Light-induced regeneration for mass production

System design and actual results of inline belt furnaces

centrotherm

Innovative
Thermal Solutions

Our goal


We are committed
to a sustainable development
of regenerative energy
generation and future
semiconductor
applications.

Our employees

624 in the Group

~ 160 in R&D

~ 230 in production

~ 80 in sales

32 trainees

(as of December 31, 2016)

Production equipment for the photovoltaics industry

	Tube furnaces	PECVD systems	Conveyor furnaces	Regeneration furnaces	R&D systems
Equipment	c.DIFF c.DIFF LP	c.PLASMA	c.FIRE	c.REG	c.LAB
Anwendungen	▪ $POCl_3$ | BBr_3 Diffusion ▪ Wet | Dry Oxidation ▪ Annealing	▪ PECVD ▪ SiN_x ▪ SiO_x ▪ $SiON_x$ ▪ AlO_x ▪ Multi-Layers	▪ Fast Firing ▪ Drying ▪ Regeneration	▪ Solar Cell Regeneration ▪ Passivation of B-O-defects	▪ PECVD ▪ LPCVD ▪ Diffusion ▪ Oxidation ▪ Annealing ▪ Further processes upon request

Regenerator development at centrotherm

2014

August: Project started

September: first prototype (only 1500 mm long)

November: start sampling, start concept phase

2015

January: start design phase

April: design completed, start manufacturing version 1

June: start testing version 1

July: version 1 delivered to customer

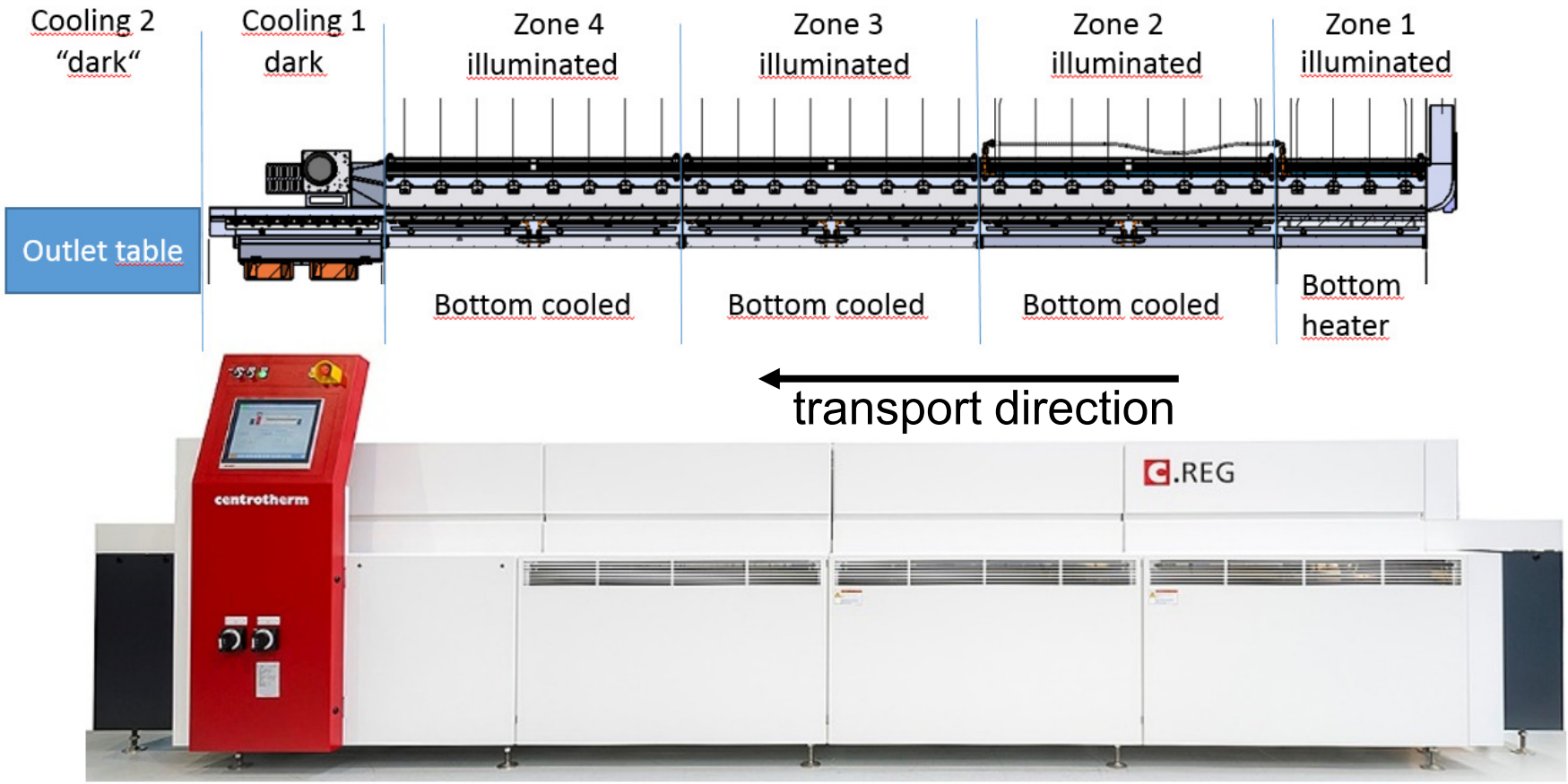
July – October: design version 1.1

2016

January: version 1.1 available

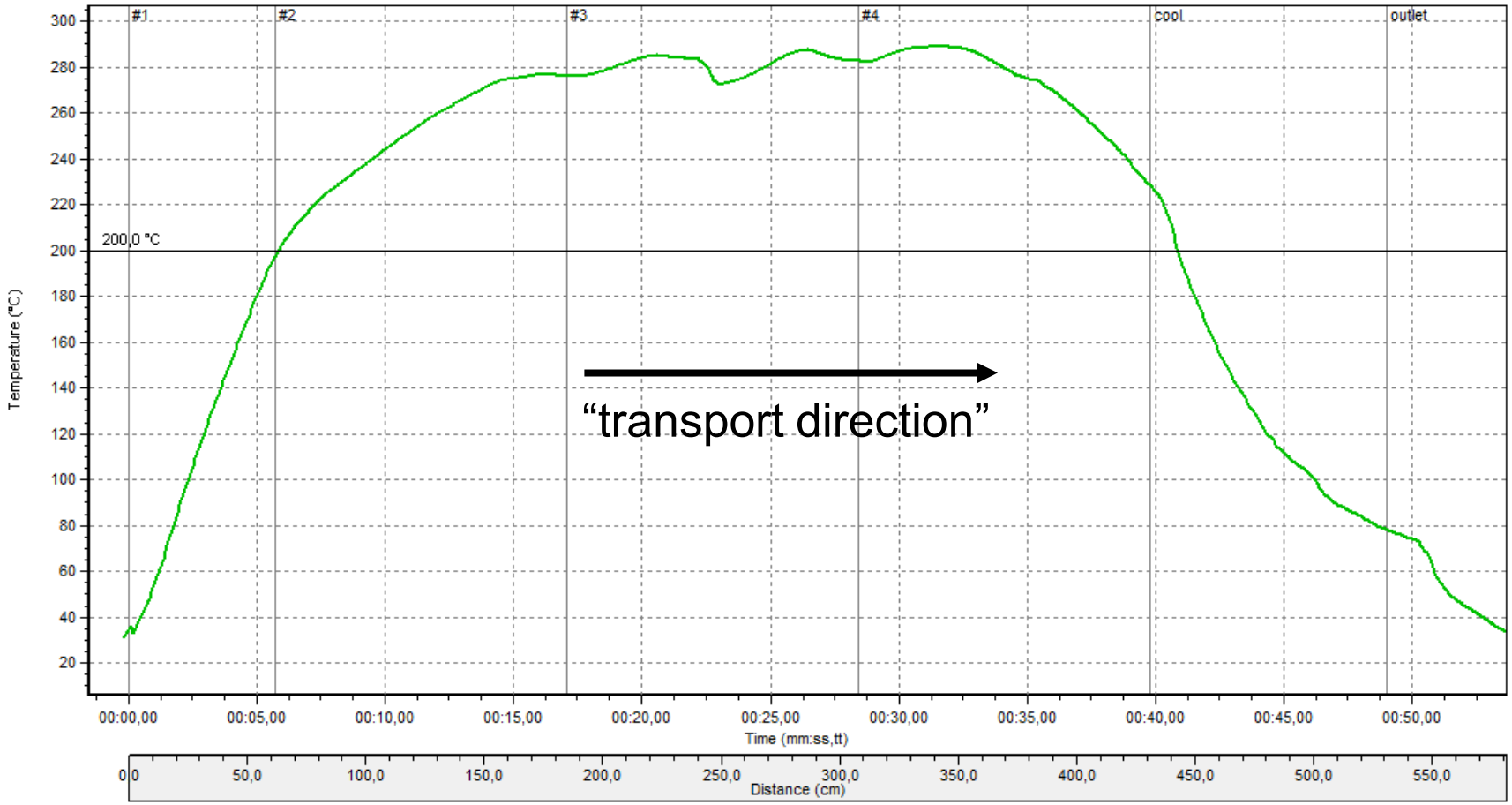
Regenerator structure

- Standard model: 4 zones = illuminated length 4200 mm



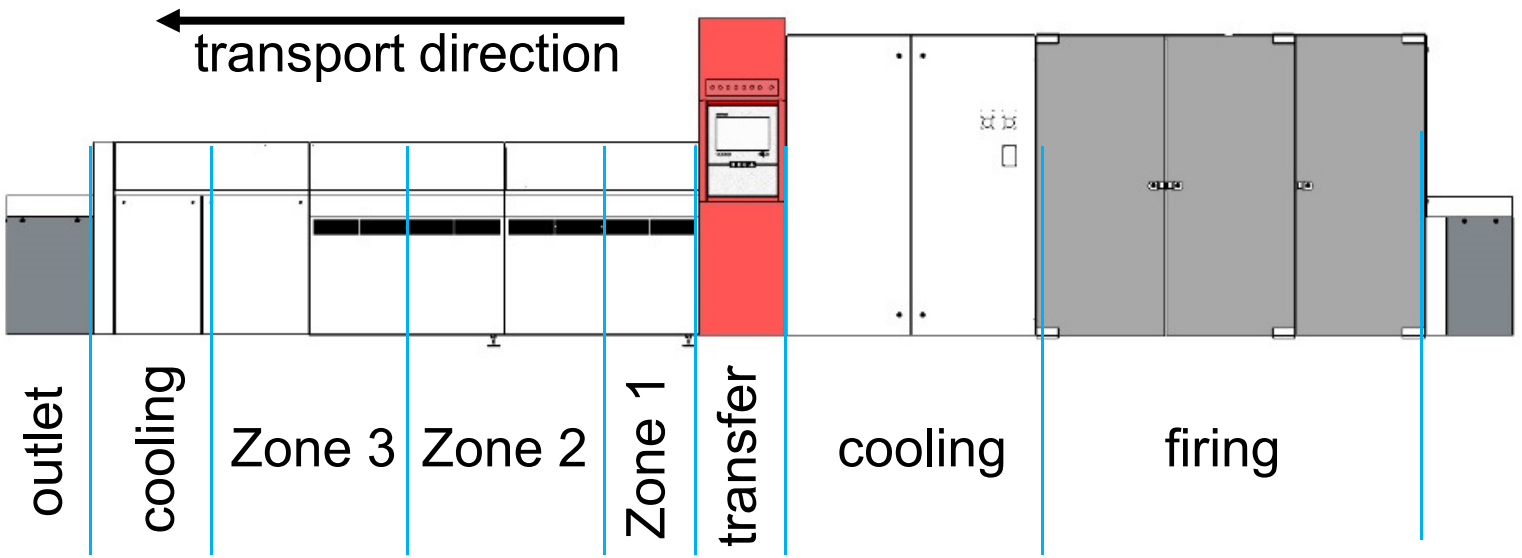
typical regeneration profile

- Intensity 90%, 280°C, 6500 mm/min, 35 sec > 200°C



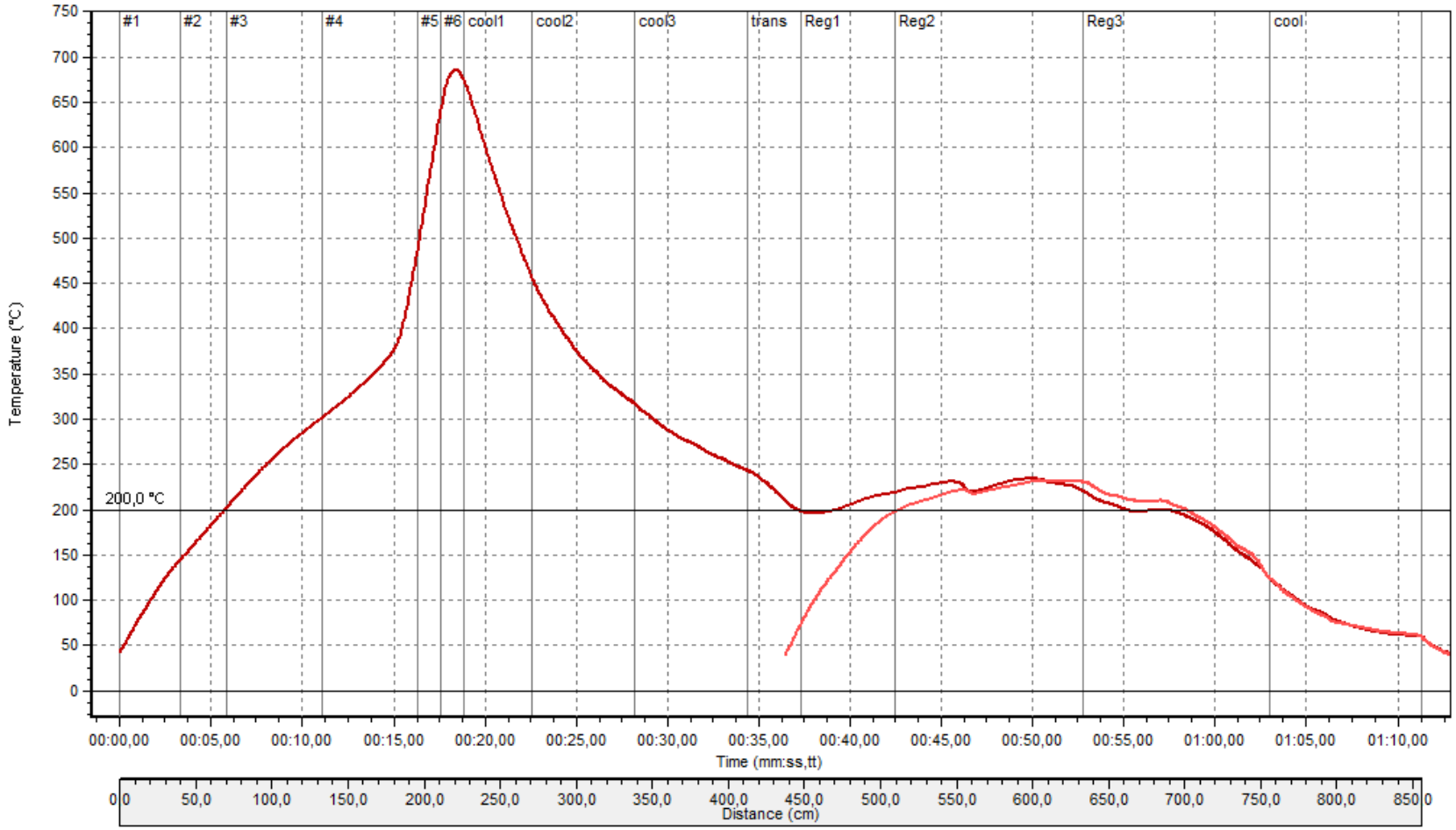
c.FIRE REG: firing furnace with integrated regenerator

- Classical firing oven with attached regenerator
- 3 versions available:
  - Illuminated length 1800 / 3000 / 4200 mm
  - Example: ‘medium’ version (3 Zones)
  - Enough for 80% of application scenarios



example regeneration profile

- Low temperature regeneration, 3-zones



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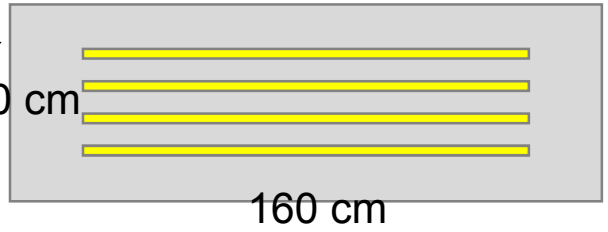
Typical regeneration experiment

- Cells ‘as fired’ (annealed state A)
- Parameter search: 3-8 groups of 5-10 cells each
- IV test before (E1) & after regeneration (E2)
- Mono: degradation 24 h @ 0.05-0.08 suns 40°C
- Multi: degradation 36-72 h @ 0.8 suns 50-75°C (temp. defined by customer)
- IV test after degradation (E3) → best regeneration parameter
- 50-300 cells regeneration with fixed parameter
- Module manufacturing, outdoor test (customer)
- Customer’s feedback (hopefully…)

Degradation test setup 0.05 suns for 120-200 cells

Cell tray: 3-4x10 cells, approx. 30cm distance from lamp



Warm air recirculation

→ Cell temperature 30-40° C resulting from heat released by fluorescent lamps
→ Light intensity 0.05 – 0.08 suns

LED lamps produce less heat → higher intensity can be realised in the same package.
Halogen lamps will overheat in closed cabinet

Fluorescent lamp 58 watts / 150 cm / color: white 865 – 24 pcs. with reflector

Degradation test setup 0.8 suns for 36 cells

- Modified light soaker for thin film modules
- 6x 400W Sodium lamps → 0.2…0.8 suns adjustable
- Water cooled/heated Al bottom plate 25-75 °C

- mc degradation (LeTiD) @ 0.8 suns 75 °C
- harsh mono degradation @0.8 suns 25-50°C

Survey of all experiments

		E2 cell parameter shift caused by Regeneration %				E3 cell parameter shift after regeneration + LID test %			
machine	**runs**	**dIsc**	**dUoc**	**dFF**	**dEta**	**dIsc**	**dUoc**	**dFF**	**dEta**
c.reg 6200	63	0.06%	0.16%	0.20%	0.28%	-0.33%	-0.81%	-0.87%	-1.05%
c.REG 6200 multi	20	0.27%	0.23%	0.03%	0.54%	-0.23%	-0.21%	0.03%	-0.41%
c.FIRE REG	26	0.08%	0.15%	0.12%	0.35%	-0.34%	-0.11%	-0.31%	-0.76%
c.FIRE REG multi	11	-0.18%	0.13%	-0.23%	-0.28%	-1.89%	-1.12%	-1.70%	-4.62%

- Average parameters for mono cells
  - 30 sec > 200°C under 8-9 suns illumination
  - Transport speed 6 m/min → 4000 wafer/h
  - Plateau temperature 270-280°C
- Average parameters for multi cells: N/A
  - Too high bandwidth of settings
  - Regeneration can take > 60 sec
  - Some materials tolerate higher temperature (300-350°C)

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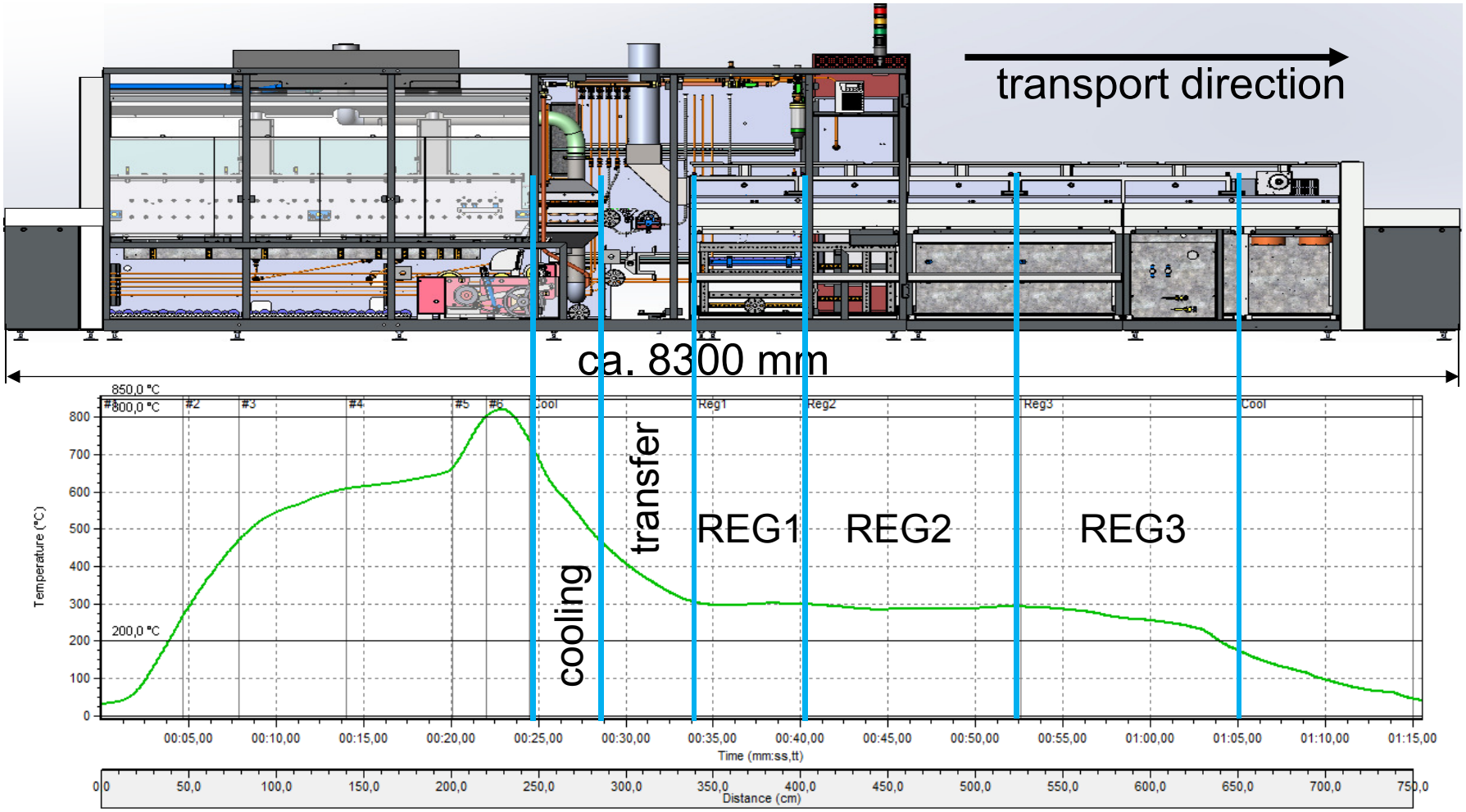
Typical issues

- Passivation instability → efficiency gain after regeneration cannot originate from B-O complex passivation
- Degradation modes other than B-O complex related
  - can be identified through degradation conditions
  - some module manufacturers request 1 sun xx hours test
- Unclear / undefined material properties
  - Only few users can fully specify wafer properties
  - Brick height, ingot growth conditions typically unknown
- Overheating of material during regeneration

- Settings dominated by throughput request
- Regenerator idle due to automatic handling failure

Nest step: optimum integration of firing and regeneration

- length reduced by 1200 mm, optimum regeneration start temp.



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summary

- The fastest & most complete R&D project at centrotherm
- We learned from our customers as well as customers learned from us
- Light injection of carriers equals ≈ 80 amps CID
- ≤ 1% rel. LID after regeneration of mono cells
- Optimum mono regeneration parameters are very well predictable
  - Standard regenerator can be sold without prior testing
- Wide parameter range for mc regeneration parameters
  - Prior testing is mandatory
  - Some materials are not acceptable
- Stand-alone regenerator recommended for maximum process flexibility

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