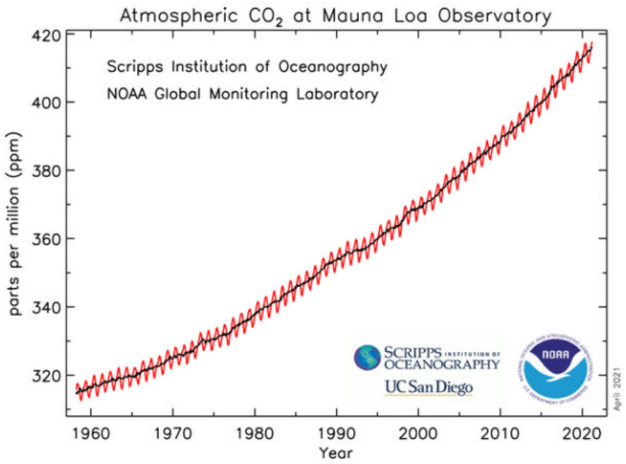
Some aspects to this complex topic

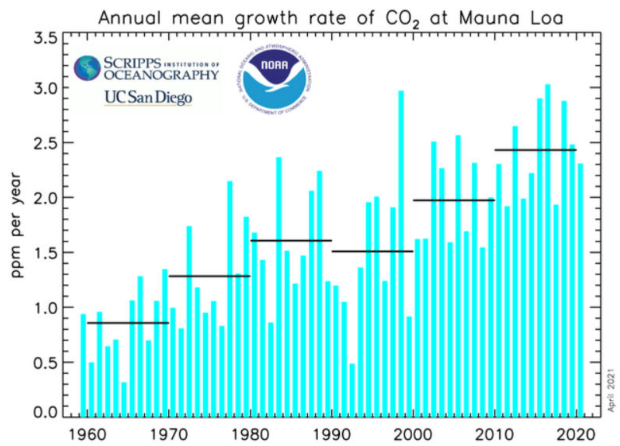
Dr. W. Kuhn

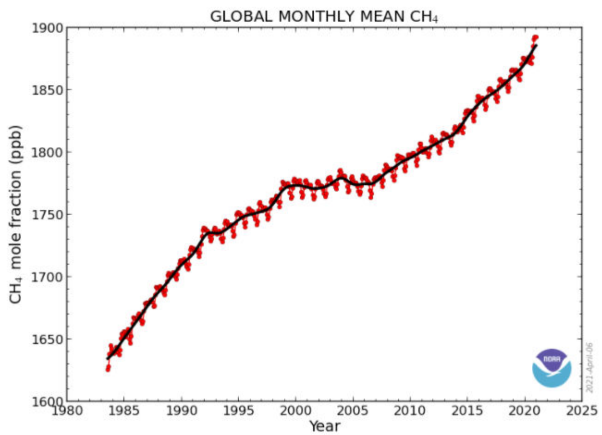
—

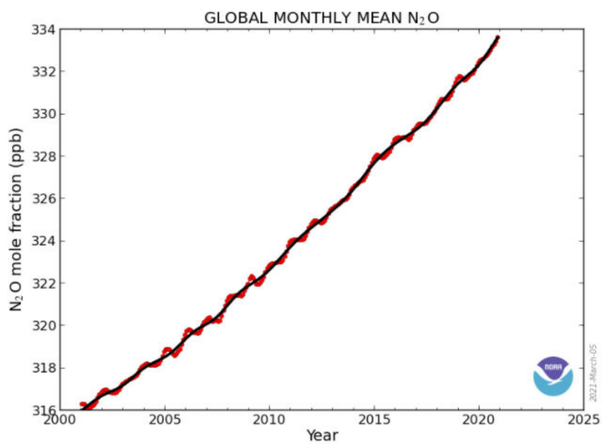
DENA workshop ‘energieeffiziente und CO2-arme Glasproduction

Vorbemerkung: priority on short term finance or science?









Industrie und Verbraucher führen einen weltweiten Crashtest durch

- ohne Gurt und Airbag

Wieviel CO2 per Tonne Glas wird emittiert?

fives

Mean values from industry survey

Table 3 EU27 Production volume and GHG emissions of the year 2007 fr… chain (CPIV 2009; calculations by Fraunhofer ISI)

Activity	Production volume EU27 (Mt)	Approx. specific emissions (kg CO_2/t product)[1]
Manufacture of flat glass	10.26[2]	677
Manufacture of bottles & jars and flaconnage	22.4[4]	518[5]
Manufacture of tableware	?	?

Glass production comprises the process steps 'batch mixing and preparation', 'melting', 'homogenization and refining', 'forming' and eventually 'annealing' and 'surface treatments'.

from carbonates

← 150 kg/t (20% cullet)

← 30-150 kg/t

The melting process contributes with about 75%

450 kg CO2 for 1 t of melted glass

Why?

Europe: 70-80 kg glass/capita/year, thus about **50kg CO2 /capita/year**

Extrapolation to earth population: **0.35 Gt/y of CO2** 'only' for glass

Fraunhofer Institute for Systems and Innovation Research

Methodology for the free allocation of emission allowances in the EU ETS post 2012

This survey does not integrate the CO2 emissions related to the production of raw materials, transportation of raw materials and products, fossil fuel extraction, refining and transport

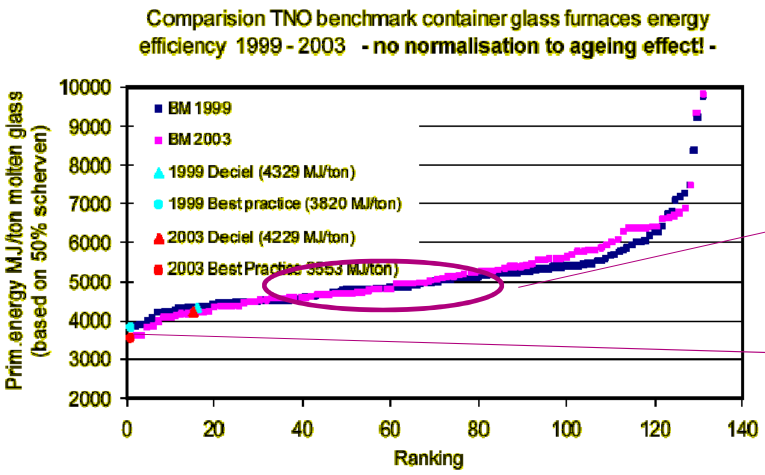
Carbon intensity of fuel combustion

Fuel	Kg CO2 / kWh
Hard coal	0.34
Fuel oil	0.28
fossil gas	0.20
H2 (green)	Near 0
Sustainable wood / biogas/oil	Near 0 My house ☺

Partial reduction

Next?

Optimum mit konventioneller Technologie?



Container glass furnace with highest energy efficiency, 50 % cullet: 3.4 MMBTU/ton

Aber durchschnittliche Behälterglasöfen emittieren 250 - 300 kg CO2/tg

Bestwert:

3780kJ/kg / 1050kWh/t

Table 11 Overview of the final benchmark values based on BAT as derived in the 2008 benchmark study (Ecofys/Fraunhofer-ISI, 2009).

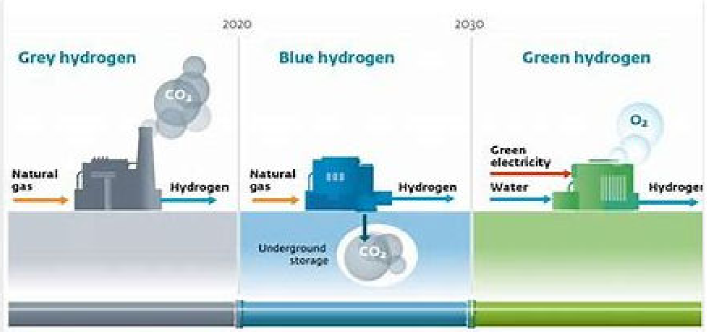
	Flat glass	Hollow glass	Continuous filament glass fibre
CO_2 emission benchmark for fuel combustion ($t\ CO_2$ / t melted glass)	0.336	0.209	0.582
CO_2 emission benchmark for process emissions ($t\ CO_2$ / t melted glass)	0.088	0.016	0.120
Total CO_2 emission benchmark ($t\ CO_2$ / t melted glass)	0.424	0.225	0.702
Assumed packed to melt ratio	70%	90%	70%
Total CO_2 emission benchmark ($t\ CO_2$ / t packed glass)	**0.606**	**0.250**	**1.003**

Sehr hohe Scherbenanteile

Wie geht es weiter?

From about 450 kgCO2/t glass to ‘LOI’ CO2 or even lower?

Hydrogen combustion?



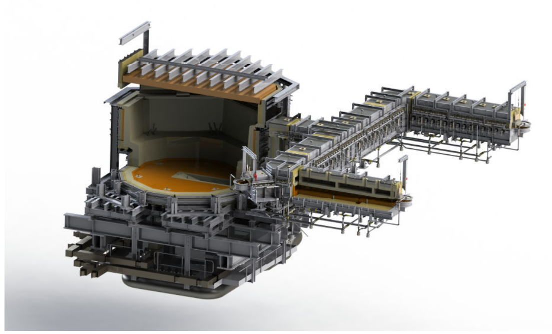
$CH_4 + O_2 \rightarrow 2H_2 + CO_2$ $2 H_2O \rightarrow 2H_2 + O_2$

Only acceptable if in blue or green

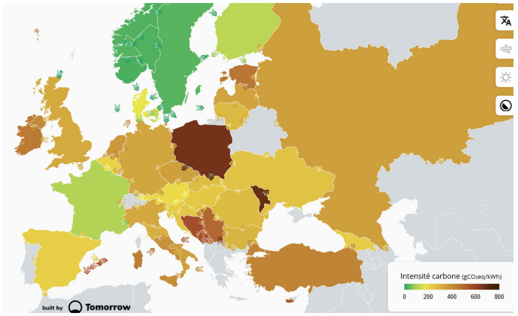
Biogas from anaerobic digestion ?

Combustion ’CO2’ is here ‘neutral’

Electric Melting?

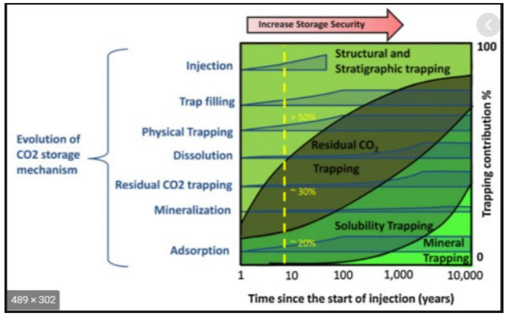


Green electricity still limited



Conventional with carbon capture and storage?

Safe, long term storage required for huge amounts of CO2



Which of these options will emerge for CO2-free glass melting?

Optionen für CO2 freie Glasöfen?

From 450 kgCO2/tg to <100 kgCO2/tg*

Fossil gas

Biogas enrichment (if enough available?)

Enrichment with H2

Gradual transition?

100% green hydrogen combustion

Hydrogen – oxygen

Hydrogen – air combustion (recup. or regenerative ?)

Flexible hybrid versions?

Electricity

100 % electrical melting – but with about 0.3 kgCO2/kWh (Europe 2020)

Ongoing transition

100 % electrical melting with only renewable electricity

Fossil fuels

Gas, oil, coal, petcoke…

Carbon capture and sequestration

Reduced flue gas volumes by oxy-combustion

No tank change, business as usual?

*For questions on reduction of CO2 from LOI, please refer to the Glass Trend seminars – for example Haarlem 2017

And the current GT project on CO2 free raw materials

Questions: Energetic efficiency, supply security, cost, technical risks, compatibility with current production methods…..???

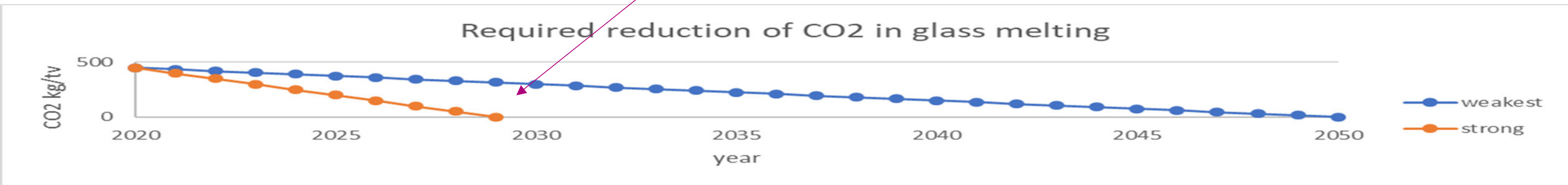
Hauptfrage: welche Zeitskala zur Umstellung?

Zeitskalen für Investitionen

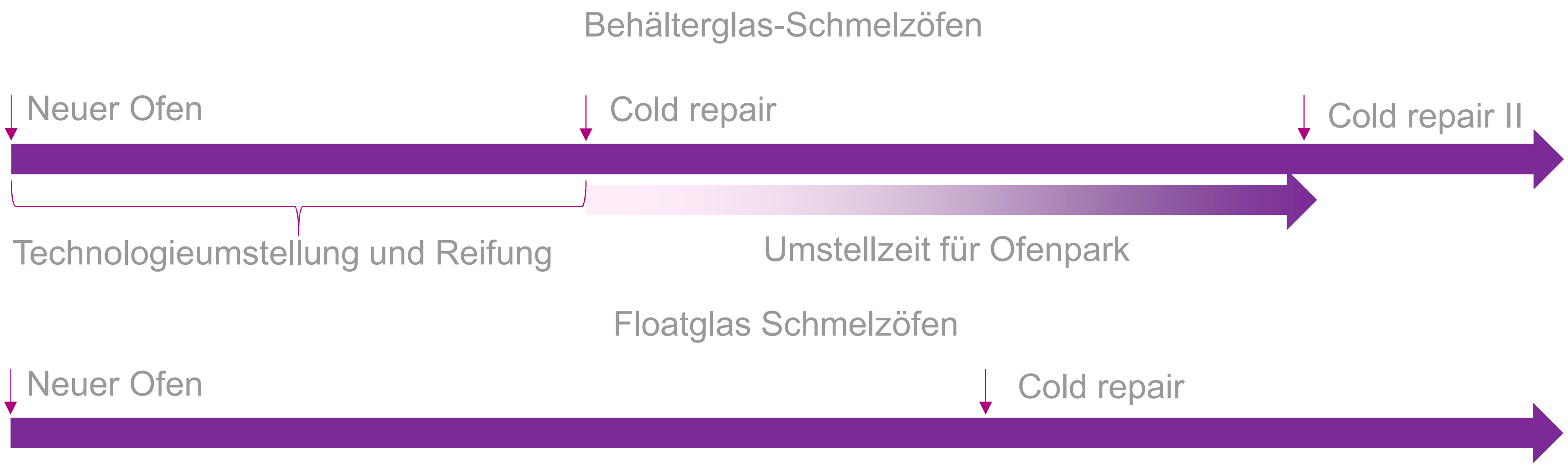
Inaktivität der letzten Jahre und Verschlechterung: nur noch 15 Jahre für null-CO2 um <2°C zu erreichen

Ziele der CO2 Reduzierung

https://reneweconomy.com.au/net-zero-emissions-must-be-reached-before-2030-for-2c-target-new-analysis-says/



Typische Zyklen der Ofenerneuerungen

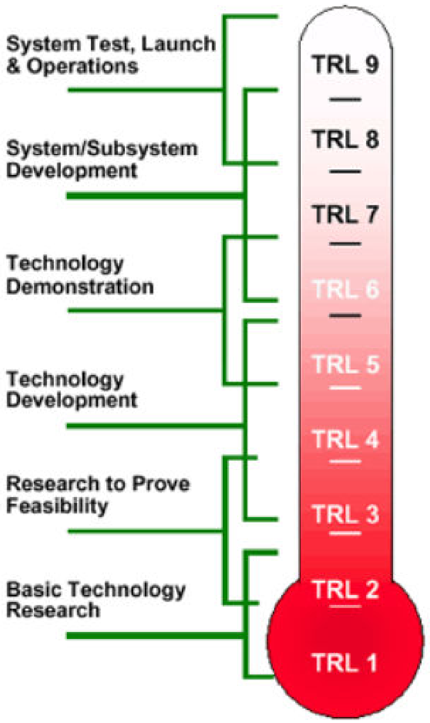


Entscheidungen für Technologieumstellung müssen jetzt erfolgen

TRL mit Focus auf Schmelztechnologie für Behälterglas

Grobe Abschätzung

Ohne Berücksichtigung der Verfügbarkeit der Energiequelle



Biomethane	Hydrogen	100% electric	Hybrid with <=50%	Hybrid with 80%
✓ Ready	✓ Test on float tank planned	✓ Ready	✓ Ready	✓ Ready If known components are used
No change of tank design	No change of tank design ? Higher H_2O levels!	Limited in melting capacity	Limited change of tank design	Bigger change of tank design

Checkliste für Wasserstoff-Verbrennung beim Glasschmelzen

- **Choice of combustion system (regenerative, recuperative, oxy-combustion) – cross firing might be inefficient (reduced flame radiation)**
- Impact on design of combustion supply and burners (injection nozzle corrosion, hydrogen embrittlement and corrosion of piping)
- **Change of flame characteristics (flow pattern, radiation and heat transfer to melt) – can be compensated by tank and burner design**
- **Impact of flue gas on melt evaporation (NaOH…) – can be controlled by careful combustion design**
- Impact on pollution species in flue gas (NOx, SOx, dust…) and flue gas treatment
- Impact of water concentration on glass properties (chemical fining, -foaming, optical absorption spectrum)
- Impact of flue gas on superstructure refractory (H_2O, NaOH….)

Road is technically open for a conversion of many melting tanks to hydrogen combustion - if all these items are positively checked/adapted !

The knowledge acquired with oxy-gas combustion presents an accelerator for the development of Air-hydrogen or oxy-hydrogen melting tanks

Die niedrige Effizienz der Wasserstoffsynthese spricht aber für die direkte Nutzung der Elektrizität

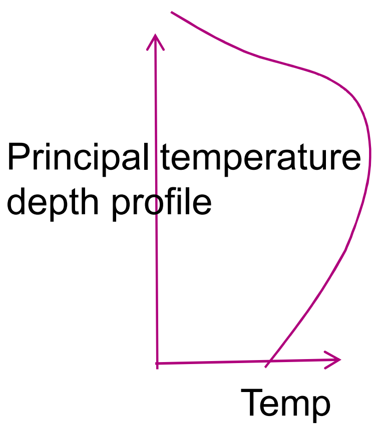
Es sei den wir bekommen eine angenehme Überraschung: pyrolytische Methanzersetzung mit Katalysatoren (112CO2 Horizon Project – seit Sept. 2020)

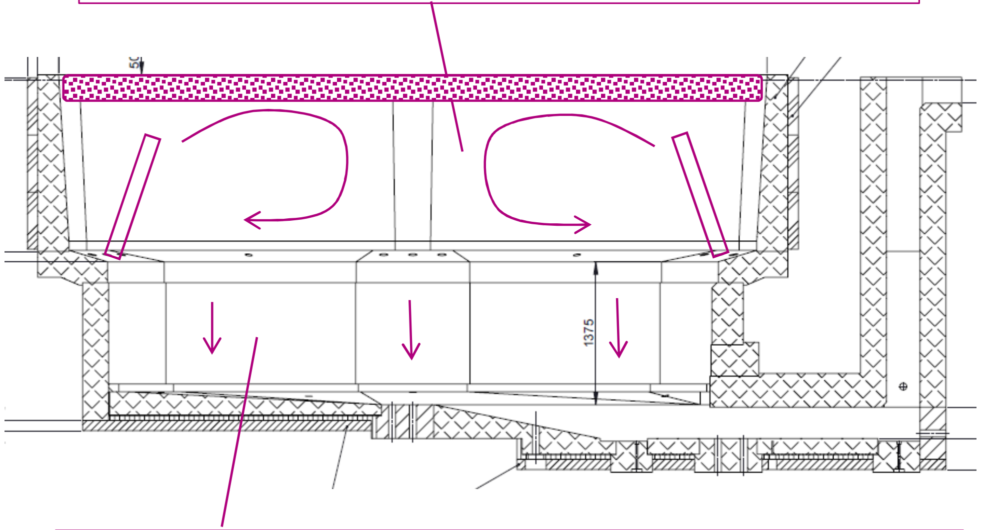
Elektrowanne im Stufen-Design und Relation zur Läuterqualität

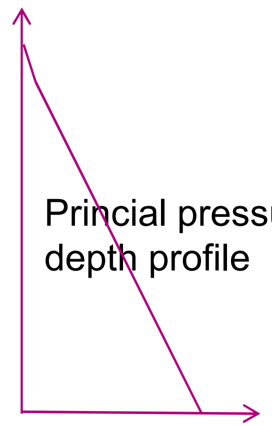
How do melt temperatures and convection determine the high temperature fining and the refining (resorption) of bubbles?

Upper, high temp zone with multiple functions
- Heat input for batch melting
- Primary fining (mainly CO_2 removal)
- Mixing of the melt for cord and grain dissolution

Stufen-Cold top Wanne nach Mr. Penberthy, founder of Penelectro – today Fives Stein Glass, KTG spin off from Penelectro





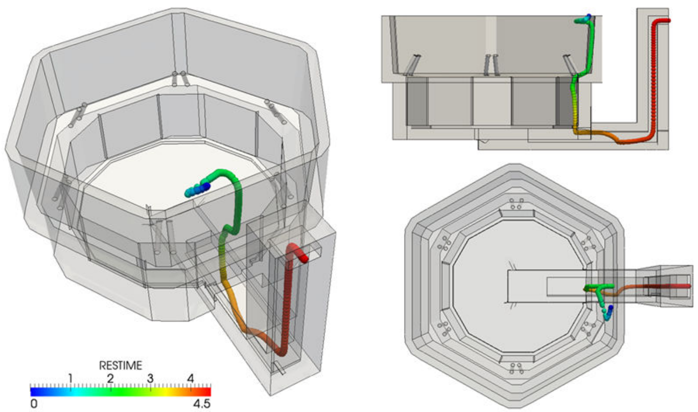


Quiescent zone at lower temperature for removal of remaining bubbles by ascension or absorption

Für deutschsprachige Leser verweise ich auch auf den ausgezeichneten DGG Fachausschussbericht Nr75 von 1997 (Beiträge Voss und Fleischmann)

Einfluss des Strömungsfeldes auf die kritischen Pfade

Typical for small electrical melters:
Shortest path near side walls



Typical for large electrical melters with shelf heating:
Shortest path in tank centre

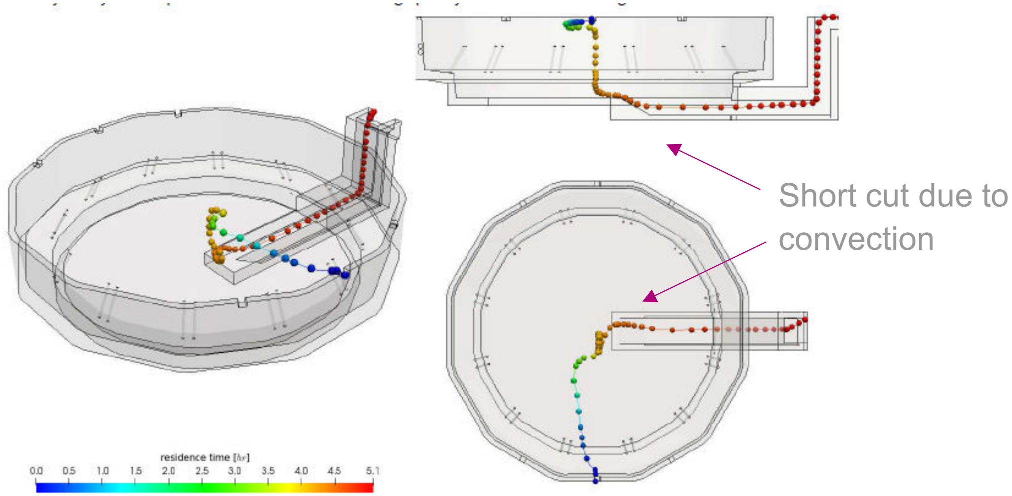


Figure 4.16 – Trajectory of the particle with the shortest residence time above the fining temperature

However, optimization allows to minimize the effect
Still very good quality achievable:

<20 seeds/kg (seed < 0.3mm)

(Quality level of pharmaceutical, perfumery and tableware)

Dieser und andere Effekte verhindern die Vergrösserung der Elektrowanne

Electrodes in bottom in central zone?

Not recommended because this will destroy the quiet zone in the lower part

Super boosted/hybride Schmelzöfen oder 100% Elektrowannen?

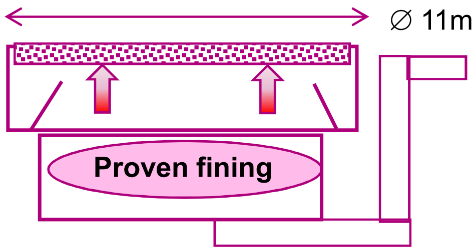
Vertical cold top concept

Shelf type vertical el. melter

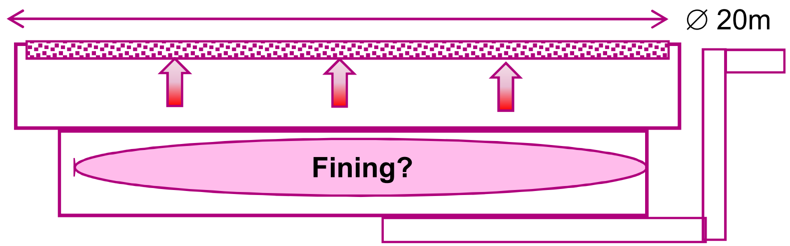
Pemberthy 1968 – Penelectro - Now FS Limited

100 m²/200-250 tpd

feasible



300 m²/ 600 tpd feasible?



2019 ICG Boston
Fundamental design aspects of electrical melting tanks that determine fining quality and upscaling limits
Kuhn, Reynolds

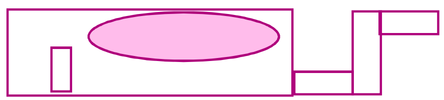
Or conserve some combustion?

Hybrid up to 80% boost feasible?

Horizontal tank concept

Proven fining processes (throat or waist type)

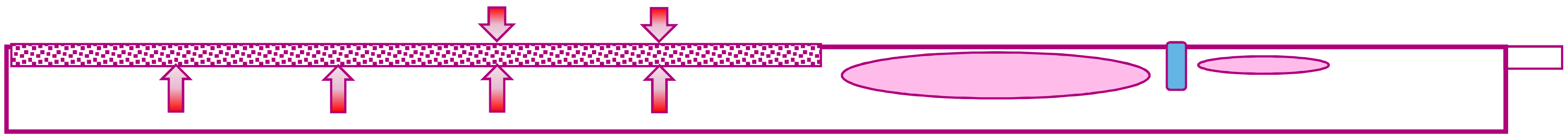
From 50 to >1000tpd



Throat type

Float type

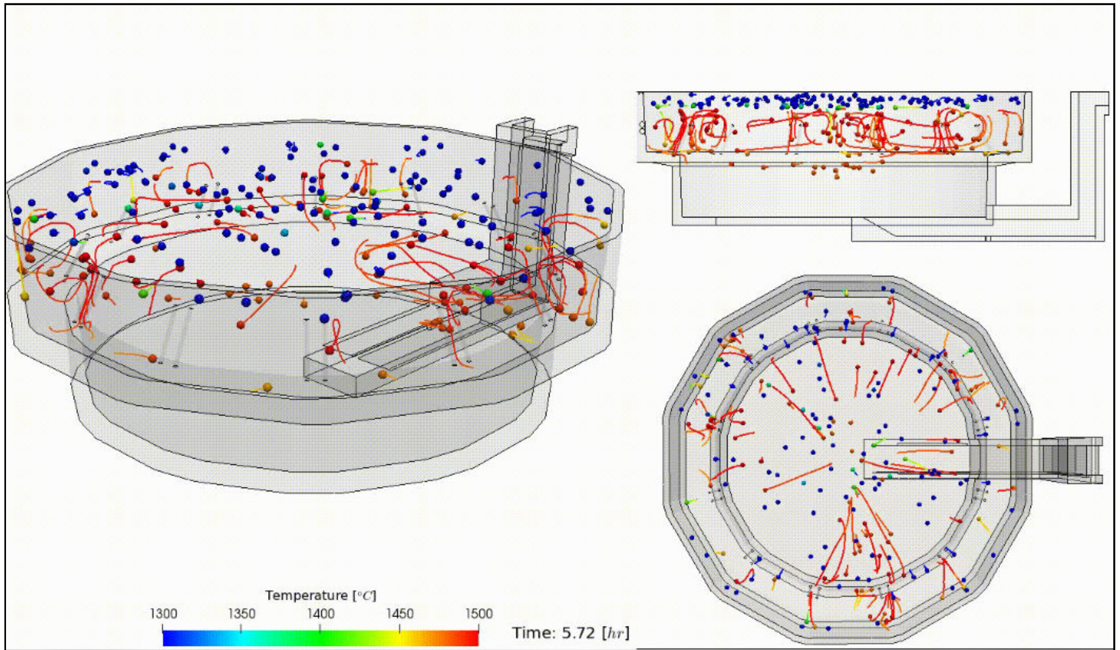
Reduced combustion



very high boosting input

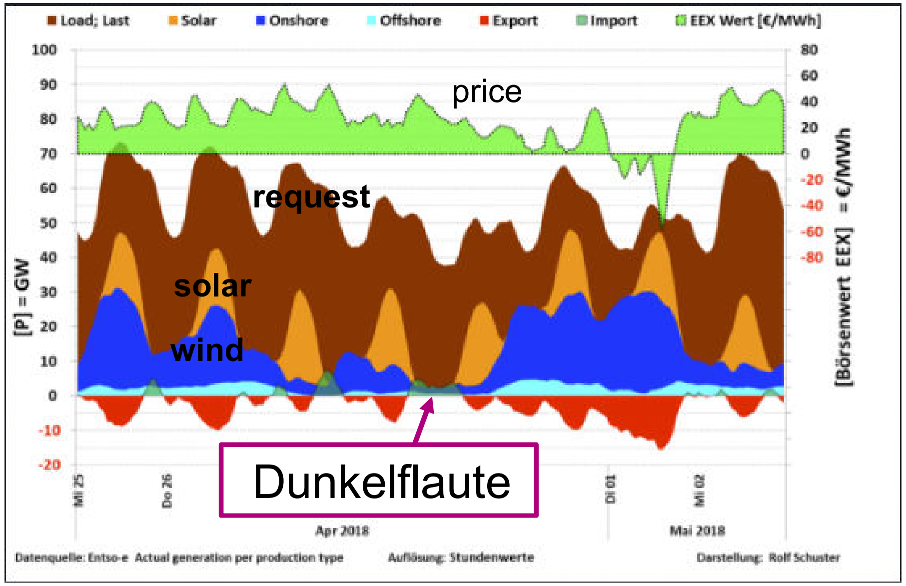
Both concepts are viable in the future from a process point of view !

100% Elektrowannen: Kapazität und Grenzen



Simulation of SO3 fining bubbles: no bubbles reach the lower zone Proven up to **250 tpd**

Fluctuation of green electricity in Germany:



Remarks:

- lifetime of a soda-lime electrical melter: 8 years
- Spec consumption: 2.6– 2.7GJ/tv (30% cullet)

100% electric melting is a reliable and ‘simple’ solution for CO2 reduction if

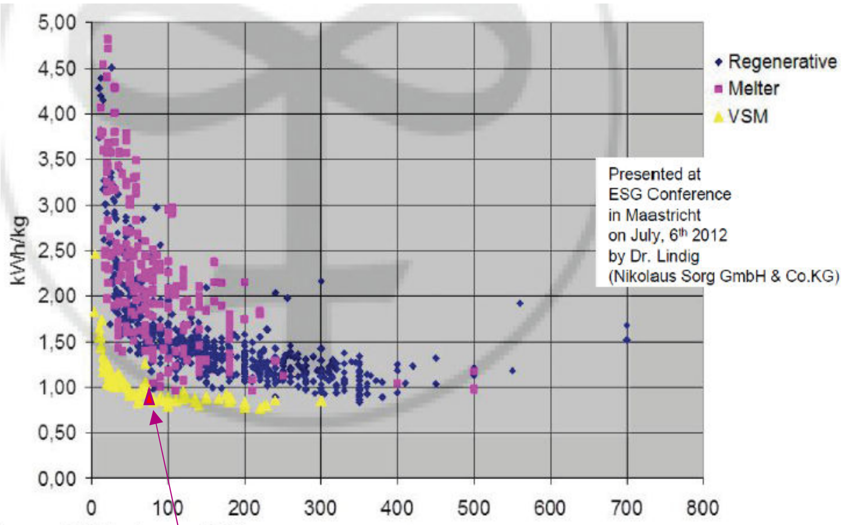
- Upscalable solution
- More flexible
- No Dunkelflaute

100% Elektrowannen: Kapazitätserweiterung

Upscaling to 600 or 1000 tpd single tanks will be very difficult with the cold top principle but

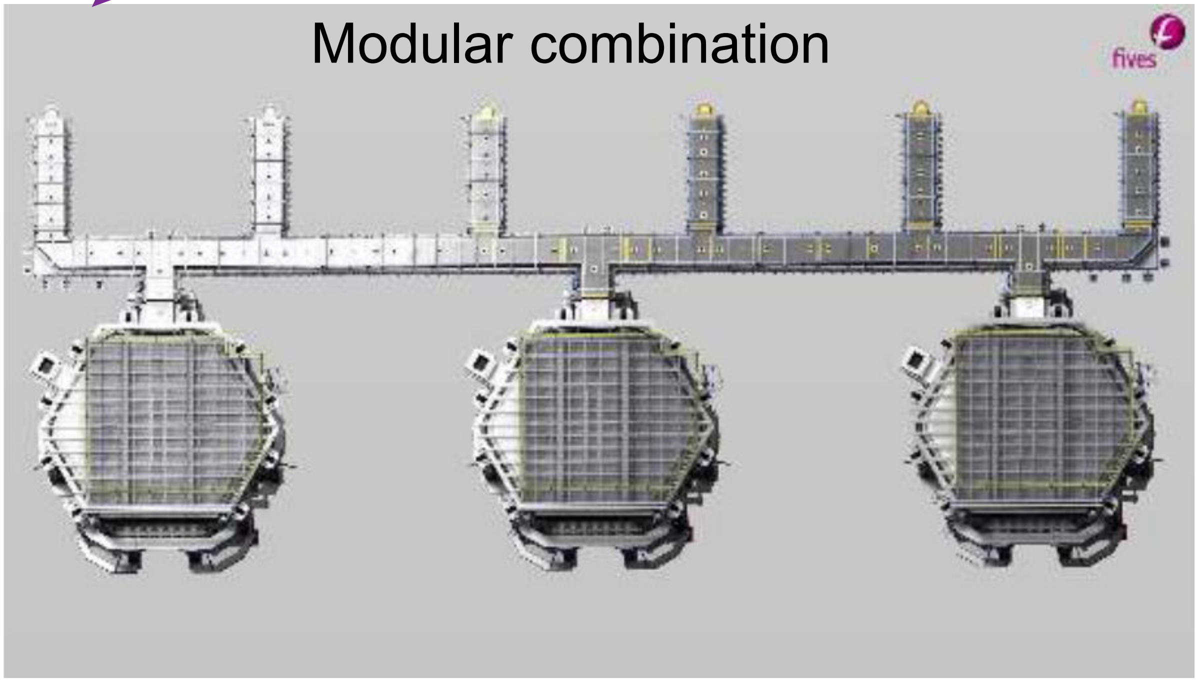
Furthermore: cold top melters are limited in flexibility (pull variation, cullet….) because the batch coverage should remain stable

specific consumption of cold top melters reaches anyway a lower limit at around 100tpd:



Source: B. Fleischmann, DGG
ICG – SCHOTT Energy Panel, Mainz, 20.11.2012

Fives PRIUM® shelf type electric melters



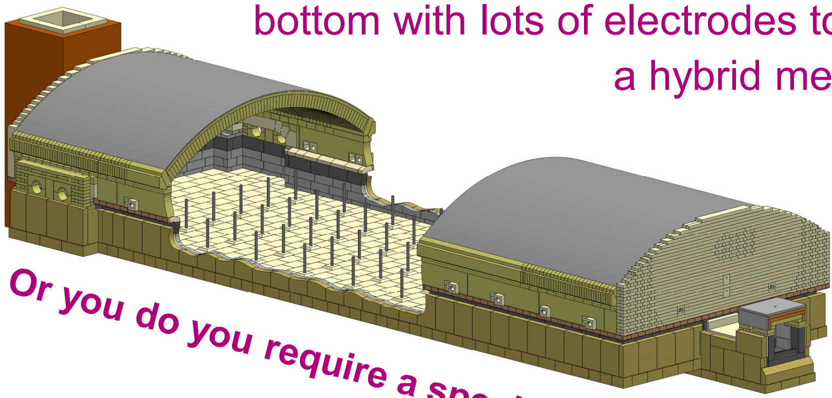
Improve 100% electrical melting - or go for large hybrid tanks?

Elektrisches boosting, super boosting, hybrid boosting……

Suggestion for terminology:

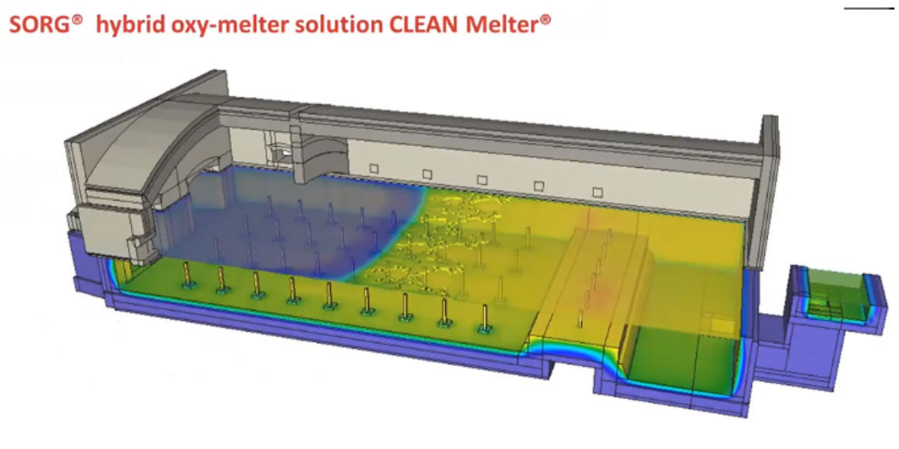
Electrical boosting:	Pull increase, stabilization of convection and quality, tinted glass….
Super boosting:	Boosting with up to 50% to significantly increase the spec. melting rate
Hybrid melting:	**Replacement of combustion power!**

Is it sufficient to just cover your tank bottom with lots of electrodes to get a hybrid melter?



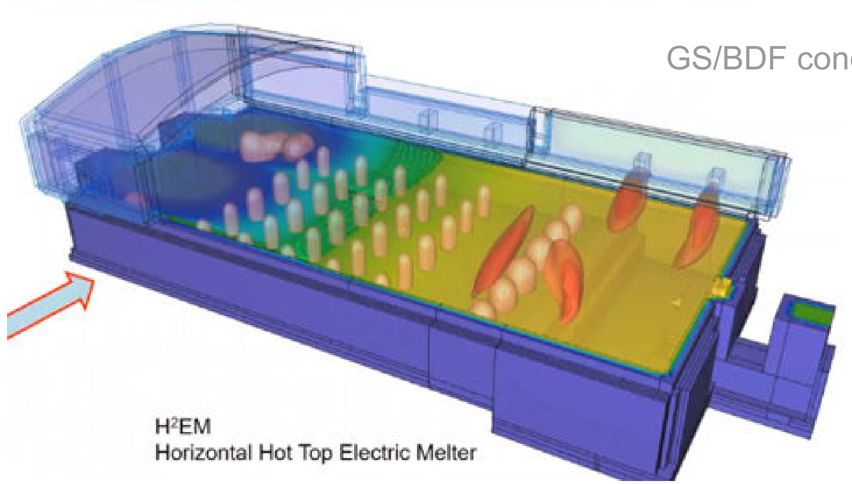
Or you do you require a specific design ?

Viele Konzepte auf dem ‘Hybrid’ Markt



+ Horn

GS/BDF concept



TECO: This being the case, the “eco” furnaces of the future are likely to be smaller, use considerably more electricity as a form of primary melting energy and have shorter life cycles. It could mean two rebuilds for every one needed with a traditional furnace. Apart from the obvious efficiency and environmental benefits, there will be shorter rebuild times with glass to glass downtime considerably reduced.

Design eines korrekt konzipierten hybriden Ofens?

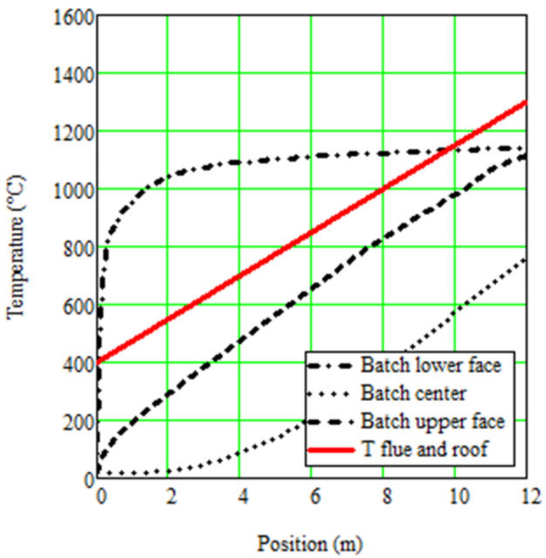
Lastenheft

- 70 – 90% elektrische Energie also nahe einer Elekrowanne?
- 20-80% hohe Flexibilität?
- Flexibilität in Produktion (Scherben, Durchsatz, Transparenz /Glasfarbe)
- Frequenz von Produkt-Wechsel?

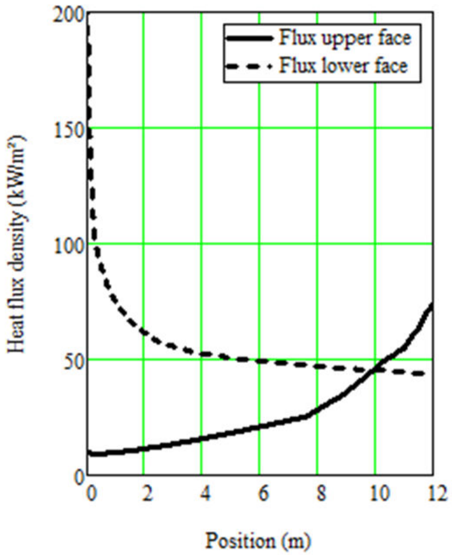
Diese Anforderungen haben natürlich einen Einfluss auf das Design des Ofens und Auslegung der Heizsysteme

Die wesentliche Änderung des Ofendesigns wird aber durch die Reduktion der Verbrennung auf 20% und die Verminderung des oberen Wärmeflusses erzwungen

Temperaturen über Gemengelänge



Wärmeflusse oben/unten



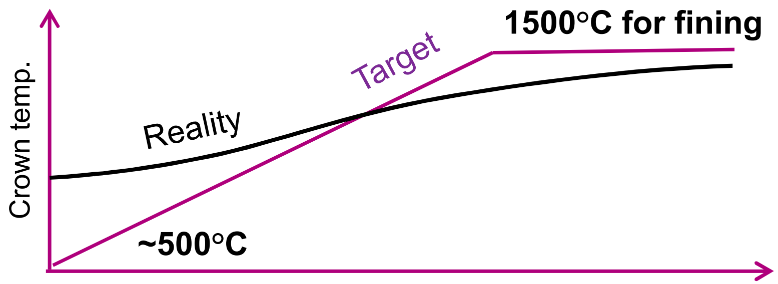
Prinzipielle Anforderungen:

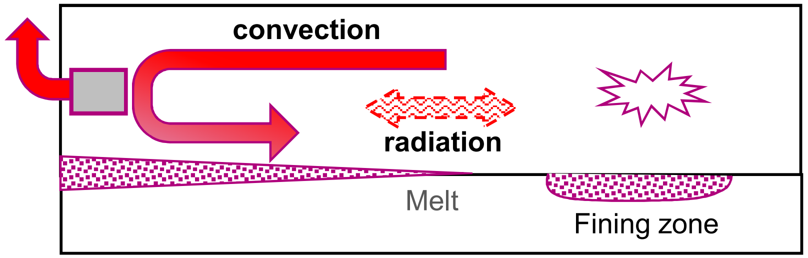
1. **Gewölbetemperatur in Gemengezone ist auf <<1000°C zu reduzieren**
2. **Temperatur im Läuterbereich ist auf etwa 1500°C zu halten**

W. Kuhn, et al. GPC proceedings 2019

Hybride Wanne: 20% Verbrennung in einem konventionellen Oberofen?

Low combustion input





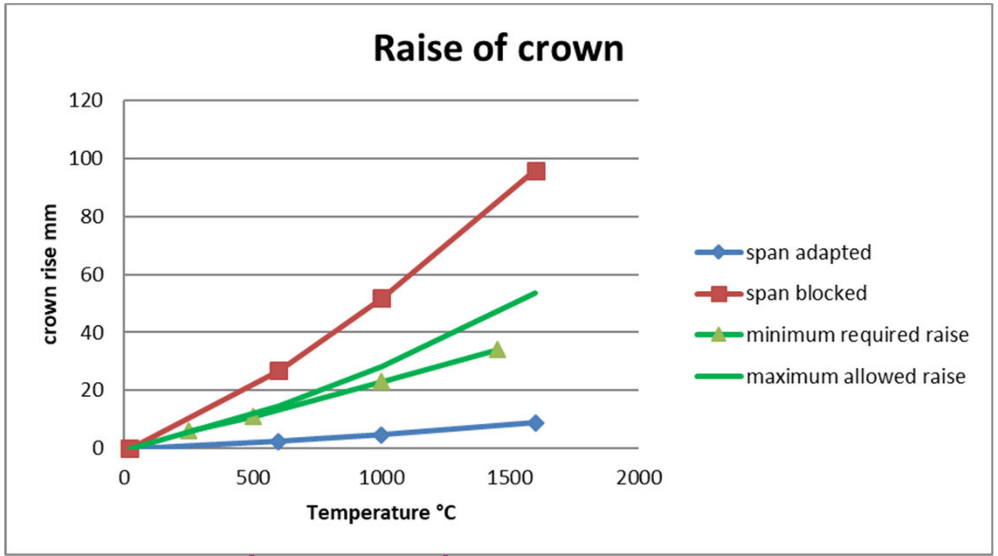
- High free surface and crown temperature required for fining
- The convective and radiative exchange with the cold batch inlet pumps on this high temperature zone
- Result: Lower fining temperature and too high temperatures in melting

Radiation and convection effects hinder the creation of a steep temperature gradient and very low temperatures at the charging end of conventional melting tank designs

Auxiliary problems ☹

- **Stability of the arc crown with lowering temperatures**
- **Condensation and corrosion by volatiles**

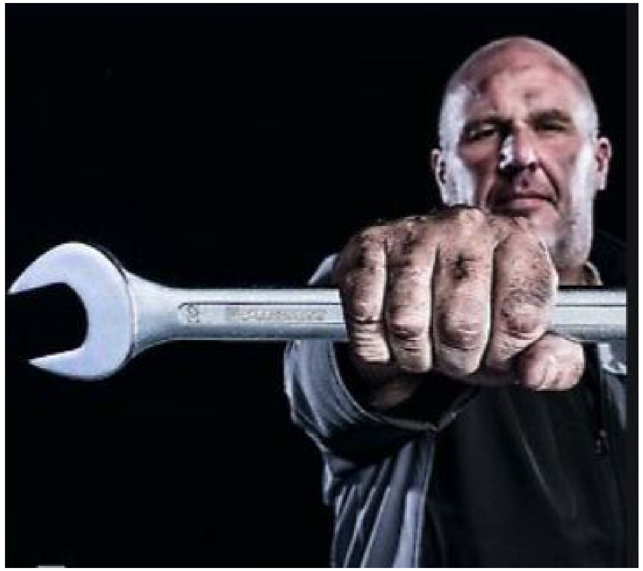
Hybride Wannen: Ausdehnung des Gewölbes- und Kontraktion



Target temperature range of a hybrid melter

1. Strong temperature gradient over crown length!
2. Change of temperatures for power input changes

No comment !



+ condensation of volatiles !

Severe limits for arc crowns !

Hybrid melting: Wannen-Design mit einer verlängerten HRA

Ps: Die ‘HRA ‘ Heat Recovery Area wurde von Fives Stein entwickelt zur Verbrauchsreduzierung bei Oxy-Wannen und zur Verminderung der Verdampfung

fives

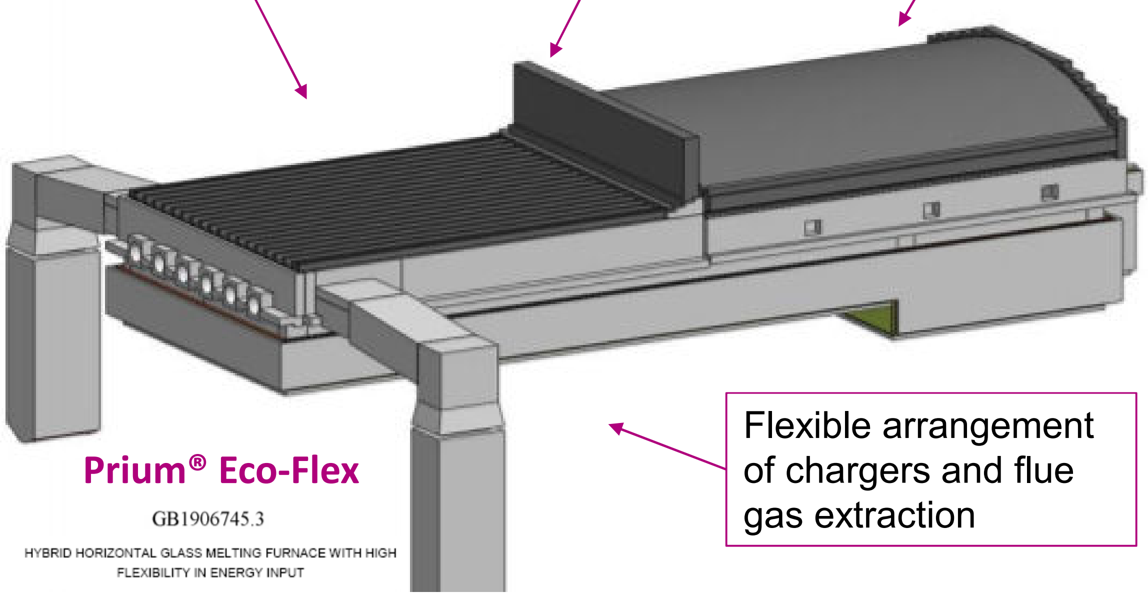
Extended HRA with well proven constructive elements!

80th GPC Columbus
W. Kuhn, et al

Flat, suspended roof from warm top electrical melters

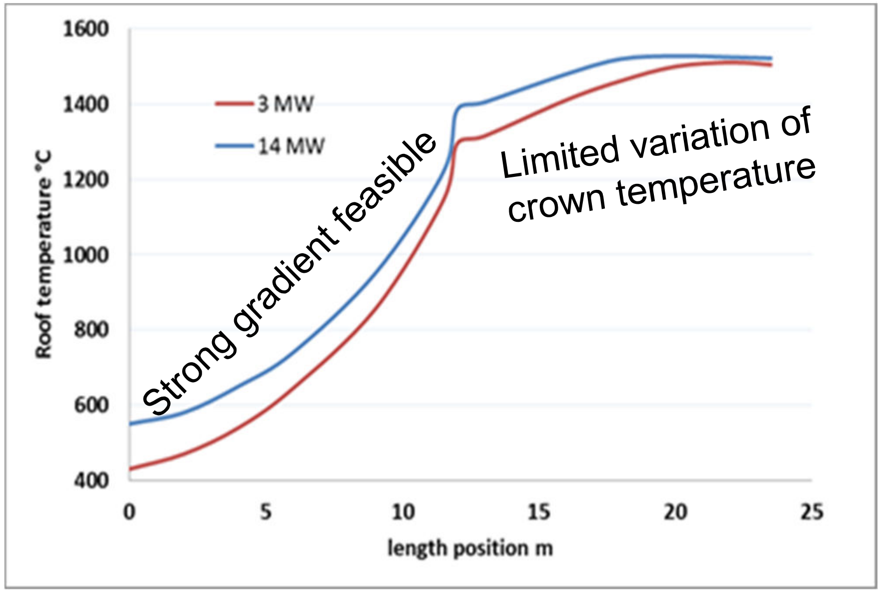
Suspended wall from float tanks

Conventional arch crown



Flexible arrangement of chargers and flue gas extraction

Tank simulation for 20 and 80% boosting



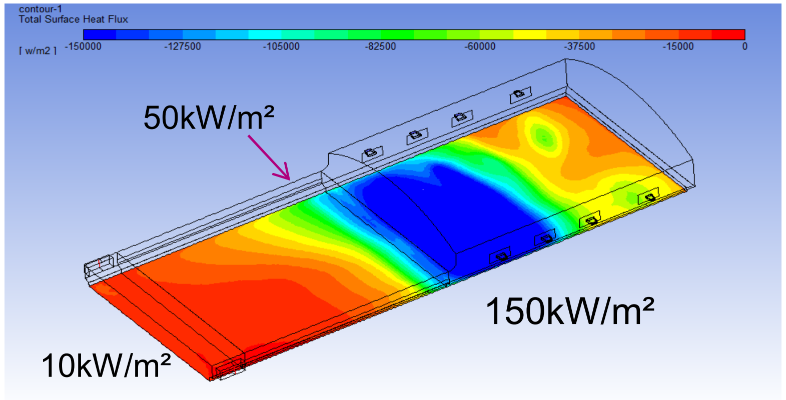
500 tpd container tank with oxy-combustion

This design fulfils all thermal requirements of a hybrid melter

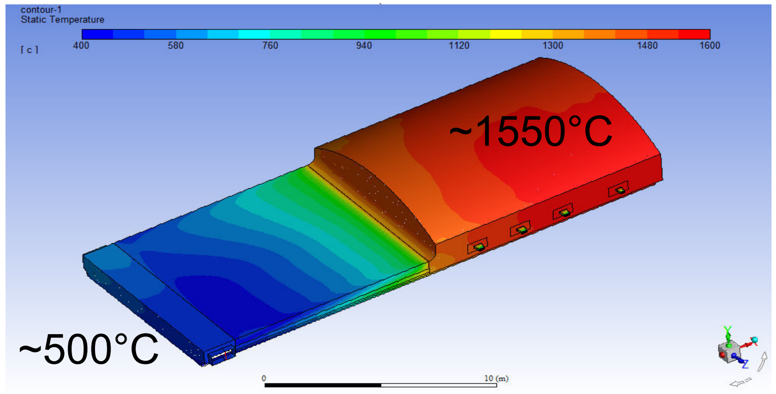
Triple Hybrid: electrical, nat. gas and hydrogen energy input

Simulation with
oxy-**hydrogen**
14MW
20% boost

500 tpd container tank



Fives - Fluent



Recall of conclusions of talk on 80th GPC

The flat roof zone reveals very beneficial for the recovery of the remaining flue energy from the hydrogen flames

Result of design work on this hybrid tank concept:

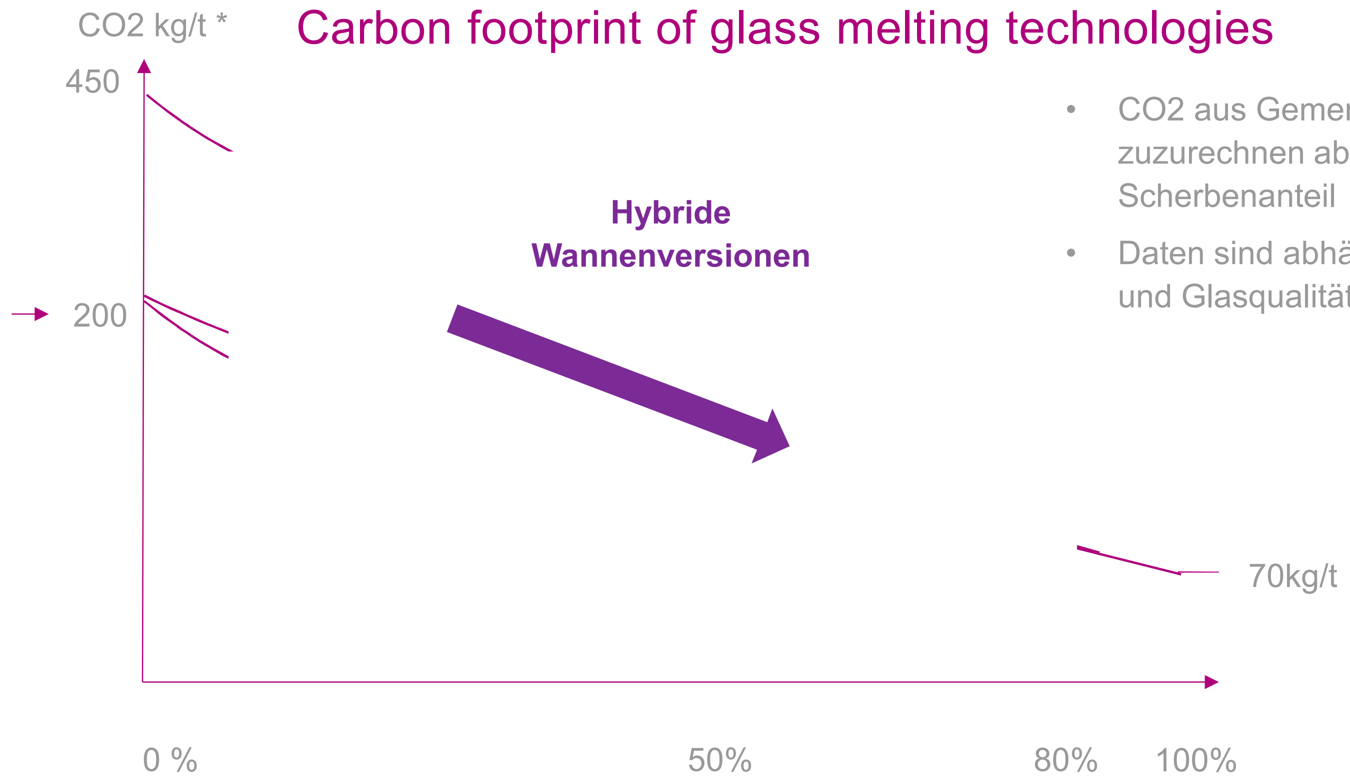
- 80% of electricity input feasible without any compromise on the degassing/fining quality.
- Fall back to lower fractions of electric heating feasible
- Very high efficiency of the combustion process due to low flue gas temperatures
- Higher flexibility in batch coverage/cullet fraction / glass color compared to cold top melters
- Convertible to hydrogen combustion with high efficiency
- Up-scalable to high tonnages
- Only limited increase of the wall loss fraction compared to cold top melters – leading to 2.8 - 2.9GJ/t (30% cullet)
- Tank construction with known and well proven elements from container, float and electrical melting tanks

CO2 Reduzierung mit Strom

Carbon footprint of glass melting technologies

Mean value in glass melting

Best performing end fired or very efficient oxy-tank including O2 production



- CO2 aus Gemengekarbonaten sind zuzurechnen abhängig vom Scherbenanteil
- Daten sind abhängig von Tankkapazität und Glasqualität

Cold top el. melter

Erdgas

0.2 kg/kWh

Ohne Sekundäremissionen

Elektrizität

0.1 kg/kWh

In einigen europäischen Ländern bereits erreicht oder unterschritten

Haupthindernis für neue, hybride Schmelztechnologie

Selbst wenn die Technologie mit TRL 8 eingestuft wird

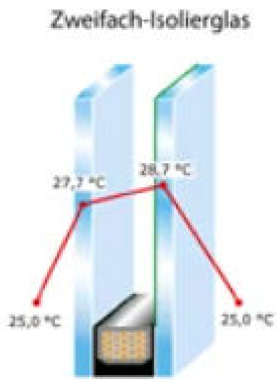
Alte Glashüttenregel

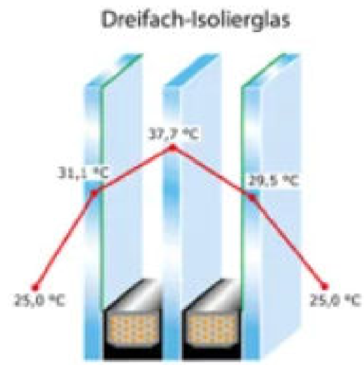
Jeder Glashersteller möchte die neueste, beste Technologie anwenden – sobald er der zweite Anwender ist

Hier ist öffentliche Unterstützung nötig um die CO2 Reduktion schnell voranzubringen

Weitere dringende Aktionen: Weniger wegschmeissen, besser isolieren

Hoher Prozentsatz von Gebäuden in Europa sind noch Wärmeschleudern





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Vielen Dank für Ihr Interesse

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