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Transfair Engineering:

Thermoforming in the Household Refrigerator Industries today

Survey about existing Thermoforming Equipment for this Application

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Content

THERMOFORMING IN THE REFRIGERATOR INDUSTRY

Survey about existing thermoforming equipment for this application

1. Selection criteria

Relevant for the selection of thermoforming lines are the following criteria in the inner liner refrigerator production according to our experience:

(1.) The vacuum thermoformer should be able to **manufacture liners of all existing and future model designs in good quality,** if needed, even a complicate refrigerator liner with 2 cavities in thin materials with a small freezer compartment (with extreme square/deepness ratio) **with normal experienced staff with losses less than 0.5 %**;

(2.) **High production flexibility** is needed to enable to produce daily needed models and **in the needed varieties per shift without capital binding by final and intermediate stocks** and no waste **(lean manufacturing)**;

(3.) Not the theoretical cycle times under optimal conditions for the machine, but **the realized produced quantities of needed different liner models per shift are relevant** for the selection of machine and technology; that means also that

- **losses of materials and production interruptions** as result of difficult technology, change over of models with different parameters to be adjusted, mistakes or **fluctuation of environmental temperature or voltage fluctuations** in electrical power supply **should be reduced to minimum** (less than 0.5%), and these fluctuation should be kept as far as possible under control by the machine itself; and
- **High availability of thermoforming production capacity** is needed, with **fast change over** of moulds, easy setting and re-starts of machine; a break-down of machine and some missing spare parts should not result into strong refrigerator production capacity reduction,

(4.) **Machine and tooling costs and, last not least, manufacturing costs of components, especially**

- **the losses of sheet edges to be cut,** which is some lines can be avoided /(Geiss, Illig), in other lines (Comi, Rigo) up to 25% of sheet size more than needed (+70-90mm on all sides!) **and**
- **the energy consumption** which is normally in the range of 13-20% of the thermoformed refrigerator cabinet liner and the required sheet thickness should be as low as possible to reduce cost of refrigerator and increase profit margin.

To respect such cost and quality relevant criteria we have to take a closer look on the available machines on the world market - especially the line concept (inline with pre-heaters versus single stations) to produce inside 1-2 days wide model ranges (fast model change-over without large intermediate storage), minimum wastes (zero loss, less cut-off) and less energy consumption, the heating concepts with IR ceramic elements, quartz elements or Halogen lamps.

The **theoretical cycle time is often the mayor criteria for decision makers**, which is wrong: In practice, not the nominal output, but the real output of machines in the model diversity as needed to avoid mountains of foodliners or big final storages is relevant, and according to our measurements in many refrigerator factories often very different from the theoretical values.

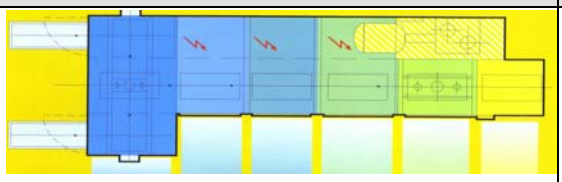
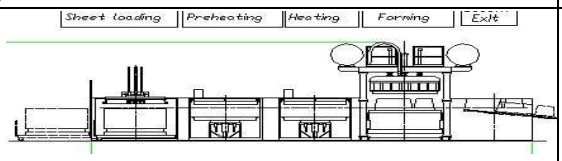
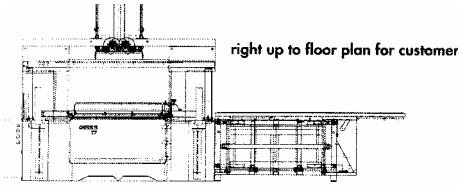
2. Thermoforming machines on the market

Comi with its fast lines is the market leader in thermoforming of inner liners in refrigerator branch.

Comi Super Line with 2-sheet loader, 1-2 preheaters and bubble suction forming

Geiss TT8 single station thermoformer with automatic sheet loader/ auto-depositing of liners and mould and sheet carriage for fast change-over of models

The existing vacuum thermoformers for refrigerator inner liners production can be sorted in 3 groups:

DESCRIPTION	Cycle times for cabinet inner liner (3,2mm HIPS)		Price Levels
	Minimum	**Ranges**	(1) **€**
(1.) Very fast lines with loading, 2 preheaters, heater, forming and de-loader stations. As inline version (Comi, Illig, Asano, Rigo, Brown), but also as rotary version (Brown) combining loading and deloading. 	**32s**	**37-60s**	**700000**
- with **NC-controlled movements**	**28s**	**33-55s**	**800000**
(2.) Fast lines Lay-out like above line, but with 1 preheater, As inline (Comi, Illig, Asano, Cannon, Kiefel, Rigo, Brown) or as rotary (Brown), last can combine loading and de-loading). The market leader in refrigerator inner liner production lines is **Comi.** 	**50s**	**55-110s**	**400000**
- with **NC-controlled movements**	**42,5s**	**45-90s**	**500000**
(3.) Single Stations Heating and forming in one station; with automatic loading and deloading (Geiss, Cannon, qs-group, Comi). The leader in this area is **Geiss**. 			
a) with ceramic heater (higher running cost) manual loaded	**100s**	**125-185s**	**155000**
b) with **Quartz lamps** (cheaper running costs)			
- manual loaded	**90s**	**115-175s**	**185000**
- automatic loading and deloading	**90s**	**105-165s**	**225000**
- automatic loading and deloading and fast change-over	**90s**	**105-165s**	**270000**
c) with **Halogen** flash lamps (much cheaper running costs)			
- manual loaded	**75s**	**95-135s**	**210000**
- automatic loading and deloading	**70s**	**90-130s**	**250000**
- automatic loading and deloading and fast change-over	**70s**	**90-130s**	**300000**

(1) Mentioned prices are without cutting and trimming station, often in the range of additional € 125000-170000.

Other technical differences will be considered in next chapters. **In a first view the prices per reached capacity are very similar,** independently if the capacity is realised with one very fast line, with about 2 fast lines or with 3 full automatic single stations. **But in practice it is not the case for a refrigerator production** (see chapter 7 f.): The needed investment per reached realized capacity in the production mix as needed in a household refrigerator production is much higher for very fast and fast lines than for single station lines.

3. Cycle times

In the past **thermoforming machines were selected and sold mainly by the theoretical cycle time** to thermoform one ideal piece – and till today in many areas of the world this is still the first criteria. Often in competition some manufacturers and their agent passes figures which are far away from reality for existing refrigerator inner liner models and under conditions made which is in practice seldom reached. It is really surprising which large range of theoretical cycle time values are granted to my customers by different manufacturers (Asano Laboratories, Comi, Geiss, Illig, John Brown, RIGO, Cannon-Shelley) in the last 20 years and what was the real difference in practice. It seems that some countries and same purchaser on the refrigerator branch side and salesmen on the machine supplier side have slower timers than others. In practice **the theoretical cycle time differences (without deducting the losses and stand still times) are marginal (0-4% max.) between the existing machine models as long as we remain inside**

- **each group**, that means we compare single stations with other single stations, lines with 1 pre-heater and heater to each other and lines with 2 pre-heaters and heater to each other and under the condition that
- the **same material** in the **same thickness** and **same size** to heat with same cut waste (not 25% more waste to cut)
- the **same heater types** (Ceramics, Quartz or Halogen lamps),
- the same **drives** to position moving parts (pneumatic, hydraulic or servo motors),
- the **same mould** with same geometry, heating and cooling channels are thermoformed by
- the **same experienced thermoforming staff**.

This is not surprising if you take a closer look to the **speed influencing factors of the machine**:

1) S**peeds of mechanical movements** are only a small portion of process time and it does not differ significantly between the a.m. producers inside each line group – with one exception: using fast NC-controlled servomotors instead of electromechanical and pneumatic movements, speeds up movements by 20-30% - representing 5-7 % of cycle in a single station, but about the double in a fast line. It improves movement preciseness and by this way limits waste on high speed line. But its cost increase of about € 100000 +/-25% could only be economically justified in fast and very fast lines in which speed of movements became a bottle neck of cycle time; while in single stations it is much more economic to add further machines allowing parallel production of more models with less model change-over and its involved change over time and material wastes. One manufacturer split the heater in 2 pieces to reduce movement ways and time and to gain space (RIGO), other uses a motor drive and crank arm for the heater movements (Geiss) which is faster than pneumatic cylinder. More relevant for cycle time cutting is that the bottom (table) and top (plug assist) movements can be step less adjusted (NC-driven, Geiss even on pneumatic ones), so that these movements can be shortened for pieces with lower deepness.

2) **Pre-blowing process** time to expend sheet to a bubble in male mould systems is practically the same, as long as the volume, the material thickness and the air pressure (normally adjustable from all) are the same and the plastic bubble height controlled (light switch); same conditions we have if we compare pre-suction systems in female mould systems.

3) **Vacuum speed** is more a problem of the mould and not of the machine itself as long as the volume of a pre-evacuated tank and size of evacuation pump was dimensioned according to the product vacuum needs and production speed. So it depends if mould is made by an experienced manufacturer. We gain only process time if vacuum forming is combined with air pressure by an upper plug assist mould (Comi, Kiefel).

4) **De-moulding and cooling time** has nothing to do with the machine, except a water spray feature. Time relevant are the material heat content, the liner geometry and the **mould construction**: male mould thermoforming systems allow **air blow** with **water spray** cooling, as long as heaters are out of water spray area. Ceramic heaters in water spray area would be destroyed and could cause fire. Machines without water spray needs 2-3 times as much de-moulding time. The alternative to cool down mould by an mould cooling circuit instead of water spraying speeds up cooling, but such cooled down moulds needs afterwards more time to heat up again for forming so speeding up by this way is limited and causes more energy costs. De-moulding time is the bottle neck in very fast line with combined air pressure and vacuum forming and NC-controlled movements, if they have no water spray system.

5) The mayor time of the cycle is anyhow the **heating** and if same quantity of heating stations and **same heating elements** are use there is very limited **chance for a manufacturer to be significantly faster as his competitor** in manufacturing of same pieces on same mould with same material and sheet thickness.

But if all other conditions (material, sheet thickness, heaters, mould etc.) remains the same very fast lines with 3 heaters can be maximum 3 times as fast as single station machines with one heater, and max. 33 % faster in comparison to machines with 1 pre-heater (= totally 2 heaters):

a) **35-60 sec**. for a very fast machines with 2 pre-heaters, totally 3 heaters,
b) **60-110 sec**. for a fast line with 1 pre-heater, totally 2 heaters and
c) **120-180 sec**. for a single station without pre-heater (by using ceramic heaters, see later quartz and halogen heaters).

The major reasons for theses more realistic cycle times as often granted by machine producers strongly under pressure of competition in this point are the following 3 points:

6) **Material and material thickness**

If better Polystyrene materials are used, for example BASF KR2713 instead of KR2710 for this kind of products the time increases by minimum 5%. **Specially a thicker sheet,** as used for a 2-cavities liner (at least 50 % thicker as a sheet for 1 cavity if material is not taken from sides to be cut away) **increases the heating time by about 100% in all machines, which would result in a cycle time increase of**

a) about 50% in a single station without pre-heater,
b) about 37% in a line in which 100% heating time increase can be split on 2 heaters and
c) about 29% in a line in which 100% heating time increase can be split on 3 heaters.

Some companies are tricky and reach higher speed, by **reducing thickness of sheet and increasing sheet size** (about +25%) to get enough material for the deep drawing refrigerator foodliner from the outer sheet areas. By this way materials needed in deep drawing foodliner areas are mainly taken from excess in sheet size, which after forming must be cut away, which **increase waste (about +15%) and costs.**

(1) Geometry

Complicate undercuts and forming sections like profiles and deep drawing areas near the frame - often used in a good design to reduce cut losses, to eliminate foam sealing material in the steel body profile, to eliminate further plastic parts and to optimize use of refrigerator space increase the cycle time by 5-12 % and needs smaller heating elements (125x63mm), at least on one heater, to allow heat temperature zone differences on smaller liner areas.

(2) Speed, material waste and losses

In practice the faster the machine works the more losses and quality problems happen. Often slightly slowing down by 5% can reduces losses by 50-80%, for example a company working near the technical borders with 3-5% losses often can reduce their losses underneath 0.7-1% so that there is no sense to work on technical borders and speeds, especially by using more sensitive fast and very fast machines. Even by recycling of losses, it does not cover more than 33% of total spend cost (material, energy, machine amortisation, machine time and work losses).

The trick of some thermoforming line manufacturer to reach higher speed **larger sheet sizes** (+70-90mm on all sides!) slightly thinner we already mentioned; it strongly increases cost per thermoformed liner, even if excess of sheet size is recycled.

There is no other section in the refrigerator production where the theoretical cycle times and the realised production per time is more different than in the thermoforming section; some companies even print in their catalogues min. theoretical cycle times. What is the sense of such figures? We have to consider real production quantities to be reached in practice to cover a wide range of models inside 1-3 shifts, which we analyse later after taking a closer look to the used heaters.

4. Type of heaters

A refrigerator cabinet inner liner is not a thin film. A complete sheet of 3-5mm thickness has to be melted till the middle inside of the sheet. **There is really no chance for anyone to speed up the heat transmission without burning the sheet surface as long as the same heaters are used.** Significant time differences are caused by different heaters only. 3 different types of heaters are used in vacuum thermoforming:

a) **Ceramic infrared heaters** (still mainly used), which needs normally 15-20 min. heating up time to reach full intensity; some faster ceramic heaters can manage it in 5-10 min.

b) **Quartz** heaters were introduced in thermoforming by Geiss (named by them „Fast“), but also used Kiefel and upon request by Cannon-Shelley, John Brown, and Comi) or similar ones called **„Quick Response Heater**“(Asano) with encapsulated heaters, reacting inside of 10s.

TQS Quartz heaters

c) **Halogen heaters**

Cal rod, gas and black body are not used acc. to my information in our branch.

The heat is transmitted from these kinds of heaters to the sheet mainly by radiation and only secondary by gas molecule pulses. The radiation efficiency, the ratio between the consumed electrical energy (kW) and radiation energy produced by the heaters, is as following for:

Type	Radiation efficiency	Radiation maximum at	Heating time reduction
- Ceramic IR elements	8-10%	3.5 µm	0
- Quartz	12-14%	2.5µm and 3.5 µm	- 5-7%
- Halogen flash	18-22%	1 µm	- 55-57%

Cost effects. The radiation efficiency is already a quite significant factor for the factory electricity bill and the cost of thermoformed piece. More relevant is that the **ceramic infra-red elements needs 10-20 min to reach their maximum efficiency, so that they have to be permanently on, even when no heating is needed** (heating is needed only 50 % of the cycle time in the single thermoforming station!) **while some IR heaters and the Quartz lamps or Quick Response Heaters are reduced to 5% intensity during stand-by** to save only by this way about 45% of their energy consumption (plus the a.m. radiation efficiency, minus a small extra start-up consumption) and **the halogen lamps are just switched on and off each time when they are needed.** Some new, faster reacting ceramic heaters are used from some companies, which allow a partial regulation of intensity inside a work cycle, but often they get this regulation only by reducing the radiation efficiency during heat up. Elstein, a leading manufacturer of ceramic heaters, can limit energy consumption of their ceramic elements in stand-by by using mirrors and thermo regulated elements, but their costs with needed thermo regulated controls are finally higher than quartz elements.

In an inline machine the heaters are use continuously so that the energy consumption difference between ceramic, quartz and Halogen is not 45-55%, but the range of radiation efficiencies, as mentioned in above table.

Time effects. Because of the mentioned wave maximums the penetration depth into the surface of the sheet are different. The deeper the radiation can penetrate the more energy can be passes to the sheet without burning the overheated surface and the shorter the heating time will be. The IR ceramics elements have waves with the maximum at 3.5 µm. Shorter waves penetrate the sheet surface deeper as the waves of standard IR ceramic element, mainly used in this application. The heating time for Quartz lamps in comparison to Ceramic elements is 5-7% less, the heating time of Halogen lamps called „Flash“ is only half of the time needed for the quartz lamps and 55-57% less than the heating time needed by using standard ceramic heater.

Halogen "Flash" lamps with 50%-57% less heating time. The flash lamps are used by Geiss reducing the heating time to half of quartz lamps and 55-57% less in comparison to IR ceramic elements because the shorter waves can surpass a thicker surface layer of the sheet as IR light and quartz lamps with longer waves and therefore more energy can be passed to the sheet without burning the surface. This in addition safes time (50% of heating time and about 25% less cycle time in a single station thermoformer), increases the capacity and reduce strongly energy costs (more absorption and less reflection).

Because of this heating time reduction a single station thermoformer with these halogen lamps are as fast as a line with 1 pre-heater using standard IR ceramic elements.

Test samples: Double cavity model 360l on single station thermoforming, KR2710, 4.8 mm, 480mm deepness

	IR Ceramic	**Quartz (Fast)**	**Halogen (Flash)**	**Halogen vs. Ceramics**
a) Cycle time (sec)	148	140	102	- 31%
b) Installed power supply (kW)	125	125	225	+80% *
c) Power consumption per piece (kW)	3.51	1.68	1.27	- 64%
d) Energy consumption (kWh)	87.56	44.49	46.18	- 47%
e) Production/h	24.3	25.7	35.3	+ 45%

* 80% higher installed, not consumed electrical power for Halogen „flash" lamps with 47% less energy consumption per hour respective 64 % less energy consumption per piece, because of 50 % less switched on, double speed of heating and higher energy efficiency. We will analyse these figures in the next chapter.

Size of heaters. The smaller the heater sizes, the better heat intensity on different surface areas can be distribute according to needs and by this way the losses on sheet peripherical cuts can be reduced, even to cut-less sheets in some cases. See chapter 8. Zero losses.

5. Savings on liner costs: Ceramic versus Quartz versus Halogen lamp heaters

About 13-20% of costs of an inner liner made by ceramic heaters are the electrical energy and a lot of costs can be saved by selecting the right heaters.

The majority of thermoforming machine producers use ceramic IR heating elements in their machine. **In the thermoforming process heating is only 50+/-5% of the total work cycle time**. In a single station it would cause that 50+/-5 % of time the heaters are wasting energy and the heat must be in addition removed to avoid overheating and fire. **Therefore heating elements, which cannot be switched off and on or at least strongly reduced during the cycle operation times, in which the sheets have not to be heated, are strong energy wasting in a single station line.** Because of the a.m. very slow reaction time of ceramic elements there is no much chance of savings per manufactured piece if the intensity of ceramic heaters is reduced during thermoforming in times the heating is not used. Comi and Asano are trying it using special ceramic heaters with 10-18% less on energy consumption, 2-4% on piece). The energy consumption of ceramic IR heaters in comparison to switchable heaters with similar efficiency is on single stations already double as much, on inline thermoformers with separate pre-heater and heaters still about 25-30% higher, depending on machine and production program. It is recommended to use electricity meters (kW) on all thermoforming machines and to register the consumption in the PLC/PC together with the produced liners to calculate running costs, but this transparency would put many thermo-forming manufacturers in trouble.

Some thermoforming manufacturers even use large thermo regulators to remove excess of not usable heat to avoid overheating and fire. Others, like Geiss, don't need to remove heat at all.

The **fire risk** in such overheated lines using even open ceramic heating elements is very high (see chapter 10).

This ability to switch heater fast on and off reduces the energy consumption to about half in a single station and by 25-30% in lines with pre-heater and heater and the cost of the thermoformed piece is about 10% in the first case less and about 5% in the second case. But also further aspects like

a) the absorption of energy of shorter waves in a thicker surface layer of the sheet in comparison to IR light,
b) energy efficiency of heaters,
c) emission of hot (182°C for PS) sheet during transport in lines with several stations to the environment or in the stations during blowing,
d) distance between heaters and sheet to be heated, etc.

influence the energy consumption.

Quartz lamps are used by Geiss, Kiefel and upon request also by Cannon-Shelley, Comi and Brown. Asano uses Quick Response Heaters, Comi and Rigo use IR ceramics, have tried upon customer requests to use Quartz, but with bad results, because the electrical terminals on the quartz lamps must be screwed to avoid micro interruptions of electrical connections. The terminal size is changing as result of fast heating and cooling of heaters which would reduce the lifetime of the quartz lamps.

The costs of **TQS quartz** element of the company Saint-Gobain Quartz GmbH (previously **TQS** Thermal Quarzschmelze GmbH, http://www.quartz.saint-gobain.com/html/infrared02.htm as spare at Geiss is € 33,-, which is double of the cost of the ceramic elements.

The cost of **Phillips Halogen lamps** is € 32,30. The lifetimes of both are guaranteed by the manufacturer of the elements: 5000h. In practice it is quite higher: 7000- 9000h. But there is still a lifetime difference of Ceramic and Quartz on one side and Halogen on the other side: The halogen lamps are completely switched off when not needed while ceramic runs permanently during production on selected intensities and Quartz lamps as well, but during stand-by with 5% intensity only. So practically not only by higher speed, also by this effect more liners are produced during the lifetime of Halogen lamps as it would be possible with Quartz or Ceramics.

By taking into account the higher costs of the quartz and halogen lamps in comparison to Ceramics we save following:

Heater type	Cost per heater	Production per lifetime	Heater costs per inner liner	Cost savings per piece (Sheet - energy savings + addit. heater costs)
164 Ceramic	€ 16,70	113000	€ 0.025	savings 0 %
164 Quartz	€ 33.00	120000	€ 0.045	savings 9.7%
240* Halogen	€ 32.30	250000	€ 0.03	savings 11.4%

Further quite relevant savings can be reached with reduction of losses and higher availability of single station machines because of less change-over. Also the lower amortisation costs of single station machines causes differences to fast and very fast machines in the range of € 0,16 respective €0,28 per thermoformed cabinet liner (see chapter 7).

6. Realised production quantities and losses

Coming back to the cycle times, the a.m. **theoretical cycle times** are for thermoforming not as important as it looks like on the first view. Really **relevant for the production is how much inner liners - in the needed model variety per day** (to avoid capital bindings in final and intermediate stocks) - **are really produced** which has passed the quality control and **how much material and cost were needed and wasted.**

Main criteria of thermoformer selection of customers are still the cycle times! Therefore expensive inline machines with 1 or even 2 pre-heaters (totally 3 heaters) dominating the market of refrigerator inner liner production with cycle times of 35-40 sec. (2 pre-heaters) instead of 70-80 sec. (1 pre-heater) or 120 sec. (no pre-heater) for a HIPS-inner liner with 3.2 mm thickness. But relevant for the production is not the theoretical output according to the nominal cycle time, but the **real output** per shift: The **% of machine running** to produce inner liners and efficiency, how many pieces passes the quality control. In this point there is a very big difference between the machines and concepts, especially between the very fast machines with 2 pre-heaters in comparison to machines with one pre-heater, and between the fast machines with one pre-heater in comparison to slower machines without pre-heater. Under environment with high fluctuation on voltage and temperature the difference is even higher.

At a **Whirlpool** factory with a wide range of models to cover for example the output of 4 Illig fast inlines with 1 pre-heater was in practice even 5% less as the output of 4 Geiss single station machines though the fast lines should be theoretically 27-33% faster. So with double investment for 4 inline lines instead of 4 single station lines less output was reached. This is probably an extreme sample, I admit, but we have to look on output, not on nominal cycle times, and we have to take into consideration the conditions we face in foodliner production to serve refrigerator production.

Several internal studies in refrigerator factories have shown that the practical efficiency in comparison to their theoretical output are the lowest with the very fast machine often in the range of 50-60 % in a mixed refrigerator production, while the efficiency in single station machines are in the range of 75-80%: Machines with cycle times of 30 sec. (theoretically equivalent to 960 units per shift) do seldom produce more than 500 units per shift (52% efficiency) if different models are needed - which is in our branch always the case - while machines with cycle time of 90 sec. are normally producing in the range of 250 units per shift (78% efficiency). **Though 3 of full automatic single station machines costs the same as a very fast line with 2 pre-heaters, in practice they produced 50% more as the very fast line** - mainly as result of 3 times less mould changes and less losses. And much lower losses in case of break down.

There are several reasons for this big discrepancy, like

a) higher frequency of mould change-over in few fast machines to reduce intermediate and final storage for a mixed production instead of several parallel working slower machines which does not need so often mould exchange (see next chapter),
b) higher losses during start up after mould changes or other work interruptions on fast and very fast machines,
c) bigger problems to master the faster machine in case of troubles with higher losses per trouble event and
d) higher sensibilities on environmental or electrical fluctuations on faster machines as on encapsulate single station machine with pyrometer to measure if correct surface temperature is reached (not possible on machines with pre-heater which needs strict time cycles).

Further comparison tests and measurements in other factories were made, which have single station lines and faster multiple station lines; the results were very similar. But the majority of factories cannot compare as they only have lines with separate pre-heating stations.

These studies were made in developed countries. In developing countries with often worse frame conditions for a continuous production the discrepancy most probably should be even higher.

7. Parallel production of different models with single stations or fast lines with large intermediate storage

The steel side panel line, the painting line, the thermoforming liner production, the cabinet pre-assembly and cabinet foaming lines should be as far as possible **synchronous and continuous to avoid voluminous intermediate storage. Also final storage has to be avoided to reduce capital binding.** Daily trucks with different destinations, but full range of products on board have to leave the factory. Therefore only a mixed parallel production can feed the market and distribution conditions without relevant capital bindings in storage. The selection of thermoforming technology has to take this aspect into consideration to reach high production flexibility and to avoid intermediate and final storage.

Often refrigerator producers are making in the thermoforming lines the mistake to use few fast or very fast thermo-forming lines. To feed for example 4 assembly lines with 4 different models such a fast line have to switch over several times during the shift to be able to produce different models at the same time. By this way a lot of intermediate storage (inner liners are voluminous, covering inside 1 shift production some hundreds of m² factory space) and a lot of production interruptions are needed. Instead of using one expensive fast thermoforming machine and to loose at least 25-40% of the capacity per shift for switch-over from one to another model, instead of loosing materials during start up with new moulds, several single station thermoformers are more economic, in the sum faster and much simpler to operate. Intermediate storage and long mould change-over time can be avoided with several single stations, each with a mould already installed and continuously running without interruptions for change-over.

In addition large intermediate foodliner storages increase work time per refrigerator by about 60s or expensive automatic foodliner handling and storage system between thermoforming lines and pre-assembly lines. Either pre-

assembly stuff run long distances to pick up foodliners or extra material flow workers are needed in this intermediate foodliner storage to do this job.

On the first view the capital costs with all needed accessories to achieve the same capacity are the same for all 3 types of thermoforming lines (very fast, fast or single station) if all lines are fully automatic. 3 single stations with automatic loader and de-loader in parallel operations reaches together the same cycle time as 2 fast lines with 1 pre-heater or 1 very fast line with 2 pre-heaters and totally would cost the same as the very fast line (€ 690000) with 2 heating stations (at 100% efficiency).

But if the **refrigerator factory has to produce parallel different models** the very fast line or the fast line are much more expensive (50-100%) per reached effective capacity as multiples of the single stations with nominally the same cycle time**. The fast lines causes a voluminous intermediate storage, logistic problems and 60s more work, the production with it become discontinuously, because the frequent change-over time have to be added only to the fast lines and not to several of the slow single station lines.** The change-over from one to other model is not only the time of mould exchange which can be managed in 5-10 min., all other works and times to reach for example the correct mould or mould area temperatures have to be added, which is normally the longest time; heater and undercut connections, the exchange or adjustments of window plates for the sheets, plug assist, sheet clamping frames, photocell position, quality control procedures etc. have to be executed. In the best versions of Comi, Asano, Illig, QS the change over is still 20-35 min **in practice** between last piece of previous model and first acceptable piece of new model (but only reachable if the mould are preheated before mounting), in other versions the change over takes 45-60 Min. Only the Geiss thermoformer with fixing window plate profiles on mould and fast change over can really manage it inside of 7 min. for a normal mould and 13-15 min for a complicate mould. Thermoformer sales people who are speaking from 5-10 min. without such automatic change-over features as offered by Geiss should be forced to do the job once to know from what they are talking about. Thermoforming is the most complex work in refrigeration production which needs the longest experience to master problems which daily occurs in practice. If the real reached sheet surface temperature are not measured like in case of Geiss, Kiefel and Comi, even a PLC/PC with control over heaters and process timings will not help, the influence of fluctuating environmental temperature (even an open door has influence) or fluctuation voltages are sufficient to force the operator to adjust the machine each time he change the mould by wasting first quantities of lines and cycle times.

In a refrigerator the foodliner production have to feed several models (4 up to 10 per day with often 2 foodliner cavities) on different pre-assembly lines to feed different polyurethane foaming jigs. If we measure the **realized capacities of 1-2 fast Comi lines,** the market leader**, (**without such large foodliner mountains as result of several production days with less model change-overs) and compare it with 3-4 parallel running **single station lines of Geiss**, the best in this market segment, **needed investment per realized capacity are very different from the first view:**

For examples: A refrigerator factory has to produce 790-900 simple refrigerator cabinet inner liners in an 8h shift with 80% efficiency (=23000 sec. working time/8h shift and 23 sec. cycle time). Let suppose only 4 different models at same time have to be produced and during one shift up to 8 different models. The very fast and fast machines have regular adjustment problems and losses, while single stations with Pyrometers don't have such losses, which is part of our calculation. The above mentioned capacity can be realised with following alternatives A-D:

A: On 4 single automatic stations, 2 with Quartz and 2 with Halogen heaters for € 950000 for 1-2 workers:
23000 sec. shift / in average 102 up to 116 sec. cycle time * 4 stations = 790 up to 900 units as long as up to 4 different models are produced at the same time. The change over can be done before starting of shift and/or during lunch so that up to 8 different models can be produced during one shift or up to 12 different models during 2 shifts without loosing capacities because of change-over; the machine can be driven with practically zero losses, on complicate pieces 1-2 pieces only.

B: On 3 single fast automatic stations with Halogen heaters and fast change over of models for € 900000 for 1-2 workers and 1 change-over time of 7-14 min. and zero losses or nearly Zero on difficult pieces.
(23000 sec. – 600 sec. for change over)/74 up to 85 sec. * 3 stations = 790 up to 908 units

C: On 3 fast lines for € 1.2 Mio. with 1-2 workers and 1 change-over of 30 min.
(23000 sec. – 1800 sec. for change over+losses)/70 up to 80 sec. * 3 stations = 795 up to 909 units

D: On 2 very fast lines for € 1.4 Mio. with 1-2 workers and 4 change-over of 30 min.:

(23000 sec. – 7200 sec. for change over+losses)/35 up to 40 sec. * 2 lines = 790 up to 903 units.

With a 47 % higher investment amount for the „very fast“ lines, and 26 % of „fast“ lines only the same capacity could be reached, which is wasting of capital. A refrigerator produced on very fast lines would cost € 0.24 more than on single station lines and € 0.12 more on fast line as on single station lines (with 1000 refrigerators/8h shift, 2 shifts per day and 230 working days/year, 5 year amortisation and 10% interest rate/year) by only calculation the amortisation, taking further aspects on account (losses, energy of heaters, machine break downs, more work time to store and to remove foodliners from intermediate storage) the difference in favour of single station lines would be much higher.

If less than 4 different models parallel respective less then 8 different models per shift have to be produced, the amortisation cost advantage of single lines in comparison to fast and very fast lines reduces, if more different models have to be produced the amortisation cost difference increases.

Furthermore see chapter 15: Lean Manufacturing principles: 1 fast thermoformer versus 3 single station lines.

8. Zero loss instead of high waste and huge recycling

Other relevant criteria of selection of thermoformers are **how far a thermoformer can avoid losses of bad manufactured inner liners and waste as a result of**

a) **mould changes and start-ups of lines,**
b) **wrong adjusted parameters,**
c) **fluctuation of conditions like environmental temperature, humidity, voltages**, sheet thickness, materials,
d) **machine failures** (heaters, interruption, electronics, compressed air, vacuum, micro and/or proximity switches, etc.) and, last not least
e) **losses of sheet areas and materials to be cut**.

Thermoforming is probably the most difficult part of the refrigerator production under the aspect of process control as every single process parameter influences all the others and the whole line is nearly as sensitive as foaming lines.

PLC/PC control. All thermoformers have to have a PLC/PC control which controls not only all times of operations and other relevant process parameters, but also the intensities of each heating element. Self-diagnose, consumption of energy, operation time and quantities produces have to be registered. Standard in Europe is Siemens S7 (Geiss, Comi). The programmes are stored on CDs or diskettes. But still there are large differences about losses. Cheap systems without PC/PLC on heaters are not considered here as they are too expensive in losses of material and time.

Small heater sizes. Foodliner losses can be strongly reduced if small heater sizes are selected. At least on upper heater the sizes should be 125x60 mm or smaller with independent controls to permit more differentiated heat distribution on the sheet surface and allow **reducing used sheet size to the size of the liner** (cut-less) or very near to it to reduce material losses or cost for recycling. Relevant is also that the upper and lower heater rows alternate. The smaller the size with Quartz the faster they are to reach full intensity. Halogen lamps have immediately the requested intensity. The regulation of ceramic IR heaters is anyhow too small to reduce intensity during thermoforming process, when heating is not needed.

Mastering of thermoforming. A single station is simpler to operate, to programme, to trouble-shoot and to adjust as a line with several stations. It has fewer parts which can fail and last not least any mistake can immediately be seen on one single produced piece without continuing quantities of losses. **This aspect of mastering the technology and avoiding quantities of losses of materials and time is strongly favouring single stations in comparison to lines with pre-heaters.** Mastering a fast line with pre-heaters including its programming of process of new models, trouble shooting, maintenance, etc. takes more than 6-12 months with several trainings and interventions of the supplier or while a good single station machine like the one of Geiss can be learnt to master inside of 2 weeks including programming of production of new complicate inner liners, trouble-shooting, maintenance.

Zero losses after mould exchange or restart. Under this aspect Geiss thermoformers are the best, followed by Kiefel. Most sold fast thermoformers, like the one of Comi, looses the first 5-10 cabinet liners during start up, which represents about 2-5% losses of a lot production of 200-250 of one model, other fast lines easily the double.

But **batches of 200-250 foodliners** on fast lines are too large! Though it wastes already 20-25% of capacity for model changes over and 2-5% of liners, it results in a very large intermediate storage, because the cycle time of 1 foaming jig is about 6 min. while fast inline thermoformers needs 42 s per foodliner. So it takes 2,7- 3,3 shifts to consume these 200-250 liners on a foaming jig without any model change. To reduce produced lots to 100 foodliners per model on fast lines, which is still too high for many models, to limit the intermediate foodliner storage is out of range: we would waste 50% of thermoformer line capacity that means half of invested high capital in thermoforming is wasted only for model change-over! Such line concept does not make economic sense to be used in modern flexible refrigerator production and fast supply chains with fast returns on investment!

In addition such fast lines like the one from Comi, often needs 25% larger sheet size (70-90mm extra on all sides) as needed on good single station lines and these excess must be cut and recycled. Even if we take into consideration that larger sheet size could be 10-15% thinner by partially using such edge material for the deep drawing area, it is still a cost relevant loss, which should be calculated into the liner cost. On single station lines the situation is better: Today good thermoformers, like the one from **Geiss can work with zero losses on single cavity cabinet liners and 1-2 liner losses on difficult cabinet liners after mould exchange or during restarts after production interruptions**, which reduce the cost of the product and the change over time and restarting time:

a) All process and heat element data per model and per existing frame conditions (different materials, sheet thickness used, environmental temperature fluctuations above 5°C) are stored in the machine memory (and on CD) and will be loaded parallel to
b) the mould exchange and mechanical adjustments of machine,
c) the mould, the window plate and the clamping frame will be heated to the correct temperature(s) and
d) the parameters (compressed air and vacuum pressures, mould temperature(s), mechanical adjustments, plug assist, photo cell position, water and undercut connections, closed door, sealing, machine status, correct programme loaded etc.) will be checked against a check list.

In this case even the first inner liner will be made correctly. Furthermore a Geiss single station machine needs only 20mm extra sheet size and not 70-90mm on all 4 sides.

No machine can start and should start operation without an operator control, but there are big differences in the machine on the market concerning

a) **self-diagnose facilities** to identify machine failures,
b) **protection of expensive machine parts like heaters against being destroyed** and
c) **avoid fire and fire protection**, as well as in the
d) **quantities of parameters which needs to be manually adjusted or controlled**.

A good machine can reduce such adjustment and control operations to 10-15 parameters, when the manufacturing programme exists. By this way 90-95% of losses as part of operator mistakes can be strongly minimised but not completely eliminated.

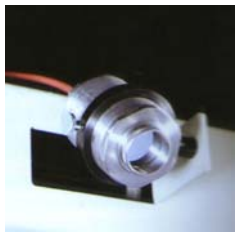
Still there is a big difference in quantities of losses as result of failures of operators or machine or of environmental conditions changes: **While in good single station machines from Geiss the loss can be reduced in such cases to 0-1 piece, in fast and very fast lines of Comi it is always multiples (seldom 2, more in the range of 3-10 pieces).**

Fluctuation in environmental temperature and humidity. Other relevant factors for losses or quality reductions are fluctuations of environmental conditions. Changing of the temperatures during day time, rain, wind, openings of doors or factory portals, all can **destroy thermoformed inner liners.** These **environmental fluctuations** have

a) **more effects on fast lines with hot pieces transported between stations and longer exposed to environmental conditions as on a piece in a more closed single station.** In addition such fluctuations

b) **can be compensated in a Geiss single station quite well** by a **radiation pyrometer** measuring the real sheet

surface temperature and starting the forming process always exactly upon reaching the nominal temperature on a reference point to avoid any waste.



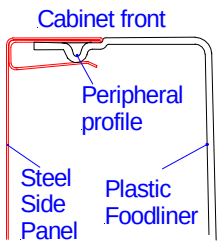
But inline thermoformers with pre-heater, heater and forming station cannot shorten or increase heating time to start forming only upon correct sheet temperature. Such inline Thermoformers can only work with a fixed cycle time. Any process time changes in such a line with heaters in more than 1 station would bring the temperature values of different zones of the sheet completely out of control while in a single station the heating time can be adjusted according to the real reached sheet temperature on each single piece without modifying much the heat distribution between the different zones on the sheet. **Kiefel** use pyrometer measurement data in their inline thermoformer to adjust heater intensity upon temperatures reached during the fixed cycle time and can compensate such fluctuations with a time delay to limit losses. **Geiss** also use Pyrometer to control cooling down time of finished product to deposit it automatically out of the thermoformer.

Temperature changes during day time needs to be compensated in a line with pre-heaters by adjusting the machine parameters while single stations with radiation pyrometers can compensate these themselves up to a quite large extend, which reduces this kind of losses significantly (30-90% depending from the range of existing fluctuations pieces and building conditions).

Voltage fluctuations. Last not least voltage fluctuations are a big problem, not only by using public electrical supplies with higher fluctuations. Even if bigger motors starts in the factory like the foaming lines with exhaust ventilators which easily draw temporarily 3x300A, 1-3 thermoformed pieces are destroyed by changing the heater intensities drastically. **Voltage fluctuations will cause big losses in a fast line with preheating stations controllable only by cycle time while a single station line can compensate such fluctuations** by a **radiation pyrometer** so that nearly no piece is lost during such fluctuations. Only if single phases can fluctuate independently from each other, which are very seldom the case and mainly a mistake in the factory electrical installation, an additional **compensation of heat intensity by phase measurement** should be added (an option offered by Cannon-Shelley and Geiss). But this can only be made in real time if quartz or flash lamps are used, because ceramic IR heaters are too slow reacting.

Such a **radiation pyrometer system** allows a continuation of work even under environmental and voltage fluctuations. In a Geiss machine it is standard. We recommend adding such a pyrometer to diminish strongly the losses and production interruptions.

Restarting losses. Any interruption of work as result of failures of machine, power or operator mistake, changes of environmental conditions, programme stoppages as result of heat, high voltage or micro-interruptions of power, compressed air or water supply stoppages, work stops for eating, mould exchange etc. causes in fast line with pre-heaters not only losses of work time, but in addition always losses of pieces during restarting, while in a single station such restarting losses are avoidable, only the piece just produced will be destroyed, if no power or during pneumatic movement no air is supplied.



Sheet trimming waste. Major thermoformers waste 70-90mm edges around all 4 sides of sheet (about 35-50% of size or 20-30% of weight) which must be cut. In best cases it can be recycled to reduce such high losses on material, work, and energy. But still it is a lot of waste and high costs only to reach the Fata Mogana of very short cycle time instead of looking on realized production output. Only few thermoformers like **Geiss** needs only 20mm edges to fix the sheet, the space needed to insert into the steel side panel profile. On Geiss machines the sheet waste can be strongly reduced, but still not to 0, because a refrigerator side panel steel profile in which the liner has to be inserted is often wider than the liner thickness so a small peripheral liner profile has to be formed, which needs peripheral liner cuts of at least 20mm. But 40-60% of recycling can be reduced, surely with slower speed, if mould is made for this machine which allows a better square-deep drawing ratio as fast inline machines. With this savings in waste and additional single station machine could be purchased and would amortize fast inside few years.

9. Double or single cavity inner liners

Higher line output by double cavity thermoforming. The majority of refrigerators have 2 doors and needs 2 cabinet liner cavities. Good thermoformers can make the 2 cavities together, so that only **half of work cycles** are needed, but

with **longer cycles** because of thicker sheets. Double cavities needs about 50% thicker sheets (4,2-4,5mm HIPS) and increases the heating time up to double and the total cycle time by 29% on very fast lines with 3 heaters up to 50% on single station lines. Anyhow because of half mould exchanges it strongly increases the output of such line (+ 30-40%) and reduces the intermediate storage of voluminous liners. But good slower single station lines as made by Geiss manage such double cavity foodliners without losses, while fast and very fast lines have more problems on such models and increased waste, so that 0,5-2% of production can be lost in addition to their already significant waste.

Square-deepness ratio on technical limits. Single door designs with small freezer compartment in 3 star versions (<-18°C) are quality wise far better and cost wise cheaper than 1 or 2 star versions (<-5°C or <-12°C) often made with Roll Bond. Such 3 star models need **double cavity inner liners** and the evaporator is made behind the liner in the foam area. In some markets or market segments, like in India, refrigerators with smaller freezer compartments (15-50l) are needed. How big this market segment is depends mainly from food habits. Anyhow **fast (with 1 pre-heater) or very fast (with 2 pre-heaters) thermoforming lines have very big difficulties to form such a double cavity inner liner with a very small freezer compartment (15-50l).** The ratio of square sheet (600-800cm²) to deep drawing (360-400 mm deepness) is so near to the technical limits of thermoforming that such lines with pre-heaters often fail and were replaced in Europe for such applications by **single station thermoformers** which **can work nearer the technical limits of thermoforming relevant to reduce costs on materials and waste**. Some new models in addition integrate into the inner liner top front – not anymore into the refrigerator top plate - the lamp and the thermostat to increase the net volume, to reach a clean inside without thermostat-lamp box and to get more creative space for the body design.
If a refrigerator manufacturer produce in the future for cost and competition reasons such models with these **double cavity inner liners of a small freezer** with an extreme square/deepness ratio, **in such a case thermoforming lines with 1 or 2 pre-heaters cannot be used anymore** without producing big losses on materials and quality problems and must be replaced by single station thermoformers.

Single vs. double cavity liner and waste. In a double cavity liner it can happen that only one cavity has a quality mistake, the other not. So some refrigerator manufacturers think that they reduce waste by using single cavity moulds instead of double. This is probably the case on bad thermoforming machines with 7-15% losses. But if such partial waste of one cavity inside a 2 cavity liner on a good fast line is in the range of 0,5-1% (for example on a good Comi or Asano machine), this “saving” by using 1 cavity mould is too expensive: the output of a fast machine is reduced by 30% using single cavity instead of double cavity moulds; so in this case of 30% output reduction on a fast machine with high investment, for example €0,9Mio. (including trimming etc.), the amortisation costs are much higher than the savings on 0,5-1% of produced liners. Having good single station lines, like the one of Geiss, this loss difference on a double cavity mould instead of single cavity mould is nearly negligible, less than 0,1% and therefore it is no question to make always the cavities needed in one work cycle for one model.

10. Safety aspects: Protection against fire, human safety and machine protection

One of the **mayor problems of Ceramic IR elements** is the **risk of fire**, practically not existing on Quartz or Halogen flash systems; not only because they are only on full power when needed and low (Quartz) or off (Halogen) when not needed, so that any overheating is completely avoided. Geiss has introduced in addition a **Ceran glass cover** covering the bottom heater (standard) or even the top heater, if needed from customer for his specific application, so that in the worse case of overheated sheets bended to touch bottom heater no plastic ever can touch the bottom heaters and burn like it is usually and regularly the case with the open ceramic heaters. Beside of patent restrictions, the Ceramic heater models even would have difficulties to use such special Ceran glasses as their radiation would strongly be absorbed by the ceramic glass and no IR transparent material to be used as cover of ceramic fields is yet known. Others have introduced mirrors to reflect the radiation, but the reflectors and increase of distance reduce radiation and efficiencies. In the last 20 years not a single fire accident on Geiss machines with the Ceran glass cover on the bottom heaters in our branch were recorded while on ceramic infrared heaters such fires happens regularly and cause high costs in repair.

Such bad IR ceramic heater machines - still mainly used in this production - must have at least efficient built-in fire extinguishers and automatic thermal switching fire detectors. **Why purchasing such risky machines with open IR ceramic heaters, if alternatives like Quartz heaters and Halogen heaters are available which in addition strongly reduce energy consumption and the cost of thermoformed pieces?**

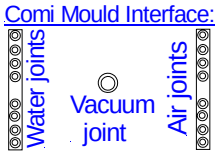
Electrical or mechanical component will once a day fail. Forming stations with heaters have to be made that heaters are really drawn out of the moving area to ensure that the mould or plug assist will not move into the heaters and destroy them. The control (contacts, cabling) of stand-by position of heaters should be doubled (like in case of Geiss). This is often not the case on many thermoformers on the market, so that fire risk and risk to destroy the heaters by mould or plug assist movements are quite high. This is not acceptable.

Human protection. Photocell barriers, door contacts and emergency switch offs with fail-safe contactors must be standard on such machines to fulfil machine safety rules (CE etc.).

11. Model change over time

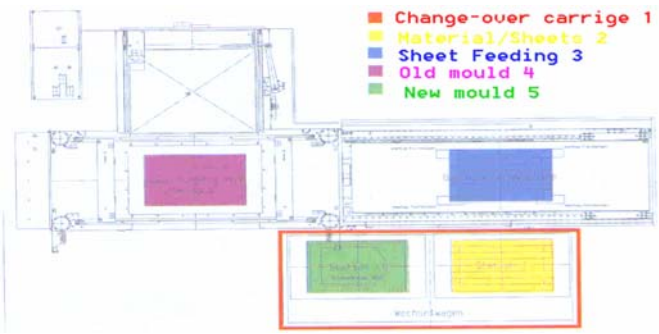
Fast tool clamping, tool and sheet carriages. All producers Asano, Comi, Kiefel, and Geiss offer - at least as option - fast mould clamping facilities carriages and/or rollers to reduce the time to exchange moulds and sheets. This is useful for any type of thermoformers. Fast and very fast machines without such facilities are absolutely nonsense while for several slower machines such fast change-over is useful, but less needed, because of less change-over. Though mould exchange can be managed inside of 5-10 min. with fast tool clamping and tool carriages and/or rollers the total change over between last manufactured piece before change and first manufactured correct piece after change is more in the range of 25-45 min. in practice. But without such facilities it would take 10-15 min. longer. It is important to study in details the foreseen change over operation of offered thermoformers (see underneath Geiss full automatic model change over system inside 7-14 min.).

Preheated moulds. Most relevant for a fast change over is the preheating of moulds to the right temperatures (80-90°C) before mounting. Mould pre-heating saves 30-60 min. on change-over time. Therefore the moulds and machine should have 2-side closing quick couplers (Hansen or else) and a further mould connection outside the machine to the thermo-regulator should exists. **Comi**, the market leader in refrigerator liner thermoforming, practically fixed a **mould connection interface standard** with a row of thermo-regulated water connectors, a row of air connectors (each up to 4 independent circuits), a vacuum hole and 2 centring pins, which helps to make mould exchangeable even between different lines. But unfortunately Comi uses only single side instead of 2-side closing couplers, so preheated mould must be emptied from hot water and again temperature regulated after installation on the machine, which increases unnecessarily the mould change-over time by additional 10 min. **A small and cheap modification of the water connectors would significantly increase machine output**, which amortise inside a day.

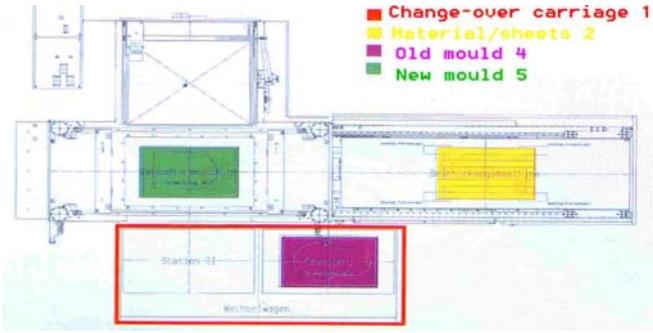


Geiss full automatic Change over system (7-14 min):

Before Change-over



After Change-over

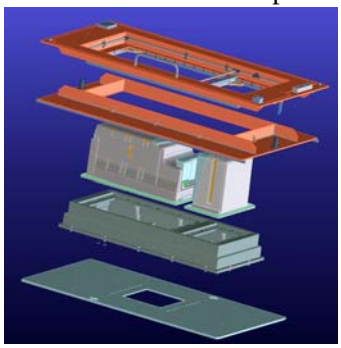


Change-over work steps:
1st Step: Double carriage (1) carries material (2) into feeding (3)
2nd Step: Double carriage (1) removes old mould (4)
3rd Step: Double carriage (1) inserts new mould (5) into machine

Universal window plates, frame profiles on moulds and sheet clamping frames. To avoid replacement and adjustments on window plates (further 5-6 minutes on change-over) and sheet clamping frames (further 5 minutes) such systems should be universal and step less adjustable or with fixed clamping profiles deposited on the mould to be mastered inside of 1 minute. Geiss has some patents on such universal window plates and clamping frames. But this is an exception. The majority of manufacturers avoid this adjustment times by removing these parts from the machine to

each mould (see next paragraph) which is not recommended as it strongly increasing the cost of each mould (+€4500-5000 per mould). These cost increase on mould are often not seen by the customer in his cost comparison of offers, but later in running if he has both types of machines to be able to compare, and these extra costs on moulds have to be paid each time a new model is made.

QS with upper and lower frames on each mould



Window plates/lower clamping frame as part of expensive moulds. Each sheet size needs different window plates used also as lower clamping frame for the sheet. Some companies like **Asano, QS and Illig** consider the window plate/lower sheet clamping frame as part of the mould. Some even the upper clamping frame. By this way these companies can reach the same change over time as possible with an universal window plate (as patented from Geiss), but the cost per mould increases by € 4500-5000, so that a company with 25-35 moulds (to be changed by each model change) have a total cost increase in thermoforming mouldings of € 112500-175000, which is already near the price of a single station thermoforming machine.

12. Sheet loading and depositing of formed parts

Double sheet loaders on machines with pre-heaters. Fast and very fast machines with pre-heaters must have 2-sheet loaders to avoid production interruptions because of finished sheet stacks causing wasting on materials during restarts which increases the costs for the machine and the materials; while good single station machines with zero losses or nearly zero losses during starts or restarts doesn't need 2-sheet loaders. Sheet loaders are for single station lines useful to run automatically; but if the investment budget is limited and work costs cheap, such machines can even run fast without sheet loader and finished liner deloading device.

Automatic or manual loading and depositing of formed parts. Single stations can be manually loaded and de-loaded without increasing the staff anyhow needed for control. The price difference between semi-automatic machine (=manual loading, full automatic work cycles and manual deloading) and full automatic machine including automatic loading and deloading of € 39000-43000 has to be reflected. But no doubt a full automatic machine can increase the capacity by 5 up to 25% depending of the work culture. Single station machines like the one from Geiss, Cannon-Shelley and Comi can be supplied with or without this full automatic feature. If the budget is limited we recommend that the machine should be prepared for the full automatic version to be realised in a second step after returns on investment.

Automatic control on sheet loader and auto-depositing of formed parts. If a full automatic version is selected (a must for lines with pre-heaters) there are big quality differences in sheet loaders, internal transport, depositing of formed piece and there control with the effect that a lot of interruptions are caused by it in practice and a lot of adjustment works are needed in many faster thermoforming lines. The more stations exist with hot, nearly melted material to be transported the more problems occur needed to be corrected. Plastic are electrostatic loaded and especially for thin sheets as used for the doors the loader must insure that **only one sheet is picked up** and passed to the next station. The used tricks are: **asymmetric controllable suction cabs and static loaded separation air**. A mechanical solution which needs adjustment by changing thicknesses is bad. All mechanics can fail and a loader or transporter to the next station - without any automatic control on executed process - is regularly failing. And even if the control stops process, parts already heated in a pre-heater are lost in addition to the parts lost during re-starts – problems which do not exist in single station lines without pre-heater(s).

13. Forming process

Forming of melted sheets towards a male or female mould is made by vacuum on all machines. Only in the pre-forming, the bubble, before forming to extend the size of sheet near the dimensions needed during forming, there exist 2 methods:

a) Pre-vacuum used in female moulds or
b) Air pressure blowing in male moulds.

Both have good results in cabinet inner liner production, as long as the air pressure bubble height in the male mould version is controlled by a **photocell**. The forming process can be improved by additional measures (plug assist, etc.).

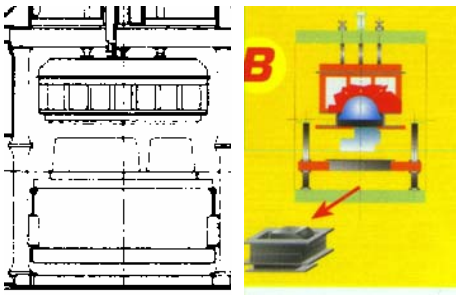
14. Male versus female moulds

25 years ago all have used only female moulds to produce refrigerator cabinet inner liners because the forming station was not hermetically closed and only closable for vacuum or pressurisation by the mould itself. After Mr. Georg Geiss has invented to close the forming station itself to allow pressurization for several reasons (support air to avoid that the melted sheet can touch the lower heater, bubble to pre-form the sheet, twin sheet forming) this was followed by all European users and European machine manufacturers by switching over to male moulds for cabinet inner liners. The reason was

a) **to reduce moulding costs by about 30%** in comparison to female moulds,
b) to speed up and facilitate de-moulding (easier access of air and water spray, less cracks by air pressurisations from inside (male mould) as by squeezing the inner liner together from outside(female mould) and
c) last not least **to improve quality**. The dimensions of male thermoformed foodliners and male plugs as used in the foaming lines are always the same and no adjustments between these 2 lines are needed. Also needed plug assist in double cavity liners which will mark the liner by touching cannot not be seen on the visible surface of the inner liner if male moulds are used.

Plug assist. Female mould thermoformers needs air pressurization and/or plug assist to insert melted sheet into the female mould of cabinet inner liners, while plug assist in case of male mould are a must 2 cavity models to squeeze the melted sheet between the 2 cavities, touching only the not visible part. It can be made by an upper moving stamp with a vertical plate. Female mould plug assist causes surface scratches on the visible part of the inner liner and are not recommended.

Comi bubble suction forming



Combined air pressure and vacuum forming. Some manufacturer (Comi, Kiefel) use male moulds in fast lines in combination with upper closable female cavity as so called “bubble suction plug assist”. While vacuum is sucking the sheet to the male mould surface the upper closed female mould is pressurized by air:

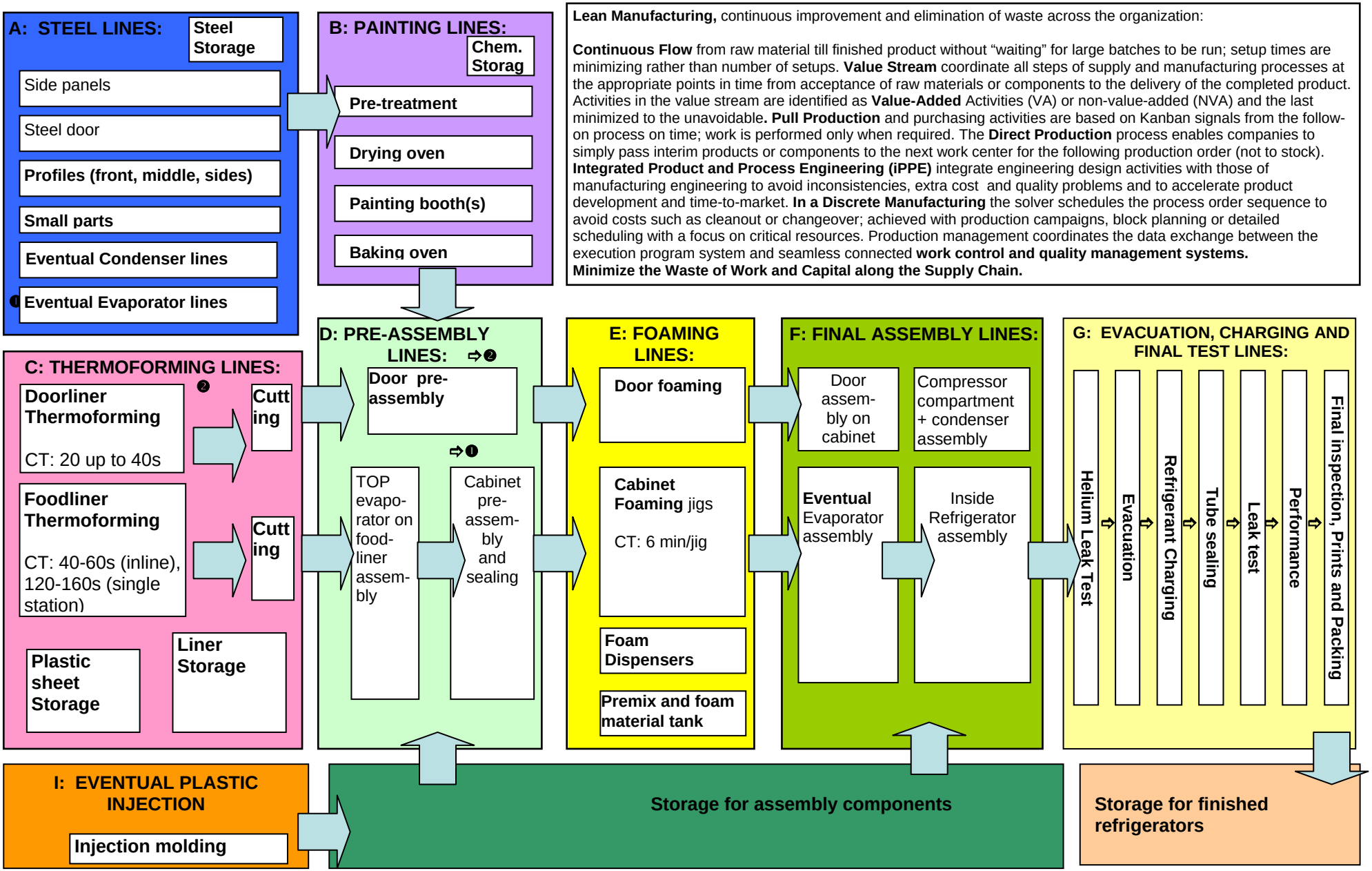
15. Lean manufacturing principles: 1 fast thermoformer versus 3 single station lines

Today majority of household refrigerator manufacturers works with **fast thermoforming machines producing huge amounts of intermediate storages** (2000-5000 cabinet liners, 1000m²). Lean principles, as standard today in car industries and other high developed branches, seem in this area still not applied. But if more and more household refrigerator manufacturers will apply it (GE, in few cases also Bosch-Siemens), the others have to follow (see car industry 10-20 years ago). Let us take a closer look on the refrigerator flow manufacturing diagram on next page.

The heart of refrigerator production is the **cabinet polyurethane forming on foaming jigs**, each with model specific mould, grouped in lines of 5-8 jigs with different models. This process needs about 4,5-6 min. curing and about 30s process movement time. So each 5-6,5 min. one model must be pre-assembled to be foamed and each 5-6,5min one model specific thermoformed foodliner is needed. 2 foaming jigs with same model pull thermoformed foodliners in cycle times of 150-195s, 3 jigs with same model in 100-130s. To run a production with 4 or more same model cabinet jigs at same time is very seldom, as it results often into large capital binding on final storages.

Only single station lines allow production synchronisation and balanced work flow, while inline thermoformers results into very large intermediate storages of voluminous foodliners and waste.

Transfair Engineering: Refrigerator Flow Manufacturing Diagram:



Lean Manufacturing, continuous improvement and elimination of waste across the organization:

Continuous Flow from raw material till finished product without "waiting" for large batches to be run; setup times are minimizing rather than number of setups. **Value Stream** coordinate all steps of supply and manufacturing processes at the appropriate points in time from acceptance of raw materials or components to the delivery of the completed product. Activities in the value stream are identified as **Value-Added** Activities (VA) or non-value-added (NVA) and the last minimized to the unavoidable**. Pull Production** and purchasing activities are based on Kanban signals from the follow-on process on time; work is performed only when required. The **Direct Production** process enables companies to simply pass interim products or components to the next work center for the following production order (not to stock). **Integrated Product and Process Engineering (iPPE)** integrate engineering design activities with those of manufacturing engineering to avoid inconsistencies, extra cost and quality problems and to accelerate product development and time-to-market. **In a Discrete Manufacturing** the solver schedules the process order sequence to avoid costs such as cleanout or changeover; achieved with production campaigns, block planning or detailed scheduling with a focus on critical resources. Production management coordinates the data exchange between the execution program system and seamless connected **work control and quality management systems.**
Minimize the Waste of Work and Capital along the Supply Chain.

Inside the **Lean Techniques and Principles** this concerns mainly

- **Waste** identification and elimination (see Toyota's seven deadly elements of waste)
- **Just-in-time**
- **One piece flow (takt time)**
- **Set-up time reduction** (SMED-Single Minute Exchange of Dies)
- **Production smoothing**
- **Balanced work flow**

Seven Deadly Wastes:

The Toyota Production System defines seven types of waste. Waste elimination is one of the most effective ways to increase profitability in manufacturing and distribution:

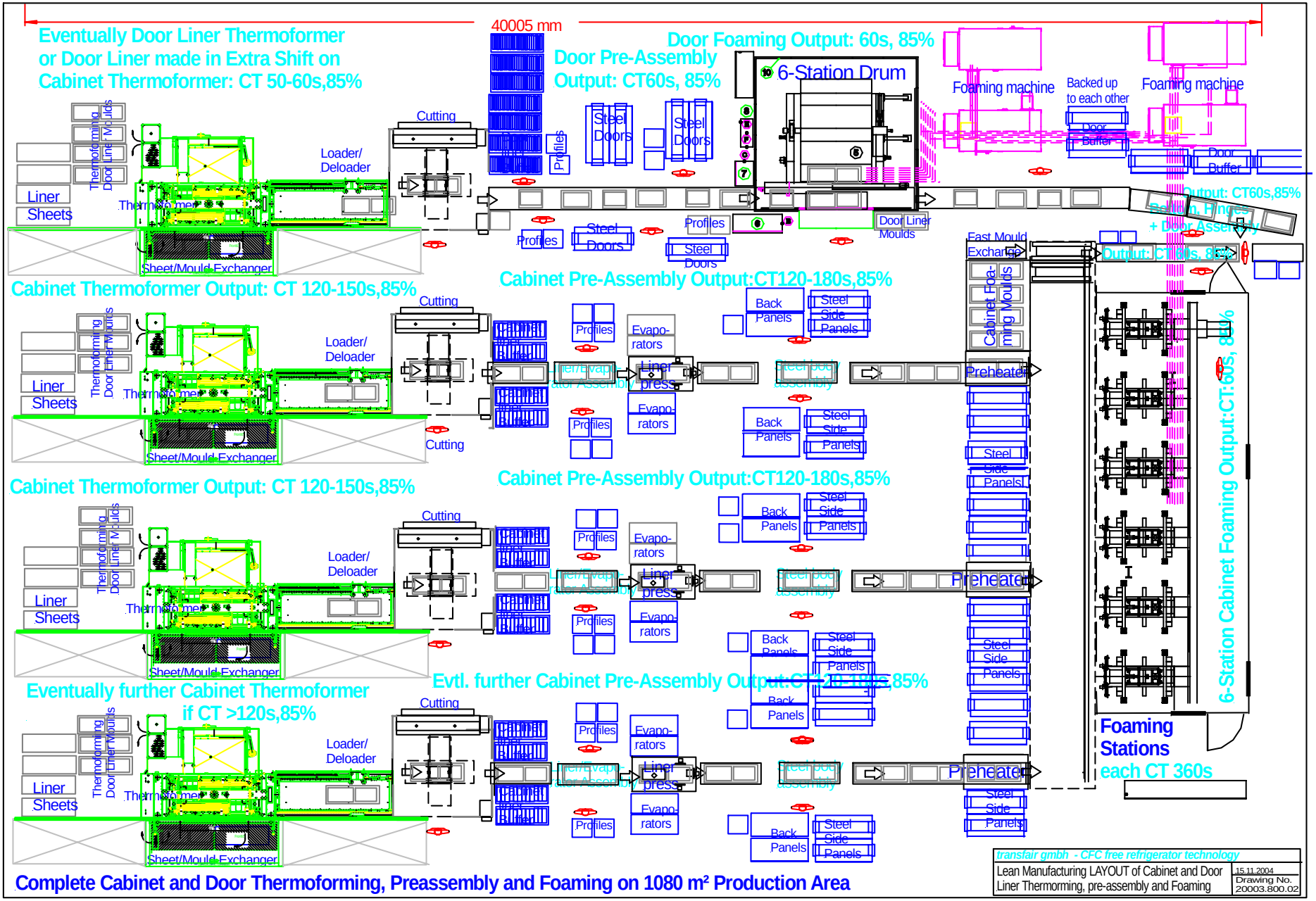
1. **Overproduction:** to produce more than demanded or produce it before it is needed. It is visible as storage of material. It is the result of producing to speculative demand;
2. **Waiting** for a machine to process should be eliminated. The principle is to maximize the utilization/efficiency of the worker instead of maximizing the utilization of the machines;
3. **Transportation** does not add any value to the product. Instead of improving the transportation, it should be minimized or eliminated (e.g. forming cells);
4. **Processing waste** should be minimized by asking why a specific processing step is needed and why a specific product is produced. All unnecessary processing steps should be eliminated;
5. **Inventory or Work In Process (WIP)** is material between operations due to large lot production or processes with long cycle times;
6. **Motion** of the workers, machines, and transport (e.g. due to the inappropriate location of tools and parts) is waste. Instead of automating wasted motion, the operation itself should be improved;
7. **Making defective products** is pure waste. Prevent the occurrence of defects instead of finding and repairing defects.

Important for a success of a refrigerator manufacturer being more and more under global competition is - beside of offering right models for the markets for lower costs with maximum profit margin – to have **high production flexibility** and **low storage capital binding**, which needs such an **integrated lean manufacturing approach.** The production lines and their cycle times should be made as far as possible **synchronous**. The single station lines for single cavity cabinet liners are with their 80-120s cycle times and for a double cavity cabinet liner 120-160s and can be made synchronous with

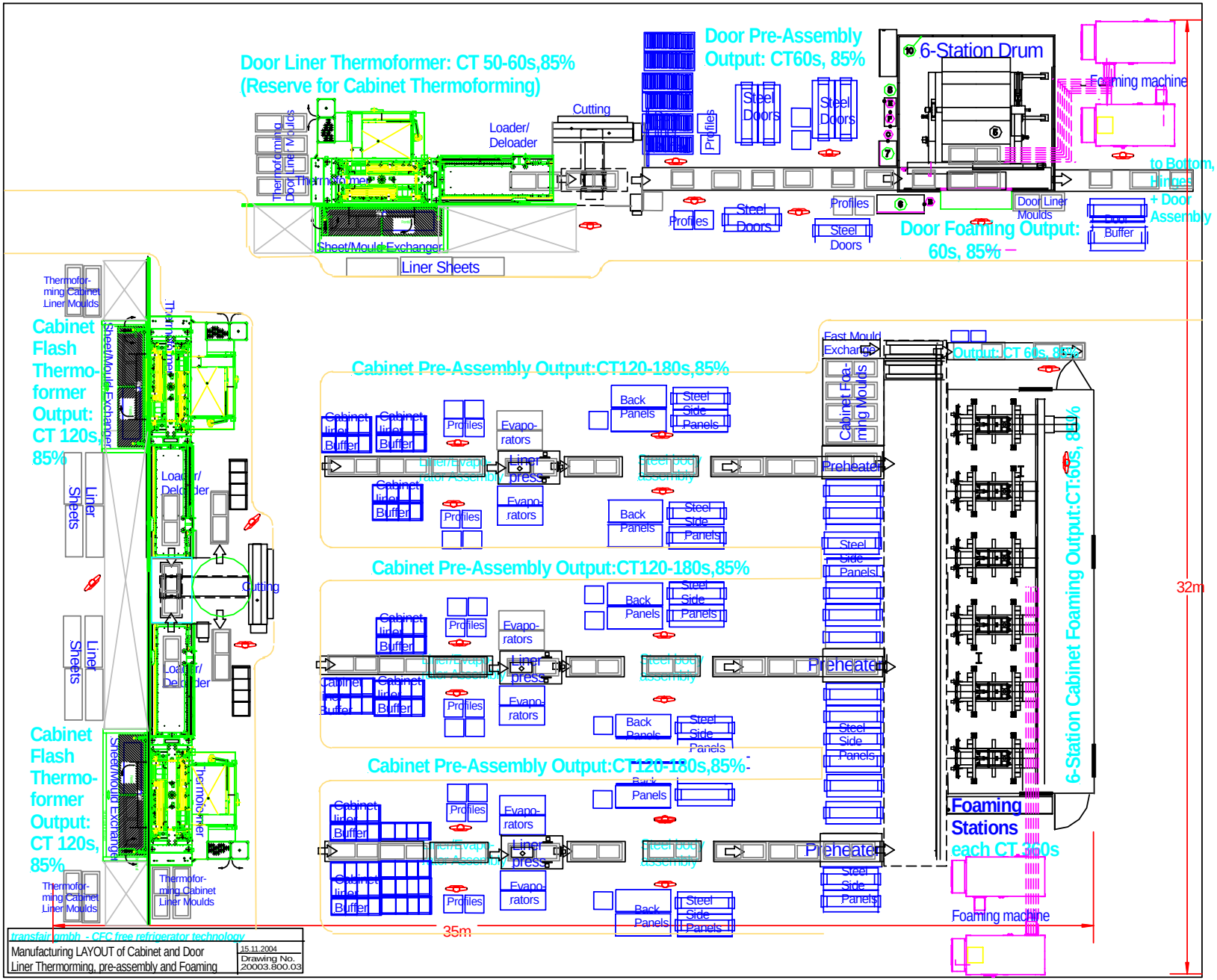
- modern enriched work pre-assembly lines as installed in main refrigerator factories Europe with a team of 4-5 persons on 2 work positions in 2 stages to pre-assemble in 1st stage a TOP evaporator on the lines and in 2nd stage the cabinet in cycles time of 90 up to 180s, mainly in the ranges around 150s
- the foaming lines with 4,5-6,5min cycle time per cabinet foaming station, mainly in 5,5-6min.

so big intermediate storage between thermoforming of foodliners, cabinet pre-assembly and cabinet foaming can be avoided. Parallel to the changing the model on a pre-assembly line, the foaming stations (for example on Crios Cannon stations inside of 5-6 min) and the assembly line behind cabinet foaming the thermoforming mould on a Geiss machine can be changed with fast change-over (inside of 7-14 min) so that only cooling down and shrinking time (95% inside of 15 min.) and a minor reserve for maintenance interventions (about 0,5-1h for Geiss thermoformer, for other thermoformers more in the range of 2,5-5h) is needed (see layout sample on next page). Single station thermoformers without such fast change-over equipment are already wasting per year €60000-80000 in additional set time, which cost more than such an automatic change-over system. Let us **compare 3 of such Geiss fast change-over single station lines with a Comi Super line** (both cost about the same, if similar equipped): To manufacture a range of different refrigerators needed in a refrigerator production to avoid final storage with such a fast line we already need 3 times more model change-over settings and restarts as if we would use 3 single stations lines with 3 different moulds. Set-up time on best fast lines takes 35min and has on good machines 2-3% liner losses, on the mentioned Geiss stations with fast change over only 7-14 min. with 0-0,5% losses. So we save not only 66,66% cases of model change-overs, but need only 7-14 min instead of 35min set time resulting to a set-up time reduction of 81% (=(1-2/3*10,5/35)*100[%]) beside of waste in losses (2-3%), huge intermediate spaces and relevant extra work (+60s per foodliner) in stocking and reuse of stocks and long transportation ways - works which are not adding any value. See on next pages one full lean manufacturing layout sample and a second layout with less investment, nearly lean, and compare it with typical refrigerator fast inline thermoforming lines in batch production with 1000m² intermediate storage, which needs only for cabinet thermoforming and its storage more space as these 2 lean manufacturing layouts consisting of cabinet and door thermoforming, pre-assembly and polyurethane foaming lines:

Lean Manu-facturing Layout of Cabinet and Door Liner Thermo-forming, Preassem-bly and Foaming with 3 or 4 Thermo-formers on 1080m²



Lean Manufacturing Layout of Cabinet and Door Liner Thermoforming with 3 Geiss single stations with Flash heaters, Pre-assembly and Foaming lines on 1120m²



Major refrigerators have 2 doors, some 1 door fridge model even a 3 start freezer. So often a **refrigerator cabinet inner liner with 2 cavities** is needed. Instead of doubling the needed cabinet thermoforming cycles and machine capacities it is possible to produce 2 cavities in one cycle, which **takes 50 % more cycle time in a single station** (or 30% in a fast line with pre-heater and heater), because of 50% sheet thickness increase. **Fast Halogen flash lamps could compensate the cycle time increase,** if shorter times are needed for the synchronisation of lines. An optimal solution is one thermoformer on each preassembly line, which produces the inner liner in the speed of the preassembly, which supply empty cabinets to 2 or 3 cabinet foaming stations, depending if the model has 2 cavities or only 1 cavity. So according to the models to be produced and foaming curing times we are quite flexible by selecting the appropriate heaters in thermoforming and the quantity of workers in pre-assembly to adjust cycle times to each other. By this way

- all the 7 above mentioned **Deadly Waste** of overproduction (intermediate storage), waiting, long transportation, inventory of work in process, motion and making defective product and edge cut waste (only with Geiss Zero loss possible) are minimized,
- the production is nearly just-in-time with smaller buffers,
- the work flow and one piece flow (The US and Japanese use for it the German word “takt” time) is relatively balanced and
- with a set up time of 7-14 minutes on each line the refrigerator manufacturing is highly flexible.

Even if we cannot use by this synchronisation 100% of thermoforming theoretical capacities, we will always waste much less (20-30%) as by using a fast thermoforming line, able to use only 50-60 %.

Breakdowns and low production losses under lean manufacturing concept

What will happen in case of a long extraordinary thermoforming machine break down under lean manufacturing concept? This is often the main argument against just-in-time and lean concepts. In case of an extraordinary long break down on a thermoforming machine, all manufacturers using a fast machine will stop refrigerator production – send a major part of staff home and latest when their mountains of intermediate storage are consumed and have to send all their staff home. A refrigerator manufacturing company using similar investment amount to purchase **3 single lines with fast change over and Zero losses**, as made by Geiss, **will just loose 7-14 min. of a part of its thermoforming production capacity**. It will change over the door thermoformer making now cabinet liners (if a cabinet line was broken), will continue refrigerator cabinet production already after about 10 min of break down (**without loosing any capacity on the pre-assembly, foaming and assembly line** as result of small buffering) in the rest day production time without mounting of doors, if thermoformed doors are not buffered. In an extra shift of maximum 4 h 1or 2 men can manufacture all the door liners lost and needed the last day and the ones needed the following day on the 2 remaining thermoforming machines. Either already in this extra 4h shift or parallel to the standard production on the first or second day the 1 or 2 shift door mounting losses can be compensated – and this only one time and not regular. Finally the factory did not reduce their planned output, but surely has some extra costs for an extra 4 shift for some workers. The break down costs and production losses on 3 modular lines instead of 1 fast line is much lower and can be compensated without consequences on remaining factory production.

Even a huge reserve of cabinet liners in the size of a complete factory hall made by a fast thermoforming line has much higher production risk as such 3 modular lines with small liner buffers established for a similar investment amount. A similar safety can only be reached if a manufacturer needs 3 or more fast lines, but still he has in such a case all the 7 deadly wastes and a 30-40% lower financial internal rate of return (FIRR) in his investment in comparison to a modular single station solution fully integrated into the manufacturing flow.

16. Summary

Household refrigerator producers with a range of different models can reach needed high flexibility in production and be prepared for future designs, can increase capital use of costly thermoforming and reduce above mentioned deadly waste and running costs as following:

1. **Investment** of the same amount as needed for fast inline thermoformers **in several cheaper single station thermoformers** with fast change-over allowing to produce parallel different models with nearly no loss of production time for mould change-over (about 81% less set-up times) **reaches 25-35% higher liner production and capital use as fast lines, reduce waste to nearly 0 for single cavities and less than half for complicate double cavity liners.** No waste in huge intermediate storage space and involved extra work operations for long ways is needed. Edge cuttings and material recycling can be strongly reduced**;** fast machines which earlier touch design limits (small square-deepness ratio, undercuts) causes more waste.

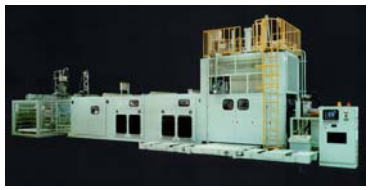
2. **The synchronisation of thermoforming cycle times with the cabinet pre-assembly, foaming and final assemblies is essential to reduce deadly wastes** (intermediate stocks, extra work, long ways of transport, logistical problems in not synchronised work processes, time waste in waiting, co-ordination and work control). Pre-assembly with evaporator behind liner or skin condensers are often pre-assembled in 6 1/2 – 12 minutes by 4-5 workers (enriched work, personal work responsibility). The needed cycle time of 90 -150 sec. are in the range of single station lines, depending of single or double cavity (3,2mm or 4,2-4,5mm HIPS) and of used quartz or Halogen heaters (IR ceramic ones are waste of energy) so that in the average one station produce the cabinet liners of one pre-assembly line and 1 pre-assembly can feed 2 or 3 foaming stations, depending of foaming curing and foaming line movement speed, 1 or 2 cavities and used heaters.

3. **Many single stations** in front of cabinet pre-assembly and door pre-assembly – even in a **lean concept** with only small buffer storage – **have much lower production risk in case of a long machine break down as fast lines. The running production will neither be stopped nor diminished** and can be compensated by the other single station machines during some hours of an extra shift with 1-2 workers.

4. In nearly all countries energy is expensive and their prices are growing. **Using IR- heaters is waste, fast switching Quartz are already saving energy; much more efficient are even Halogen Flash lamps, saving energy, heating time and costs,** even if their purchase costs are higher and their lifetime limited.

5. Most thermoforming machine producers consider **window reducer/clamping frames as part of mould** (about €4500-5000 per mould or 15-20% of mould value) needed for each model and not as part of the machine. **A universal window and clamping frame** like **Geiss** is offering **save 15-20% of mould costs on each mould needed and speed up the set-up time**. In some world areas (America, Far East, partially also in other areas) female moulds are use, which are normally more expensive, but male moulds reach better qualities and the thermoformed liner can be faster cooled down.

17. Thermoforming machine manufacturers



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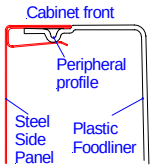
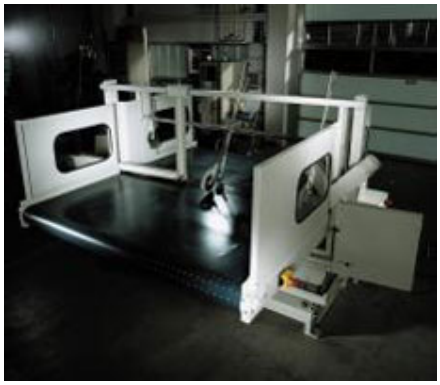
18. Trimming of thermoformed refrigerator cabinet and door liners



Modern designs of cabinet liners have often a small profile of about 3 mm to be inserted into front side steel profile of refrigerator side panels. Such profiles and often even the deep drawing part are too near to the sheet clamping frame to be trim-less manufactured. Therefore after thermoforming the perimetrical sheet parts must be trimmed. Good thermoforming machines can manage to reduce sheet trimming losses to 20-35 mm. All cutting and trimming methods needs that the liner must correctly be positioned by a liner specific holder (support plate) and kept into the position even against trimming pressure. Trimming can be made by following methods



Geiss Saw Station

(1.) 2 row **horizontal band saw** with exhaust ventilation (€ 18-23000 with manuals loading/de-loading). Disadvantage is that it makes dirt, and needs to be kept away from dirt sensitive thermoforming.

(2.) Punching press with punching tools. Punching tools on large pneumatic, eccentric or hydraulic presses are not recommended because they are not flexible; tools must be change, if liner model change and each size need its own expensive tool. But it can do trimming and hole punching, if needed together. More economic and flexible would be a movable turntable in front of a long punch which trims the 4 edges of liners, similar to the guillotine (item 3.).

Rigo Bilama or
Comi double blade Guillotine

(3.) The main used method of liner trimming is 1 or 2 rows **Guillotine** manually or automatic PC/PLC controlled. With turntable the liner can be trimmed on 4 sides. A PC/PLC controlled single blade machines works in cycle times of 25-28s and costs about €95-105000, while a double blade machine works with a cycle time of 20-25s and costs €135000-150000. Integrated into an automatic line its price grows up by €30000. Strong advantage is that it produces **no dust**, problematic for thermoforming, like robots and CNC trimming spindles. Which needs to be enclosed and exhaust ventilated.

(4.) **Robots** with a trimming spindle are cost wise in similar price level as automatic guillotine station if all parts needed trimming are added, like liner positioning and de-positioning, liner holder, exhaust ventilation, safety enclosure, programming are included but could even make some inner hole cuts, if needed. Same possibility, flexibility and price wise similar are a CNC machine with trimming spindle (item 5. i.).

(5.) **CNC controlled trimming and cutting machines.** There exist different types, depending of needed axis (3 up to 5) and used cutting and trimming method:

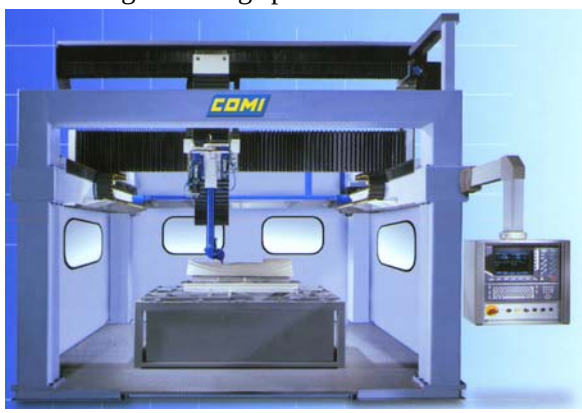
Geiss CNC trimming machine

i. **Trimming spindles,** like Geiss f. ex. FZ 2000x1000x560mm (€150-190000) and other manufacturers, which needs a good dust extraction, filter and air circulation system, to be added.

The advantage of such universal CNC trimming machines is that it can be used for tool making and repairs, workpiece holders, modelling and prototyping.

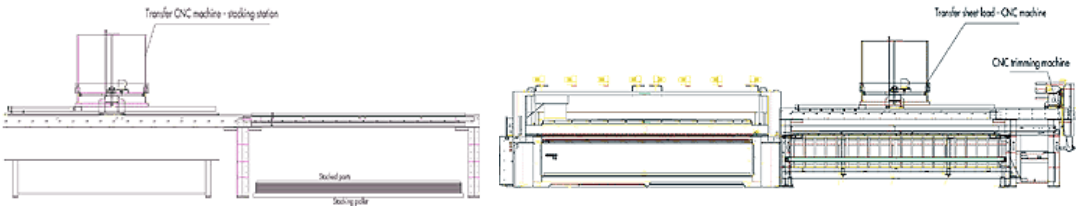
ii. **ultrasonic cutting machine,** like Geiss (€200000) can cut only plastic sheets up to 4mm thickness, sufficient for door liners and single cavity liners, but not applicable for double cavities liners (4,2-5mm). Even there exist CNC machines which have ultrasonic and trimming spindle in one machine.

iii. **CNC laser cutting** (Comi, Geiss, Kiefel) is as flexible as trimming with spindles, but makes already a **nice cut surfaces without any additional work step**. Speed is the same as using trimming spindles. Laser makes no noise and dust, so exhaust ventilation is simpler; air still must filtered by active carbon or catalytic with less service costs. The disadvantage is their price (about €400000). Liner edges are inserted into steel profiles, so their trimming does not need nice surface, but perhaps other cuts, if any. If this justifies the much higher investment must be checked. Normally good liner designs only mark holes by thermoforming mould, but do not cut them to avoid extra work to close such holes by a masking tape before foaming.

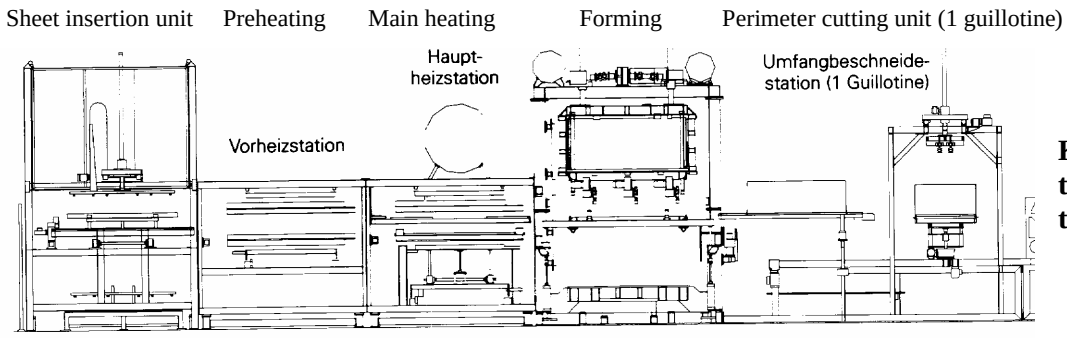


Comi Laser Cutter

(6.) **Thermoforming and trimming in a combined line.** Each version can be made in line with thermoformer (Comi, Kiefel, Geiss) or as independent station.



Geiss thermoforming and trimming IN ONE



Kiefel inline thermoformer with trimming guillotine

The machines in versions (2.) trimming and punching tool, (4.) robots and (5.) CNC trimming can also make holes and cuts inside the liner to replace completely liner punching machine (next chapter).

19. Punching of thermoformed refrigerator cabinet and door liners

Many cuts and holes inside the liners, which always need to be sealed before foaming, can be avoided by design tricks or easier made after foaming upon markings or deepening made by the thermoforming mould. But still some models, like some freezers with inside cabinet coils and No Frost models still need holes and squares to be punched inside the liner before foaming.

The most flexible way doing such holes inside the liners is to use a.m. (4.) robots and (5.) CNC trimming machines using trimming spindle (i.), ultrasonic cutter (ii.) or laser cutter (iii.).

Cheaper, but less flexible solutions are **special design liner punching machines**. The punching is normally made by pneumatic cylinders with punching tools. A good machine is made in a way, that it as flexible as possible:

- the punching tools with cylinder should be gliding guides movable in 2 dimensions on different positions, and
- on the liner side(s), backside top or bottom, which need to be punched.

In this case only punching tools have probably to be replaced in case of model change.

20. Questionnaire for the selection of thermoforming machines

1) New Vacuum thermoforming production capacity needed:

a. How many refrigerator cabinet inner liners are needed? _____ per 8h shift
b. How many refrigerator door liners are needed? _____ per 8h shift
c. How many different models per shift to be produced in average? _____ per 8h shift
Maximum? _____ per 8h shift
d. How many shifts per day pre-assembly and foaming lines runs? _____ per day
e. Double cavity cabinet liners needed? *Yes/No*
and ____% of such models in total production
f. Maximum cabinet liner size (height x width x deep): _____ h x _____ w x _____ d mm
But 80% of models only need up to following sizes: _____ h x _____ w x _____ d mm
g. Maximum door liner size (height x width x deep): _____ h x _____ w x _____ d mm
But 80% of models only need up to following sizes: _____ h x _____ w x _____ d mm

2) Existing Vacuum thermoformers in the factory, which needs new thermoforming capacity:

a. Manufacturers:				
b. Model:				
c. Sizes for mould max. (l*w*h):				
d. Male or female moulds				
e. Plug assist YES/No				
f. Heater type (Ceramic IR, Quartz, Halogen or else)				
Cycle times from ___ to ____ sec. for cabinet liners for door liners				
Total change over time last–first pc.				
kVA installed				
kW consumed				
Construction year				

3) Cabinet liner design problems for thermoforming

a. Undercuts on models
- For drainage tube _____, _____, _____, _____, _____, _____, _____
- For other reasons _____, _____, _____, _____, _____, _____, _____
Which ones (make small sketch or enclose drawings):

b. Perimetric small profile exists (to be inserted into steel front profile)? *YES/NO*
c. Min. distances between outer trim cut and deep drawing area of cabinet liner: _____mm
d. Sheet materials *HIPS, ABS*
e. Sheet thickness for cabinet liner (single cavity): from _____ to _____ mm in HIPS
from _____ to _____ mm in ABS
f. Double cavity cabinet liner needed *Yes/No* and _____% of total refrigerator production
g. Single cavity max. cabinet liner size(height*width*deep): _____ h* ____ w* ____ d mm
But 80% of models only need up to following sizes: _____ h* ____ w* ____ d mm
h. Double cavity max. cabinet liner size(height*width*deep): _____ h* ____ w* ____ d mm
But 80% of models only need up to following sizes: _____ h* ____ w* ____ d mm
i. Maximum door liner size (height x width x deep): _____ h* ____ w* ____ d mm
But 80% of models only need up to following sizes: _____ h* ____ w* ____ d mm

4) Environmental and frame conditions:

a. Power supply voltage fluctuations totally: between _____ and _____V
and between 1-2, 2-3 and 1-3 phases between _____ and _____V
b. Power stabilizers or stable electrical generators exist? *YES/No* with _____ KVA
c. Big electrical power consumers of ____ kW in factory are switched on and off during thermoforming on same power supply system of totally _____ kVA
d. Temperature fluctuation inside factory hall
in the months from _____ till _____ per day: between _____ and _____ °C
in the months from _____ till _____ per day: between _____ and _____ °C
e. Factory costs of electrical power per kWh in € or US$: ___ _____
f. Staff
i. 2 persons/shift experienced in thermoforming *YES/NO*
ii. monthly salary: in € or US$ _____

5) (Trimming (perimetric cutting) machines needed?

Min. and max. height of liner _____mm _____mm
Min. and max. width of liner _____mm _____mm

6) Holes/square punching of liners needed for how many models? Quantity _____
If needed, please add design
Remark: For drainage tube punching not needed.

7) **Thermoforming moulds needed?** Quantity _____
If needed, please add design