"Making Glass Better"

A revision of the ICG glass roadmap with respect to progress made in energy saving for melting since 2008

Dr. Roland Langfeld, Frank-Thomas Lentes, SCHOTT AG, Germany

Functional Glasses: Properties and Applications for Energy & Information
January 6-11, 2013, Siracusa, Sicily, Italy

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www.icglass.org

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About ICG

Aims

The ICG (International Commission on Glass) is a non-profit international Society of national scientific and technical organisations with particular interests in glass science and technology. It was founded in 1933 and has grown to become the recognised world-wide organisation in the field of glass with presently 37 member organisations bringing together the world's most respected universities, scientific institutions, companies of the glass industry and allied organisations.

The aim of ICG is to promote and stimulate understanding and cooperation between glass experts in the fields of science and technology as well as art, history and education.

The ICG achieves these objectives by organising Technical Committee work (e.g. laboratory round robins, comparative studies, topical meetings), compiling information on glass (e.g. publishing scientific and technical papers, reports and books) and by sharing and disseminating knowledge on glass in advanced educational courses and workshops. A further major role is to organise international meetings. Every three years the ICG holds an International Congress on Glass while Annual Conferences take place during the intervening period often in conjunction with national society meetings.

The ICG is financed by subscriptions from Member Organisations set in proportion to the annual glass output of the respective countries. Additional income arises from Associate Member Organisations, the sale of publications and royalties.

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5th December 2012
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Agenda

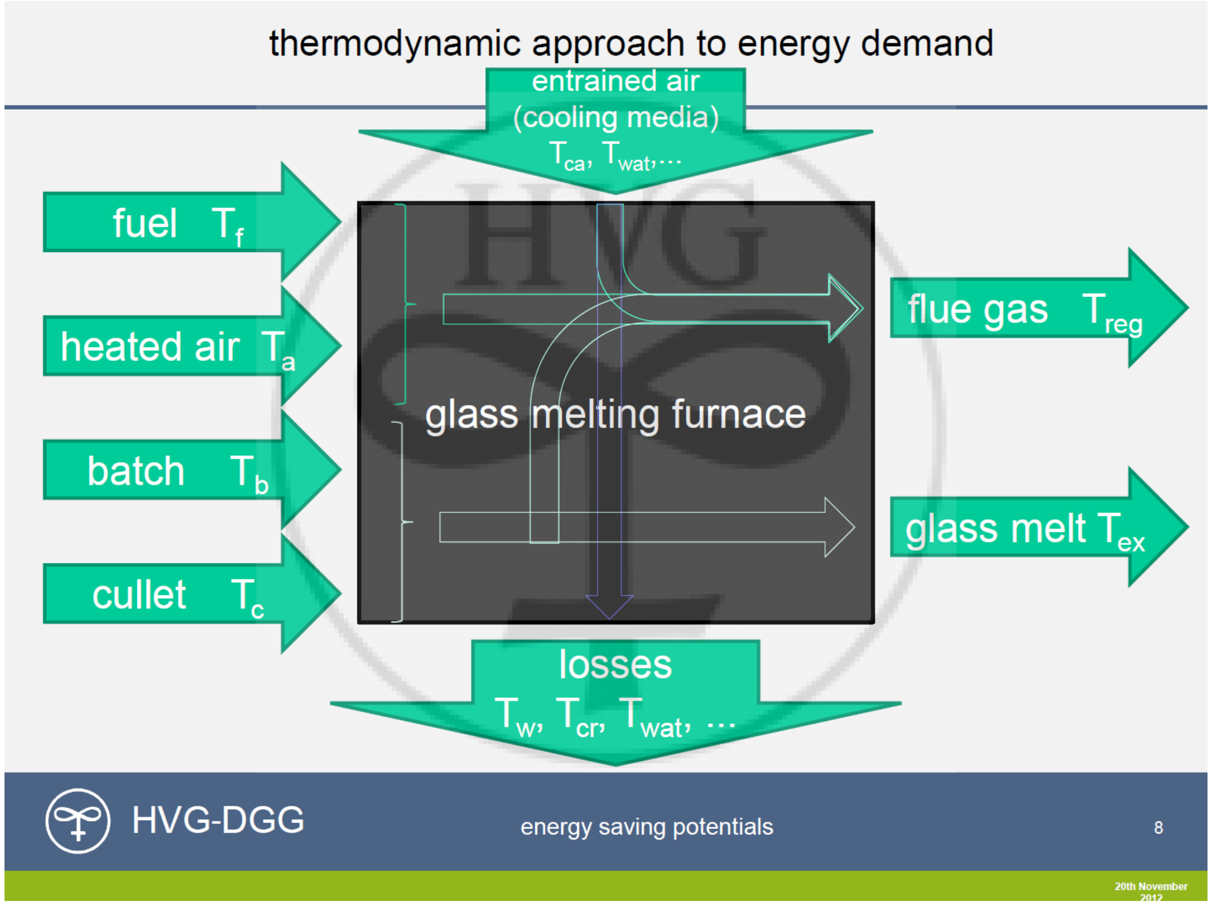
Introduction

ICG Roadmap 2008

ICG – SCHOTT Energy Panel 2012

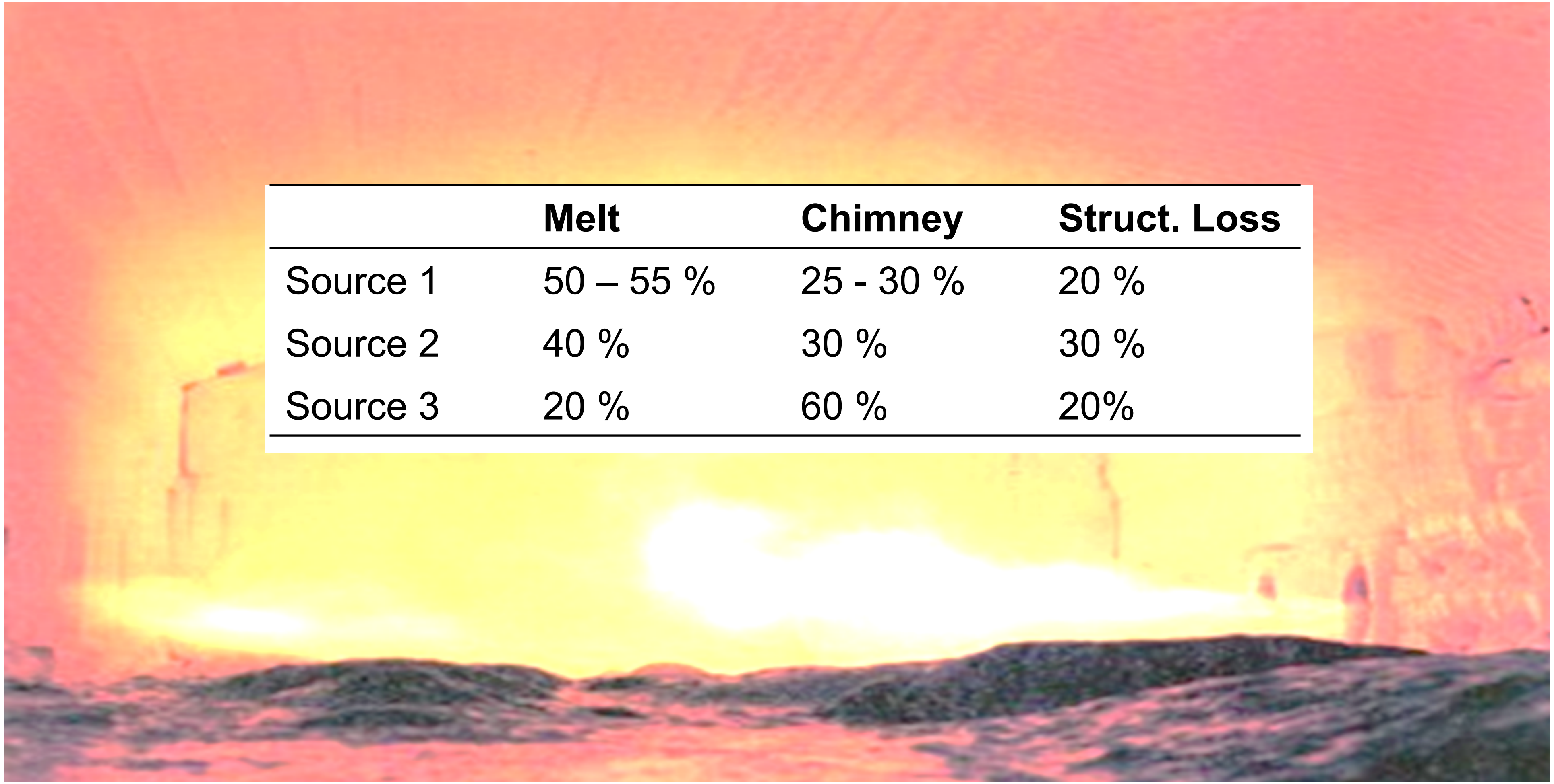
- **General outline**
- **Specific situation in specialty glass industry**
- **Selected results**
- **Conclusions**

Energy consumption in glass melting basic considerations



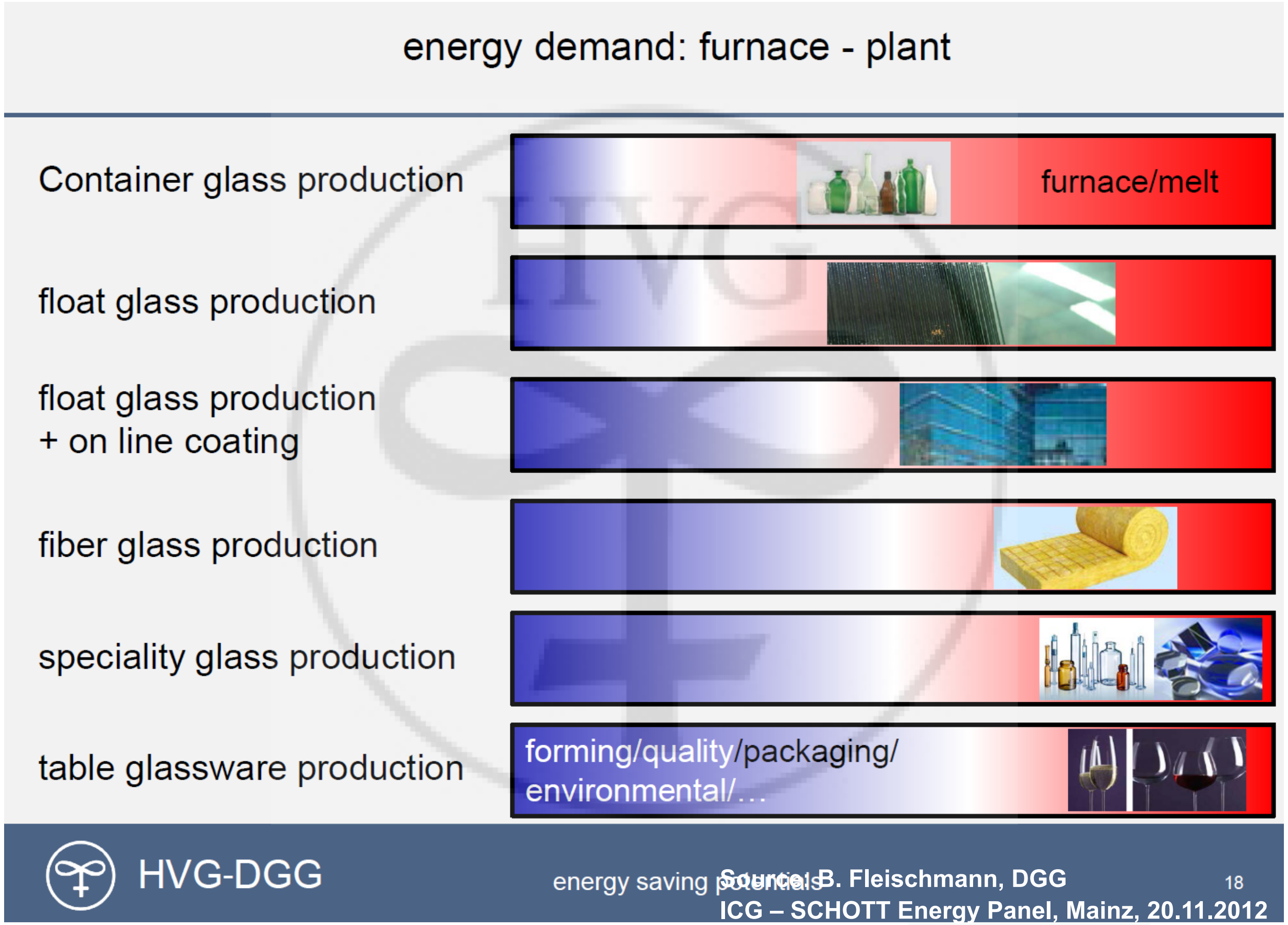
Source: B. Fleischmann, DGG
ICG – SCHOTT Energy Panel, Mainz, 20.11.2012

Glass melting is by far not energy efficient



	Melt	Chimney	Struct. Loss
Source 1	50 – 55 %	25 - 30 %	20 %
Source 2	40 %	30 %	30 %
Source 3	20 %	60 %	20%

Energy consuption beyond melting



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

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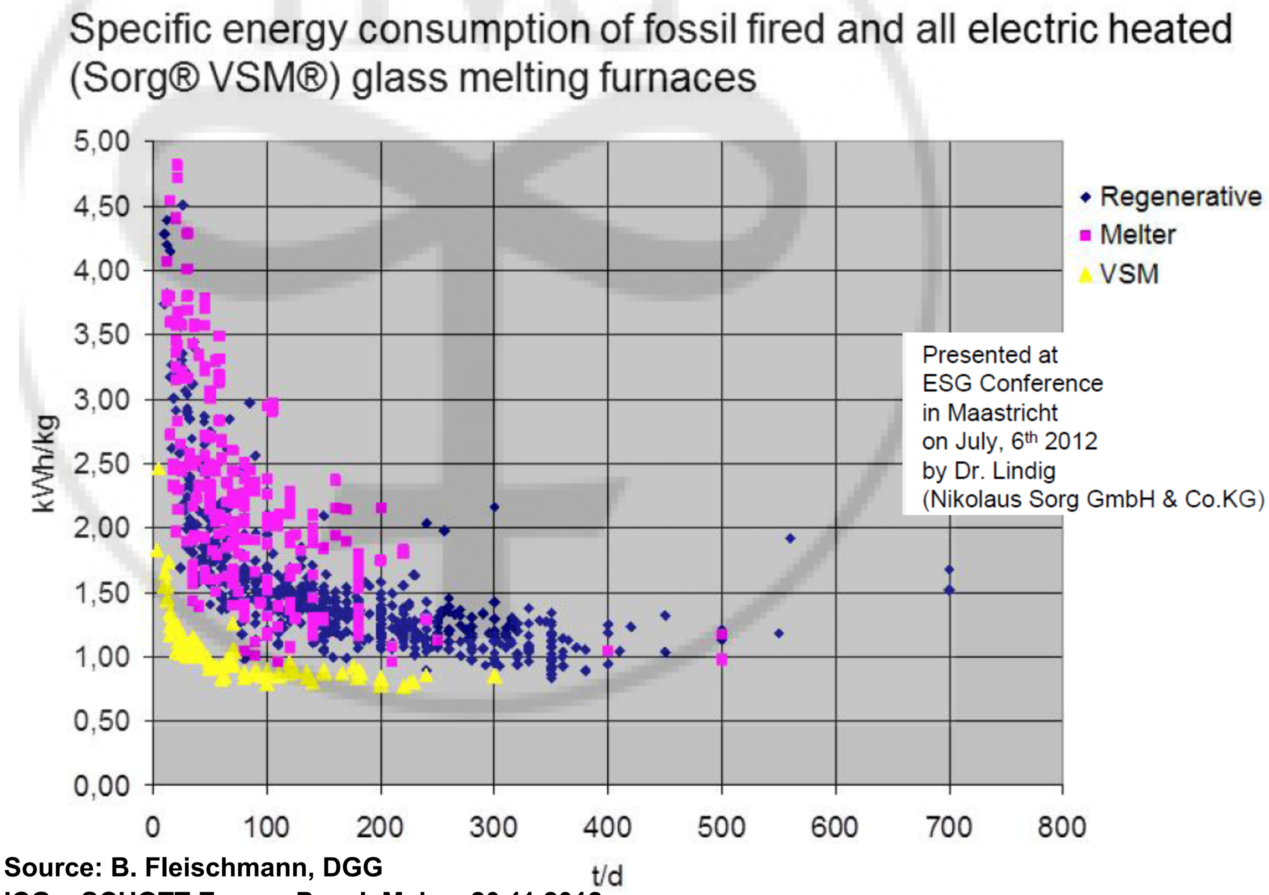
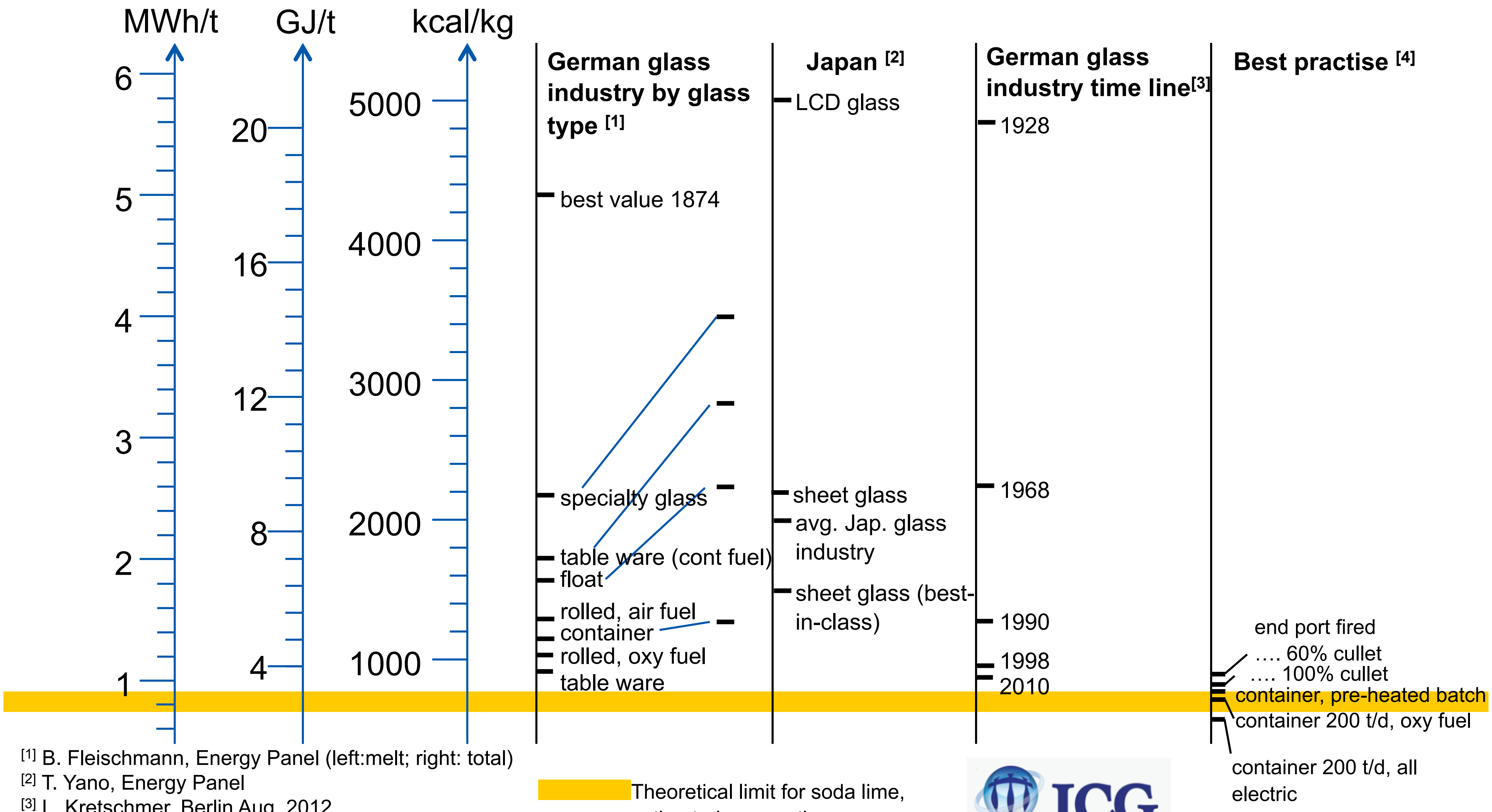
Specific energy consumption depends on glass type, tank size, heating technology, tank lifetime, ..., …



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

Specific energy consumption
Soda-lime seems to come to a limit.



[1] B. Fleischmann, Energy Panel (left:melt; right: total)
[2] T. Yano, Energy Panel
[3] L. Kretschmer, Berlin Aug. 2012
[4] R. Beerkens, Energy Panel

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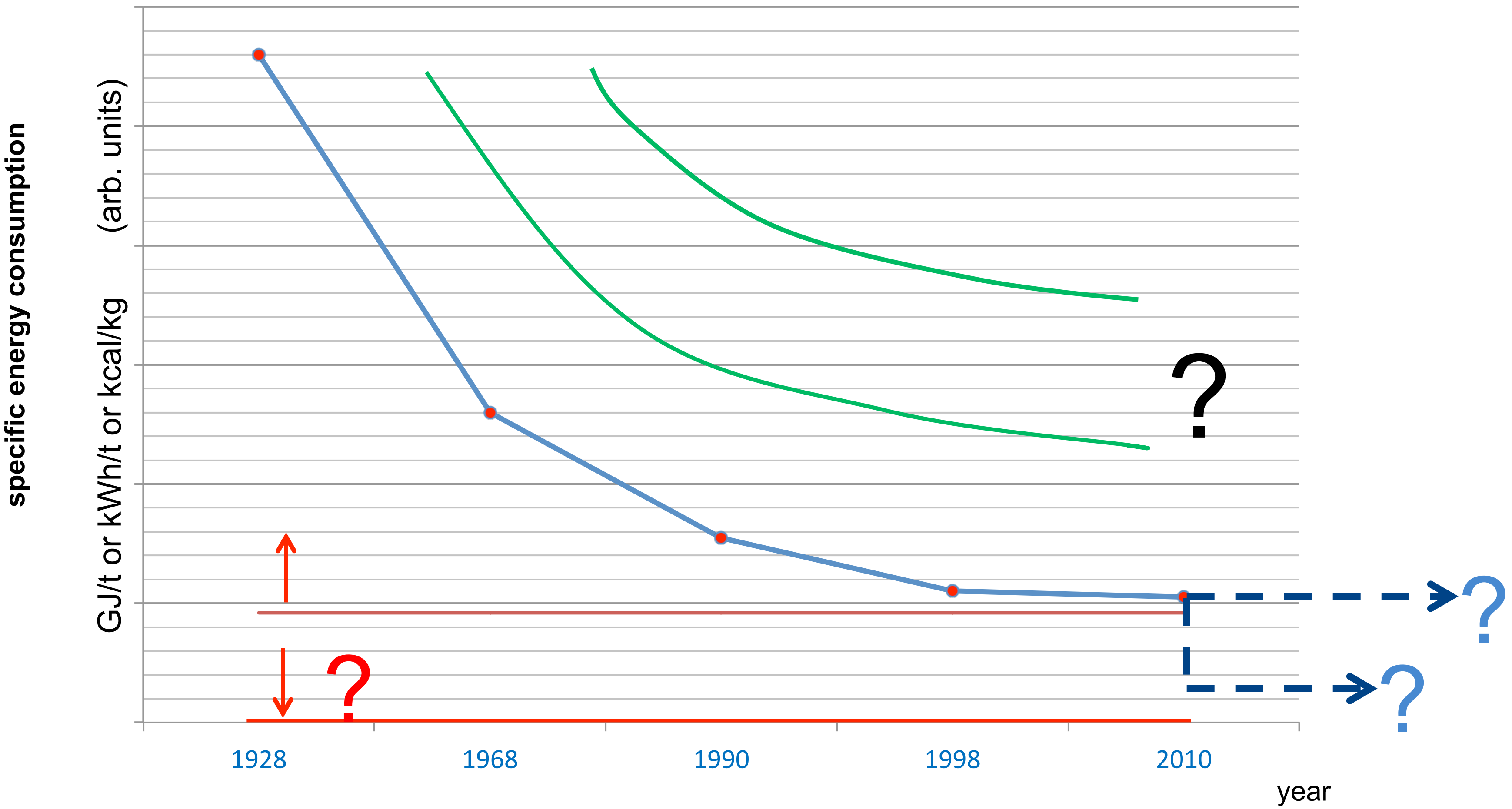
Specific energy consumption
Quo vadis ?



Agenda

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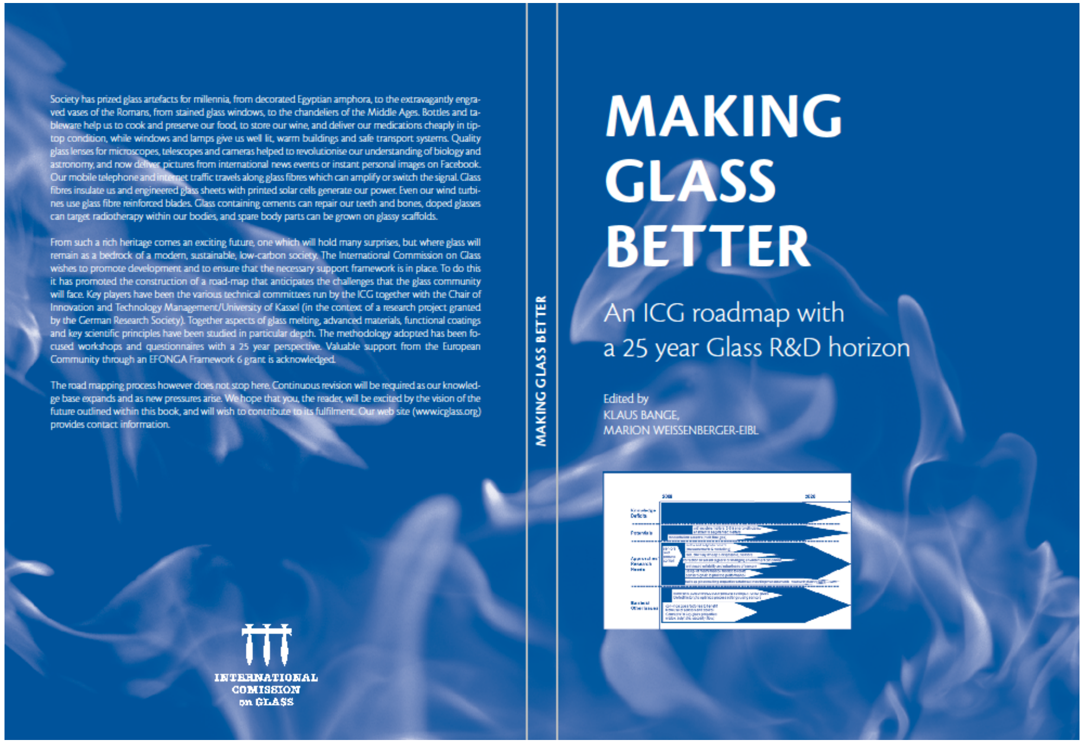
The ICG roadmap process

Roadmapping workshops

…results are published in Aug. 2010

1. glass melting technology
2. materials for technical and medical application
3. basic glass science
4. glass surfaces & stress corrosion mechanism
5. application related topics



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The ICG Glasroadmap: process & structur

Glass Melting Technology

Workshop held in Brigg 2008 by

Ruud Beerkens & Klaus Bange

with

16 participants from 7 countries

coming from

Industry, industry associations, institutes and research centers

and additionally

Feedback from **questionaires**

(> 50 participants)

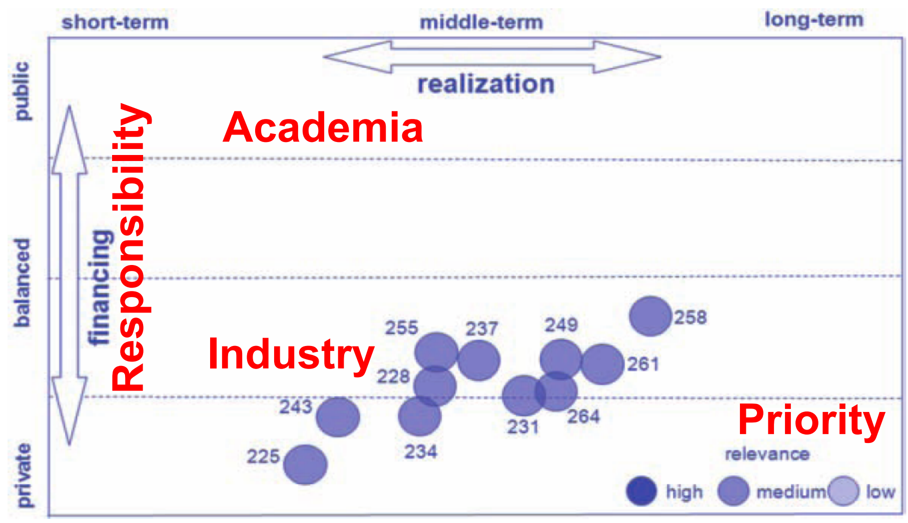
Improvement in traditional melting technology

Advanced melting technology

Sustainability aspects

Forming and joining

Time frame



Visualization of results

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ICG Glasroadmap

example: melting and energy & environment

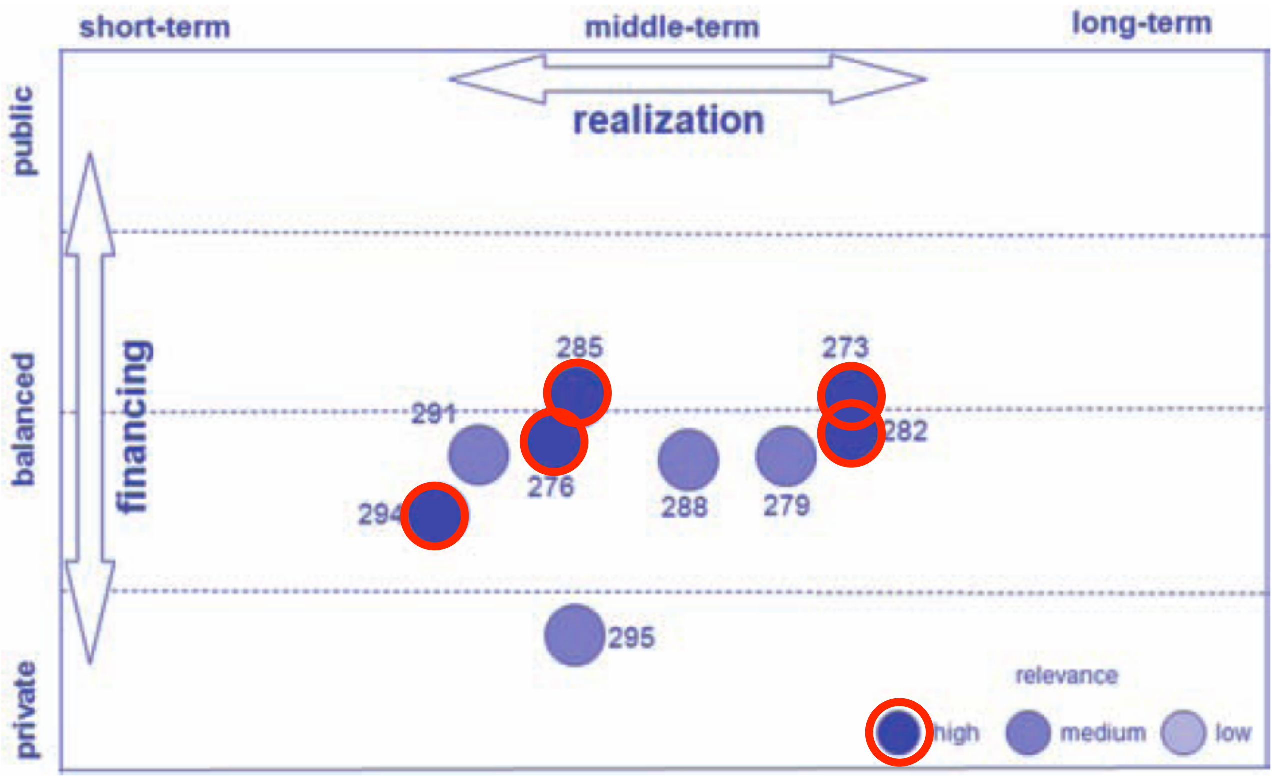


Figure 3.1.9: Sustainability aspects in the melting process by: • 273 Increase of energy efficiency above 65% • 276 Improve energy recovery • 279 Independence from single energy sources / Improve flexibility of melters for multiple energy sources • 282 Reduce use of fossil fuel (CO2 and Costs) • 285 Minimise emission of pollutants • 288 Cost and performance-neutral replacement of potentially harmful addivtives • 291 Energy savings by increased use of cullet • 294 Improvement of sorting / cleaning processes of cullet • 295 Energy savings by increasing yield

Energy-Related Topics Discussed in "Making Glass Better"

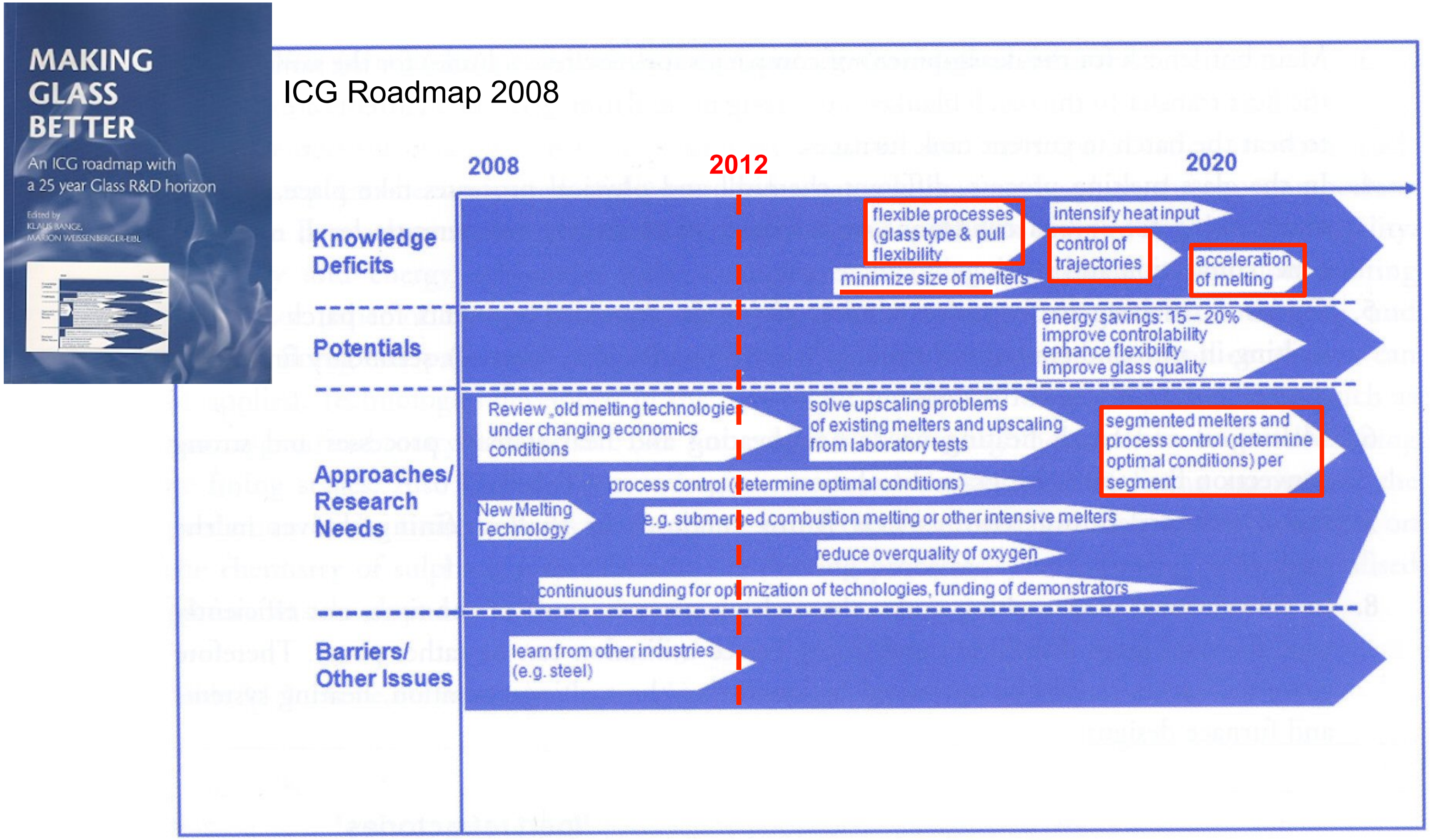
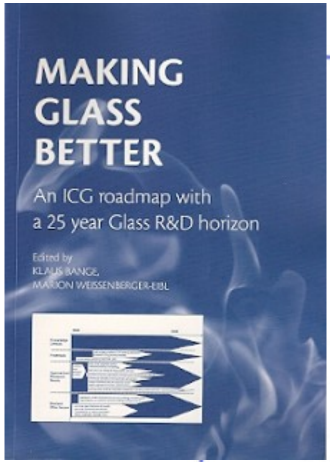


Figure 3.1.2: Roadmap "New Melting Technologies"

Energy-Related Topics Discussed in "Making Glass Better"



ICG Roadmap 2008

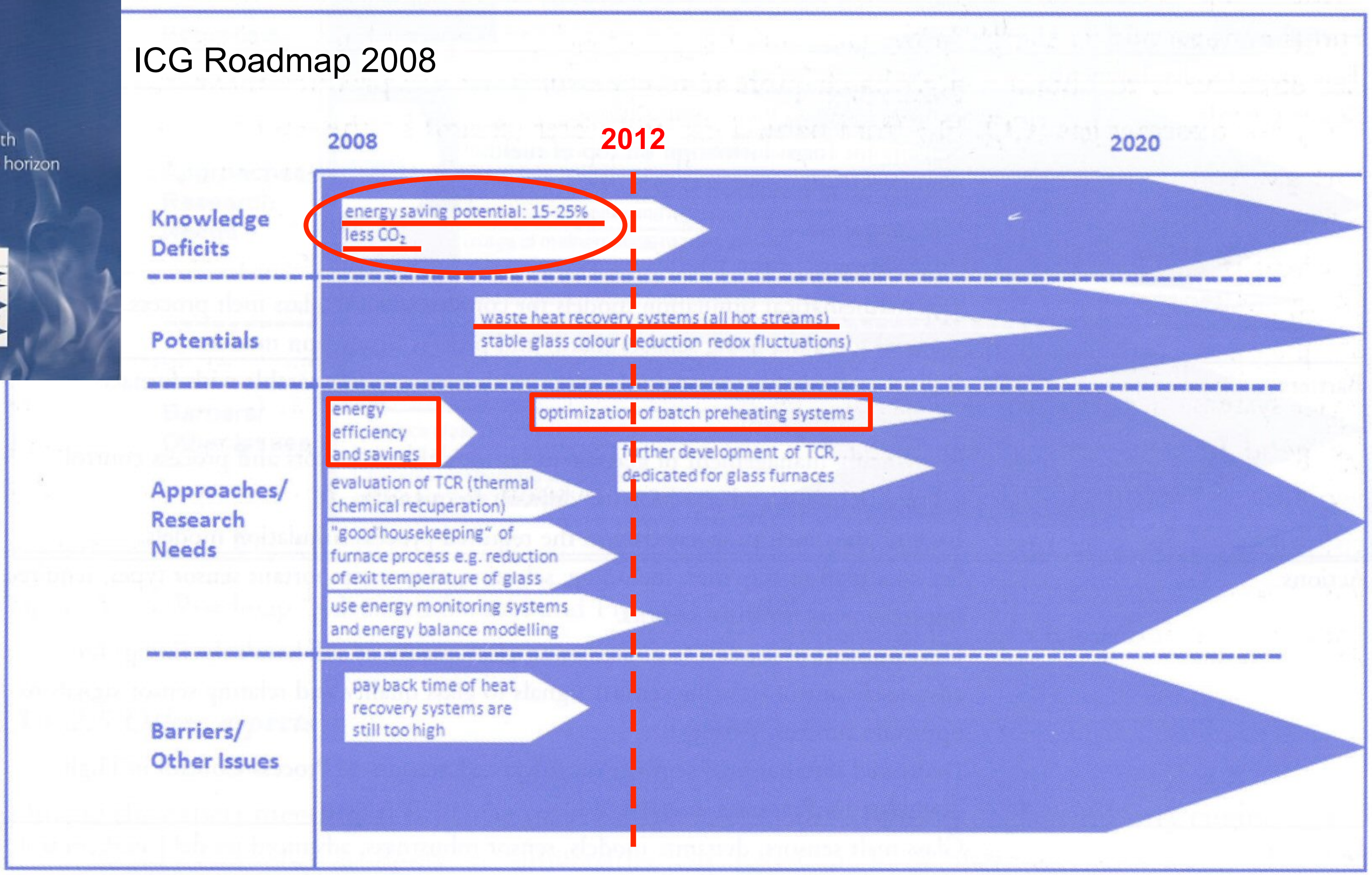
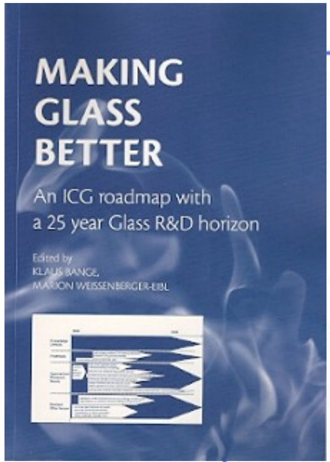


Figure 3.1.5: Roadmap "Energy Efficiency and Waste Heat Recovery"

Energy-Related Topics Discussed in “Making Glass Better“



ICG Roadmap 2008

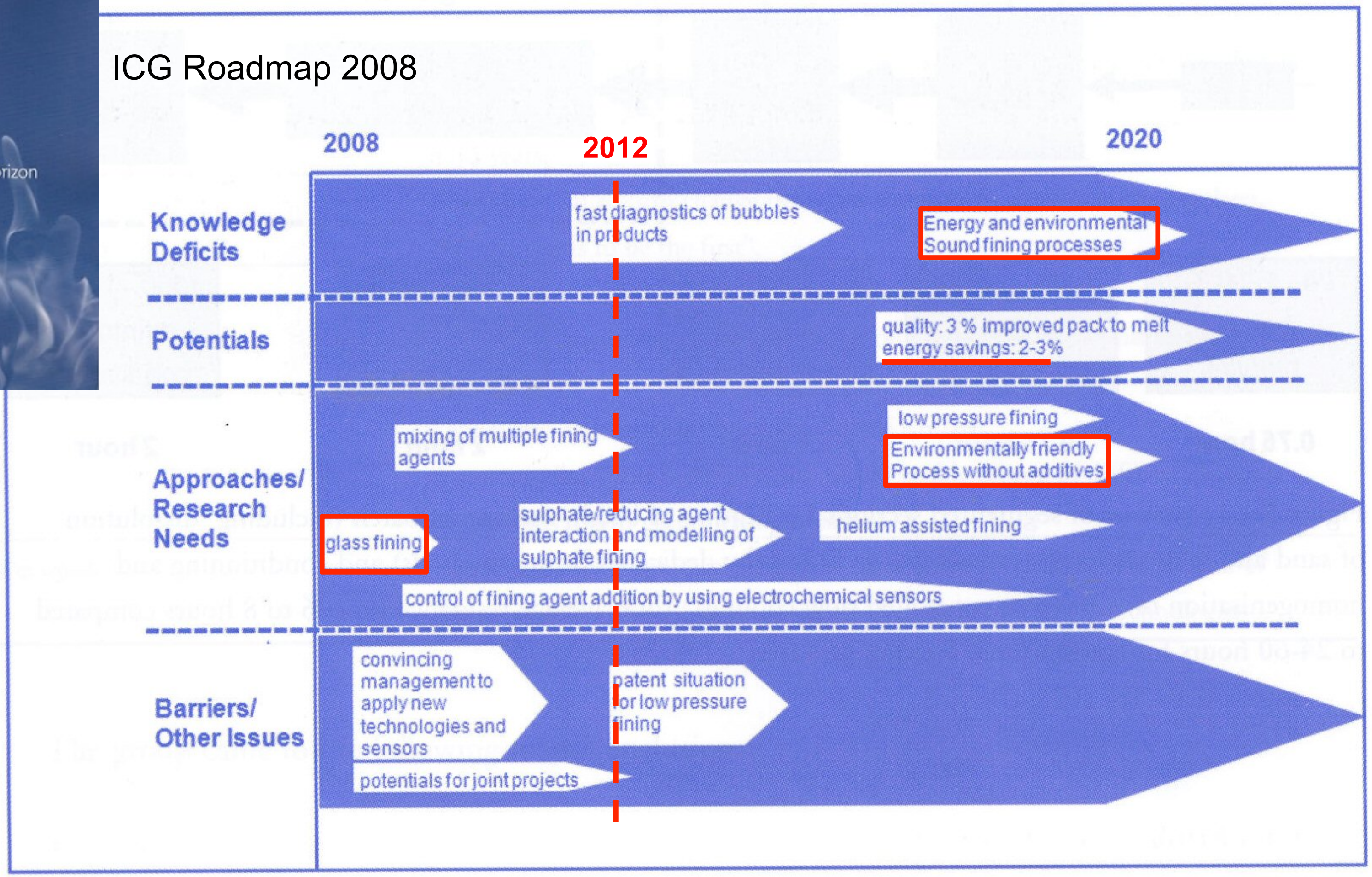


Figure 3.1.3: Roadmap “Glass Fining”

Results 2008

New glass melting concepts & Advanced fining processes

- Currently applied glass melting furnaces show a **very wide residence time distribution for the melt in the tank** and an **average residence time** about **5 times the minimum residence time**.
- The **glass melt** is on average about **5 times longer** in the **melting tank** than necessary when comparing with **laboratory batch processes**.
- Main **bottleneck** for the development of compacter melters (less volume) for the same pull is: the **heat transfer to the batch blanket**: strong re-circulation glass melt currents are required to heat the batch in currently applied tank furnaces.
- In the glass melting process, different chemical and physical processes take place, each of them asking for special conditions with respect to chemistry, temperature level, residence time, convection & stirring.
- **Optimum melting performance** requires **physically separated segments** for batch heating, melting-in and sand grain dissolution, primary fining (bubble removal) and secondary fining and thermal conditioning of the melt.
- Melting-in and batch heating needs new heating and heat transfer processes and strong convection.
- **Faster primary fining requires new fining methods or shallow fining shelfs in the tank.**

Results 2008

Tailored batches & cheaper batches replacing soda by other raw materials

- There are methods to improve the melting kinetics of batch materials by **batch pretreatment** methods: **tailored batches**.
- Tailored batches can be **pelletized batch** or premixed batch or using other raw material grain sizes or using different melting routes (mixing and melting in stages).
- Grinding & milling of batches and simultaneous mixing of the finer batch presents a potential for improving melting kinetics and obtained glass homogeneity.
- **Soda** is one of the most expensive raw materials (per ton glass) in most glass productions, it is recommended to search for alternative alkali-containing raw materials.
- There is a need for **methods** to develop tailored batches and **to use results from labscale tests** (e.g. batch free times, melting rates) to the estimate the effects **on industrial scale** (energy savings, changes in batch blanket dimensions, increased pull).

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Results 2008

Glass quality & Higher temperature refractory materials

- Definition of **glass quality** and development of measuring methods for glass quality
- Glass should not be over-qualified for certain applications where such high quality is not required. Over-qualified glass will be too expensive and needs extra energy for producing it.
- Faster detection and diagnostics of glass defects are required to correct the glass production process in case of glass quality problems

- **High temperature refractories** are enablers for **rapid melt**ers and fining processes
- Combinations between refractory metals (e.g. molybdenum or alloys) ceramic refractories in combination with adapted furnace designs may reduce refractory wear at the most critical areas (throat, metal line)
- Glass industry should stress refractory companies to invest in more research for developing higher temperature refractories . The problem here is, that glass industry does not have a big purchasing power (… is too small).

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Results 2008

Waste gas heat recovery to reduce energy consumption

- The highest potential in saving energy can be exploited by installing **waste heat recovery systems**.
- Flue gas heat losses amount to about 30 to 35 % of the energy input in the average glass melting process and can be reduced to about 17-20 %.
- **Prime candidates for waste gas heat recovery are pre-heaters for batch and/or cullet.**
- Cullet pre-heaters are rather efficient; batch-cullet pre-heaters operate best with pelletized raw materials or high cullet levels.
- **Barriers for introducing preheating systems are due to high investment costs (payback times).**

Agenda

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Energy Panel 2012
Goals

- review of progress achieved since Brigg meeting 2008
- identification of hurdles
- results of new melting concepts
- identification of mid-term potentials for energy savings
- a first glance on alternatives

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Energy Panel 2012
Presentations & Speakers

Energy reduction in glass melting: thermodynamic considerations and limitations
Prof. Conradt, RWTH Aachen Universiy

Analysis of Glass Melting & Fining Performance of Glass Furnaces in Relation to Energy Efficiency
Prof. Beerkens, CelSian Glass & Solar b.v.

Efficient bubble removal
Prof. Nemec, The Academy of Sciences of the Czech Republic

Inflight melting of glass
Prof. Yano, Tokyo Institute of Technology

Future energy saving potentials in melting glass with furnaces based on the invention of Friedrich Siemens
Dipl.-Ing. Fleischmann, Hüttentechnische Vereinigung der Deutschen Glasindustrie e.V.

Energy efficiency improvements of soda-lime float glass furnaces
Ir. Fasilow, ACG Europe

Preparation of glasses via a sintering route of nanoparticles
Prof. Clasen, Saarland University

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Specialty Glass and Glass Ceramics:
What can we learn from progress made with soda-lime ?

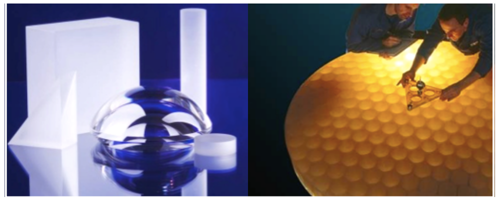
Home Tech

Glass Ceramics

Pharmaceutical Systems

Borosilicate Glass

Advanced Materials

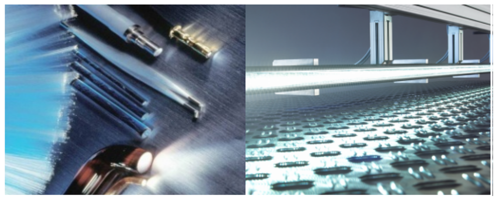


Optical Glass & Glass Ceramics

Flat Glass

Electronic Packaging

Lighting and Imaging



Solar
Borosilicate Glass

Specific situation of specialty glass industry

What makes our business "specific" ?

- more / other raw materials
- various glass types
- higher melting temperatures
- multitude of forming technology
- diverse batches/small lot sizes
- specific energy consumption
- quality requirements

classic („soda-lime-silicate glass"):
soda ($CaCO_3$), lime (Na_2CO_3), silicate (SiO_2)

specialty glasses today:
different oxide, carbonate, nitrate, sulfate ...

technical glasses up to ~ 7 components
optical glasses up to ~ 14 components

Specific situation of specialty glass industry

What makes our business "specific" ?

- soda-lime glass
- alumosilicate glass
- non-alkaline-earth borosilicate glass
- borosilicate glass (containing alkaline-earth)
- high-boron-containing glasses
- LAS-Glass ceramics

←

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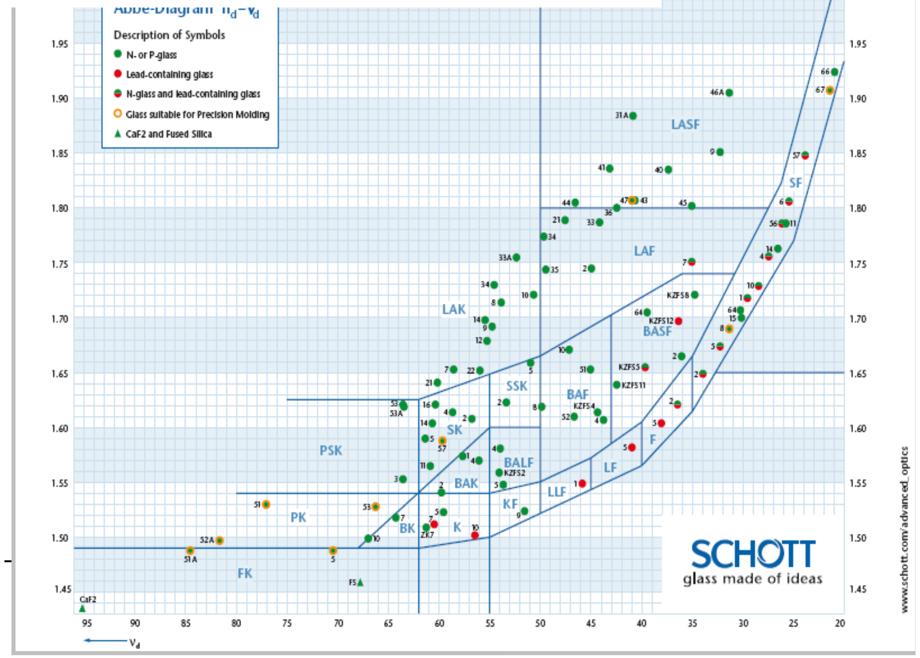

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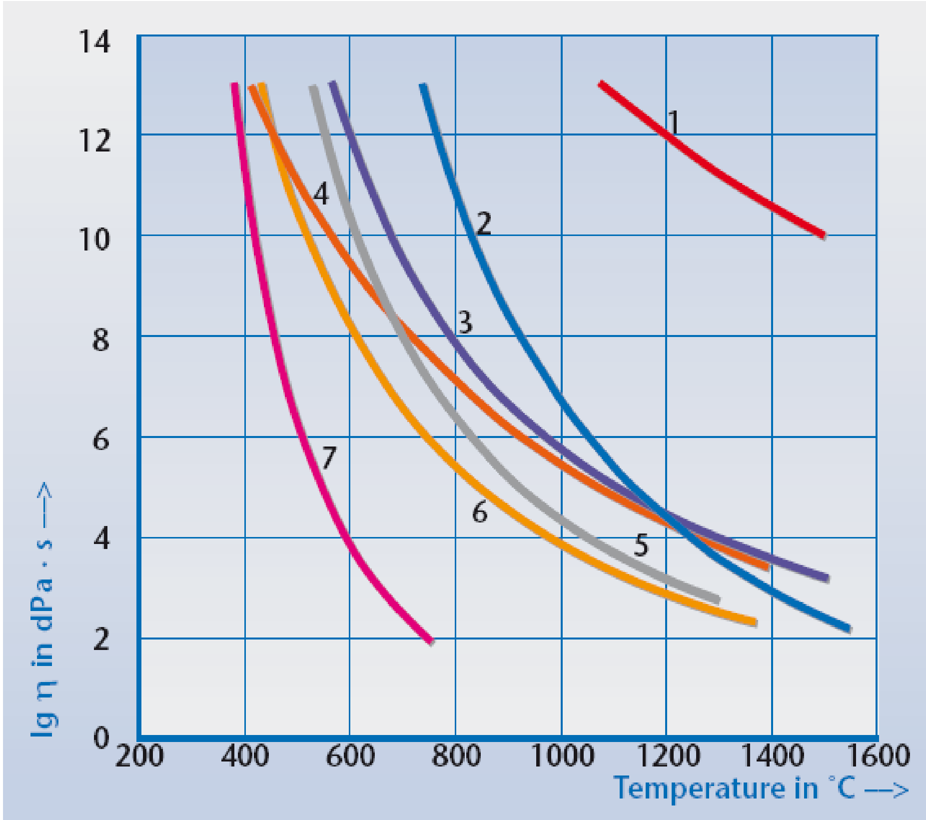

Fig. 10. *Viscosity–temperature curves for some important technical glasses. 1: fused silica, 2: 8409, 3: 8330, 4: 8248, 5: 8350, 6: 8095, 7: 8465.*

Specific situation of specialty glass industry

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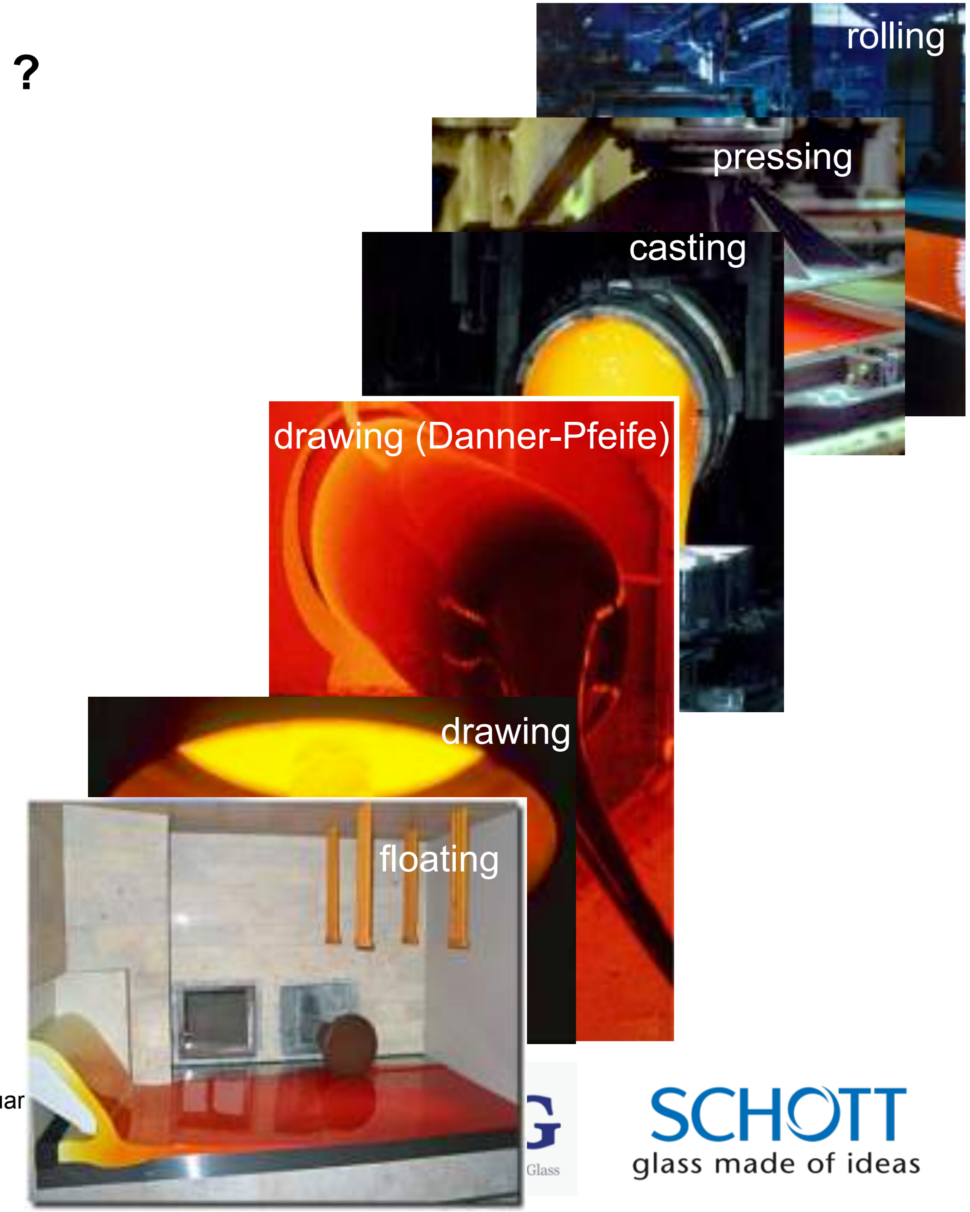

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Specific situation of specialty glass industry

What makes our business "specific" ?

Throughput:

0,5 – 80 t/d

continuous/batch

- more / other raw materials
- various glass types
- higher melting temperatures
- multitude of forming technology
- diverse batches/small lot sizes ←
- specific energy consumption
- quality requirements

Specific situation of specialty glass industry

What makes our business "specific" ?

- more / other raw materials
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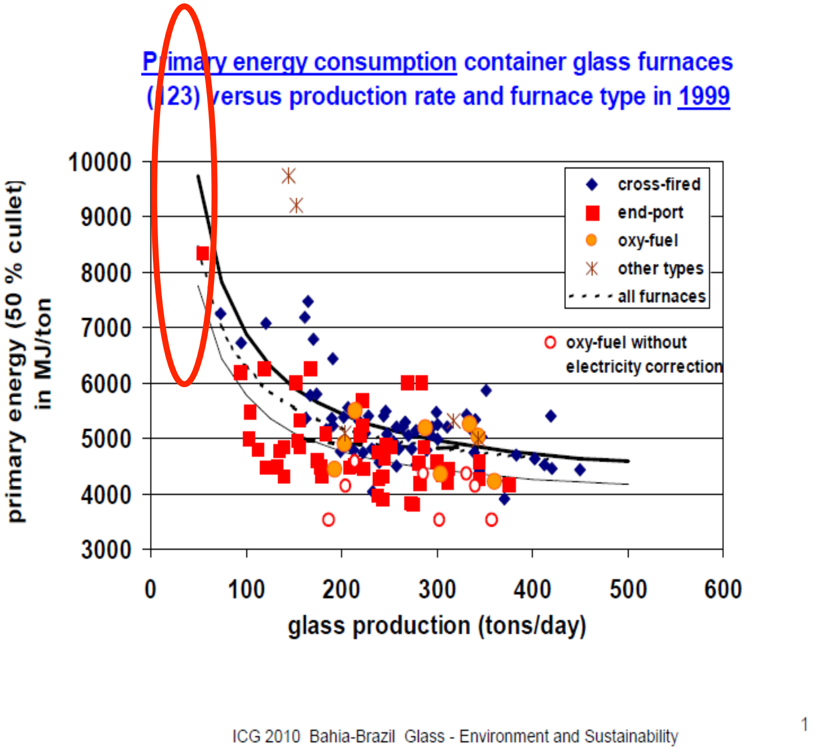
- multitude of forming technology
- diverse batches/small lot sizes
- specific energy consumption ←
- quality requirements

$1kW_{electric}$ p.a. ≈ 1000 €

- glass production is an energy intensive process
- less than 1/3 of the energy input is used for the generating of the glass melt itself
- most of the energy input is lost in the process



Specific situation of specialty glass industry

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Specific situation of specialty glass industry

Summary

Specialty glass manufacturing energy consumption is generally different/higher from soda-lime glass manufacturing for several reasons:

- higher melting and refining temperatures → 1650 °C plus
- refractory material limitations and cooling → HZFC < 1750 °C
- slower reaction rates for melting and especially for **refining** → $E_L = f(T \cdot t)$
  → How can **rates for achieving glass** quality improved, where are bottlenecks or "lazy" volumes ?
- smaller tank systems with higher surface to volume ratio → 50 t/d
- significantly higher demands to glass quality in terms of homogeneity and freedom of **solid inclusions and bubbles** → "0" inclusions
- batch cullet ratio (internal cullets, external cullets virtually not available) → pros/cons ?

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Dipl.-Ing. Bernhard Fleischmann

(Hüttentechnische Vereinigung der Deutschen Glasindustrie e.V.)

Future energy saving potentials in melting glass with furnaces based on the invention of Friedrich Siemens

Selected topics:

- Valuable source of **statistical data** for energy consumption (focus on Germany)
- **Analysis of specific energy consumption dependency** on glass type, tank size, quality and environmental requirements etc.
- Detailed **energetic analysis** of different approaches for energy savings

Prof. Dr. Reinhard Conradt
(RWTH Aachen University)

Energy reduction in glass melting: thermodynamic considerations and limitations

Selected topics:

- The concept of **optimized reactions paths** can help to reduce the glass melting temperature and to speed up reactions kinetics. A **lower liquidus temperature**, e.g. by reducing the SiO_2 contents, and the corresponding low-viscosity primary melts enhance the mobility of the glass constituents; **small grains sizes** further help to speed up the conversion of batch raw materials into the glass melt at lower temperatures.

- **Waste heat energy** advantagely can be used for solid state reactions in order to synthesize silicates from SiO_2 and other batch components already at temperatures between 300 to 500 °C.

- In **analogy to heat exchangers** the power efficiency $1/\eta = P\downarrow in / P\downarrow ex$ and the latent heat flow in glass tanks must be properly balanced to reach optimum conditions. Mismatched reactions kinetics (e.g. around the batch blanket) should be tuned for better energy efficiency. **Measured energy balances of glass tanks help to reveal and to improve heat flow balance.**

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Prof. Dr. Ruud Beerkens

(CelSian Glass & Solar b.v.)

Analysis of Glass Melting & Fining Performance of Glass Furnaces in Relation to Energy Efficiency

Selected topics:

- In order to understand the performance of glass melting processes and criteria for good glass quality, the industrial glass melting process has been analyzed. **Tools for analyzing** such processes are:
  - **Computational Fluid Dynamic Modeling (CFD modeling)** for designing and optimizing glass making processes
  - **Energy Balance Models** to evaluate tank performance
  - **Process control** to minimize energy consumption and to stabilize glass quality
  - **Laboratory test**, to examine the properties of the (industrial) batch: batch free time, foaming tendency, fining onset temperature etcetera

- Large discrepancies between melting and fining rates determined at laboratory scale and production scale can be explained by the **very wide residence time distribution** in glass tanks: the minimum residence time is only 15-20 % of the average value in most industrial tank furnaces.

- In order to overcome this problem the concept of a **segmented melter** with separated process sections and optimized flow pattern is evaluated both by CFD simulation and experimentally.

Prof. Tetsuji Yano

(Department of Chemistry and Materials Science, Tokyo Institute of Technology)

In-flight melting of glass

Motivation:

To overcome the efficiency-limits of the Siemens melter by eliminating the batch blanket.
Granulated batch are injected to the melting chamber either by oxy-fuel burners or via a plasma arc.
Conversion into glass droplets within 10 ms !

Consortium of Asahi, Toyo Glass, Nat. Inst of . Mat. Science, New Glass Forum, and Tokyo Inst. of Technology
Melting soda lime in a 1 t/d tank achieved spec. Energy consumption of 3.8 MJ/kg
For alkali free borosilicate glass 10 MJ/kg have been demonstrated

The roadmap for in-flight melting foresees a 100t/d melter in 2020

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Conclusions (1)

Incremental

- Main progress in energy savings can already be made by **applying best practice** and implementing **incremental improvements.**
- Step-by-step improving glass composition, glass furnace insulation and optimizing chemical (re-) fining are **promising ongoing tasks**.
- Energy saving by **TCR or Hotox is leaving the conceptual phase**, first installations on pilot-scale are under discussion. First reliable results on performance and economy are to be expected within 2 – 3 years (short term)
- Tough **return-on-invest requirements** will slow-down rapid implementation of promising concepts (e.g. batch preheating, electricity from flue gas heat).

Conclusions (2)

Radical new concepts

- **Rapid melter- concepts** (like inflight melting) made a lot of progress and are close to the end of first trial runs. Main unsolved problem is the extremely high bubble content of the glass, there is no feasible rapid (re-)fining concept in sight. Major breakthrough in solving this issue on pilot plant level is not expected before at least 3 years (mid term). In-flight or SCM (submerged combustion melting) should be combined with effective fining and defoaming processes.

- **Segmented-melter concepts** are leaving conceptual stage and it is going to enter pilot stage. Significant results are expected mid-term.

- Industry requires short (2 years) return-on-invest for the transfer of new energy saving technologies. As a consequence, the necessary development and improvement of these technologies is shifted into the **pre-industrial stage (pilot plants), requiring high invest for R&D**. This type of projects can only be managed by industry/academia-consortia.

Conclusions (3)

New boundary conditions

- Industry will be forced to **re-think the concept of large, long-living efficient tanks**. Small aggregates, flexible in terms of throughput and glass-type may become economically preferred. (mid term)

- Esp. in specialty glass industry **saving energy and improving glass quality are divergent goals**, there are no short term technical solutions in sight to solve that contradiction.

- **CO_2 emission** certificates will remain an issue on European level. Industry will have to fight for exemptions to be able to compete on global level. So far in terms of energy costs and CO_2 emissions fossil fuels and electric melting have no distinctive advantage over each other.

- **New resources of unconventional fossil fuels (shale gas)** in the US and other countries will have a significant impact on energy prices worldwide. Combined with the threat of an economic downturn there will be less pressure on industry in general to force energy savings there (short & mid term)

- Special **situation in Germany**: whether Germany will tap into its shale gas resources depends strongly on the acceptance and political decisions (mid term). Other European countries (France, Poland) will presumably behave differently.

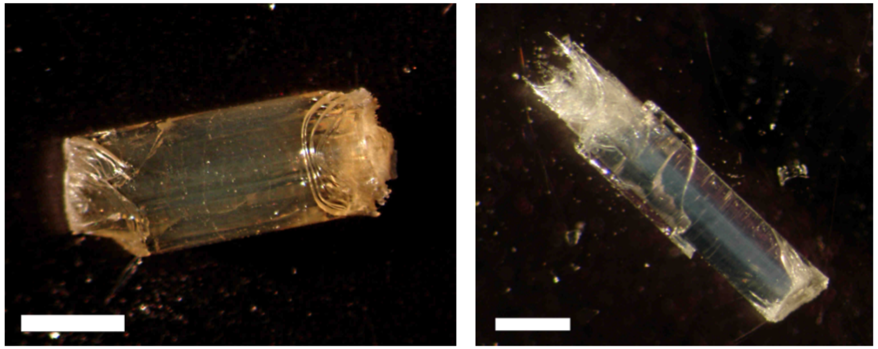
Energy Panel

Think different !

Glass production at 10 °C: Glass Sponges (*Hexactinellida*)

Glass Sponge species *Lophelia*

Monorhaphis chuni produces a single needle-like glass fiber up to 3 m in length and a diameter up to 8 mm !! It lives deep down in the Pacific Ocean and uses the glass fiber as an anchor into the ground.



Optical micrograph of a glass needle produced by species *Monorhaphis chuni (scale is 0,6 mm)*

Obrigado

Vielen Dank

Dzienkuje

Gracias

Maraming salamat

Komapsumnida

Shukran gazilan

谢谢
(Xie xie)

Cok sagolun

Dakujem vám

Mnogo blagodarya

Stort Tack

Thank you

Merci

Multumsec

Spasibo

Bedankt

Nagyon Köszönom

Grazie

Terima kasih

どうも有難うございました。
(Arigato)

Paljon kiitoksia

Efharisto poli

Dekuji

Shukriya