DG206 Manufacturing Technology

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Where innovation starts

If you think knowledge is expensive
try ignorance.

Jonathan Ive (Apple), 2010/06/30 On materials and manufacturing

- "A big part of the experience of a physical object has to do with the *materials*, we experiment with and explore materials, *processing* them, learning about the inherent properties of *the material–and the process of transforming it* from raw material to finished product; for example, understanding exactly how the processes of machining it or grinding it affect it. That understanding, that preoccupation with the materials and processes, is very essential to the way we work."

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Goals of this assignment:

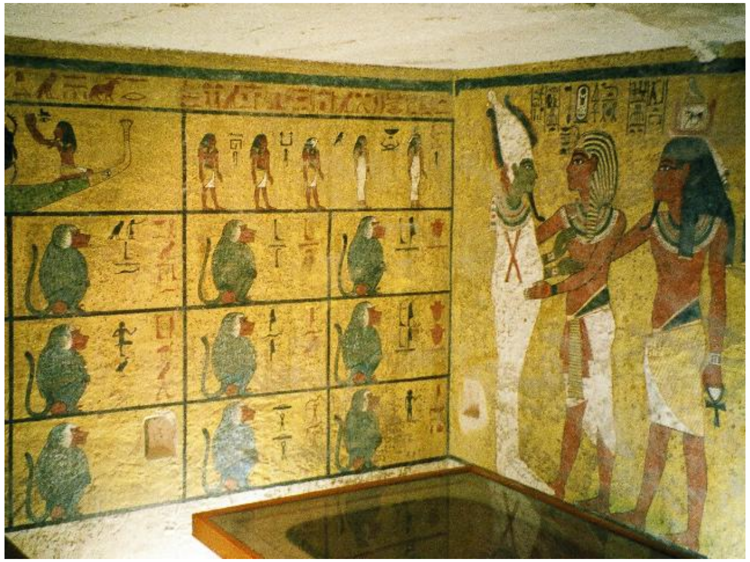
- Get to know multiple manufacturing techniques
- Know what can and cannot be manufactured.
- Being able to analyse a mechanical product for manufacturing
- Knowing when to consult an expert
- Writing a report about
  - A manufacturing topic to be studied
  - An analysed mechanical product

Assignment literature:

1. M.P. Groover, Fundamentals of Modern Manufacturing, Materials, Processes and Systems, Prentice Hall, New Jersey.
2. M.F. Ashby, Materials Selection in Mechanical Design, Pergamon Press.
3. CES Edupack 2010, materials database http://w3.id.tue.nl/nl/intranet/ict/software/
4. R. Thompson, Manufacturing Processes for Design Professionals, Thames&Hudson, 2007.

Everything has been manufactured

Valley of the Kings,
Luxor, Egypt



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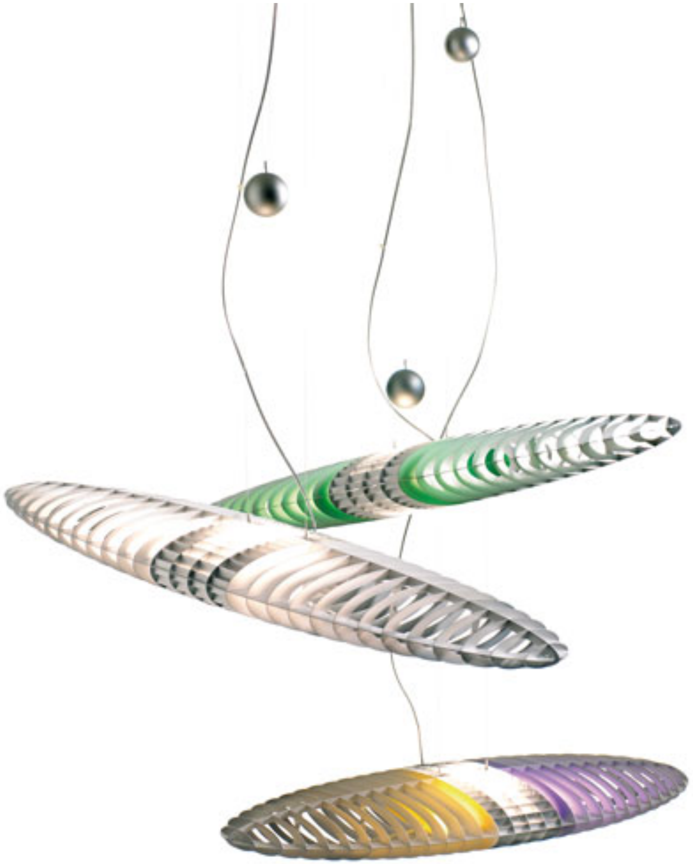
Allessi

Magis

Apple

Luceplan



Titania

Assignment structure

- First meeting: today
    - Introduction into manufacturing

- Second meeting:
    - Presentation per group (2-3 persons) of a studied topic from M.P. Groover, Fundamentals of Modern Manufacturing

Assignment structure

- Third & fourth meeting
  - GTD excursion, multiple manufacturing techniques will be demonstrated
- Fifth meeting:
  - Presentation of the analysis of the manufacturing of a chosen product
    - For single piece and small lot size manufacturing

Introduction

- What is manufacturing?
- Types of manufactured products
- Production quantity versus product variety
- Manufacturing processes:
  - Feasible process / materials combinations
  - Achievable tolerances / roughnesses / section thicknesses
  - Feasible process / shape combinations
  - Economical batch sizes
- Some manufactured mechanical products

Manufacturing defined historically:

- **Derived from manus (hand) and factus (make).**
- **The combination meant: “made by hand”**

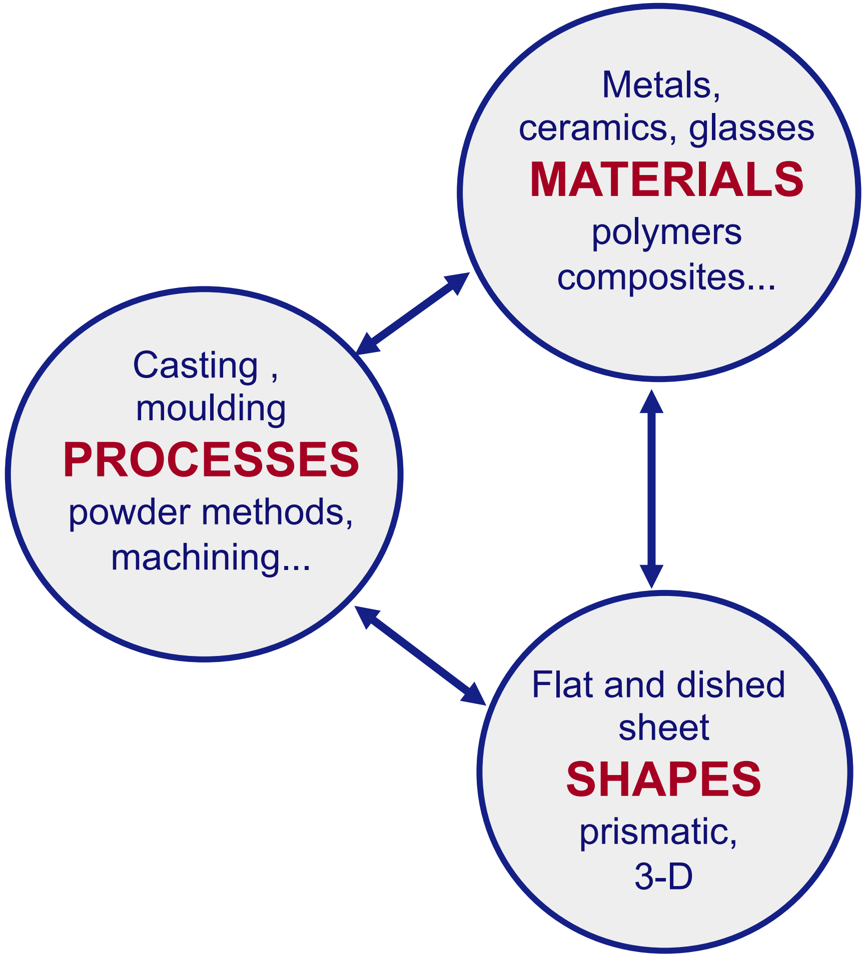
Manufacturing defined technologically:

- The application of
  - physical and / or chemical processes to
    - alter the geometry, properties, and/or appearance of a given starting material to make parts or products. Includes assembly!
- Manufacturing is almost always carried out as a sequence of operations to reach the desired final state of the product.

Manufacturing defined economically:

- **Manufacturing is the transformation of materials into items of greater value by means of one or more processing and/or assembly operations.**
  - **Keypoint: “Adds value”**

Strong interactions between:



Metals,
ceramics, glasses
MATERIALS
polymers
composites...

Casting ,
moulding
PROCESSES
powder methods,
machining...

Flat and dished
sheet
SHAPES
prismatic,
3-D

M.F. Ashby

Manufactured products classes

- Consumer goods
  - Products purchased directly by consumers
    - Cars, personal computers, TV’s, …

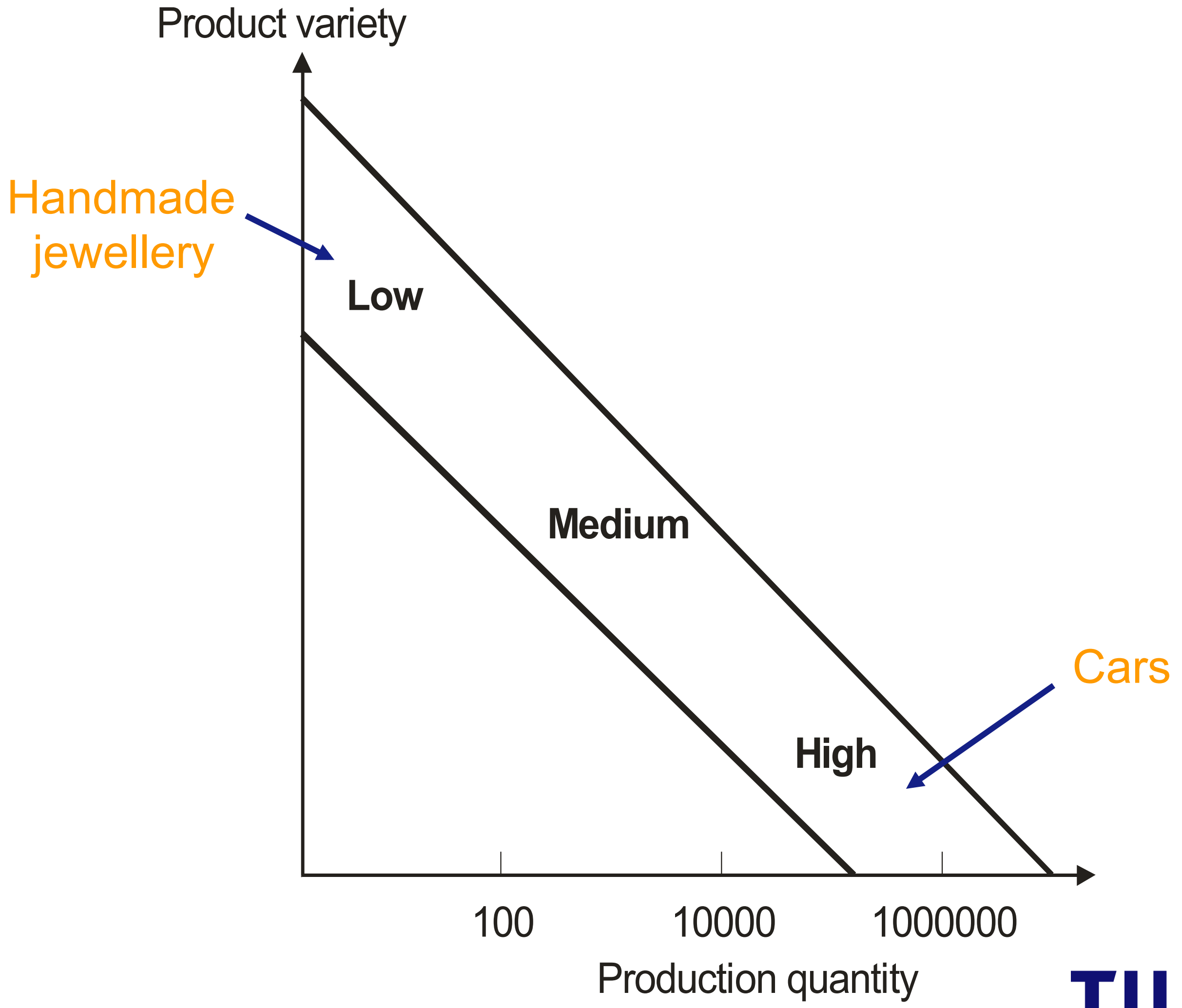
- Capital goods
  - Products purchased by other companies to produce goods and supply services
    - Aircrafts, railroad equipment, machine tools, …
  - Mostly complex and thus expensive

Production quantity and product variety

- Production quantity ranges:
  - Low production: 1-100 units/year
  - Medium production: 100-10.000 units/year
  - High production: 10.000- millions units/year

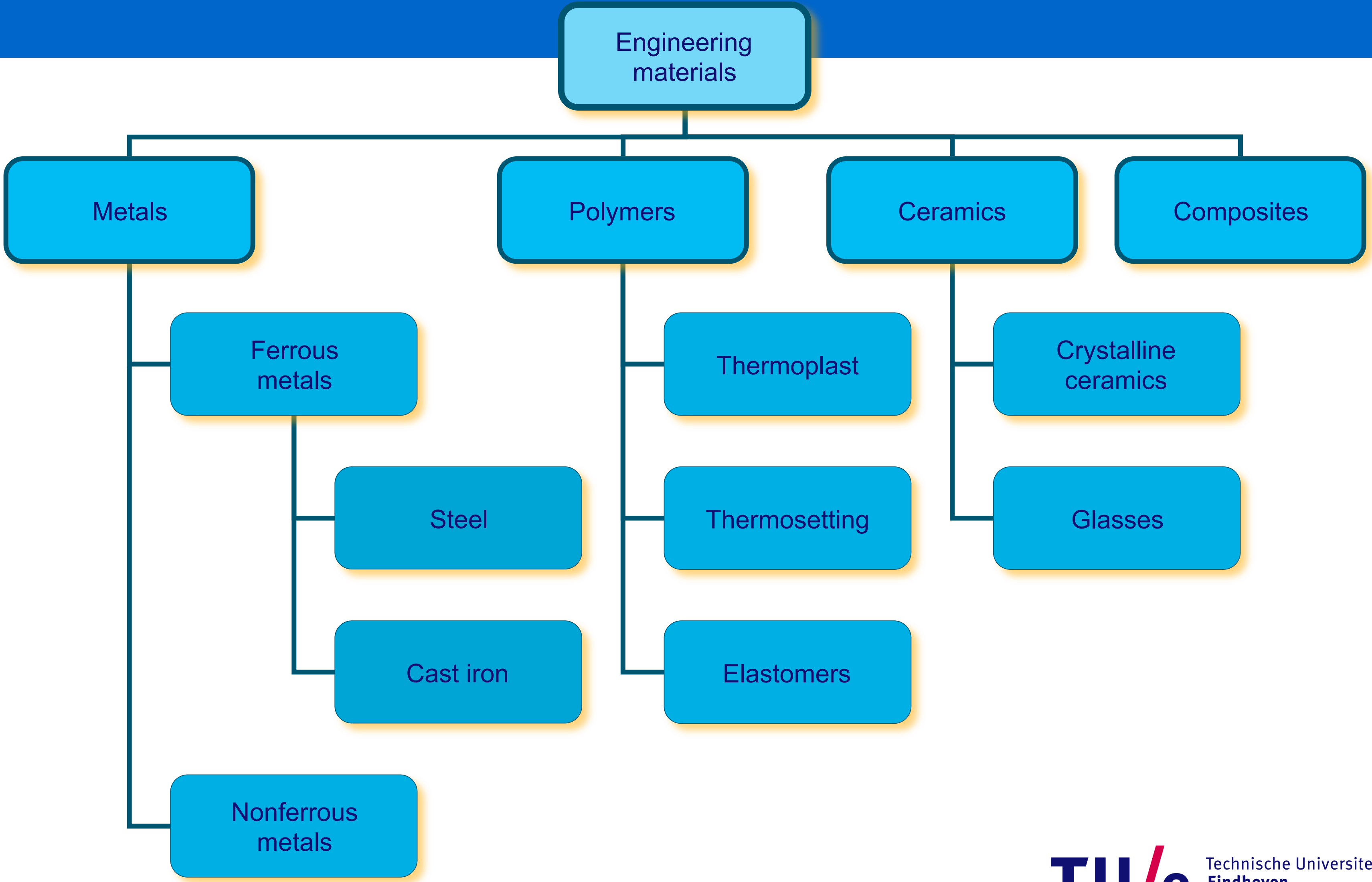
- Product variety
  - Different products have different shapes and sizes, functions, different markets, …

Production quantity and product variety



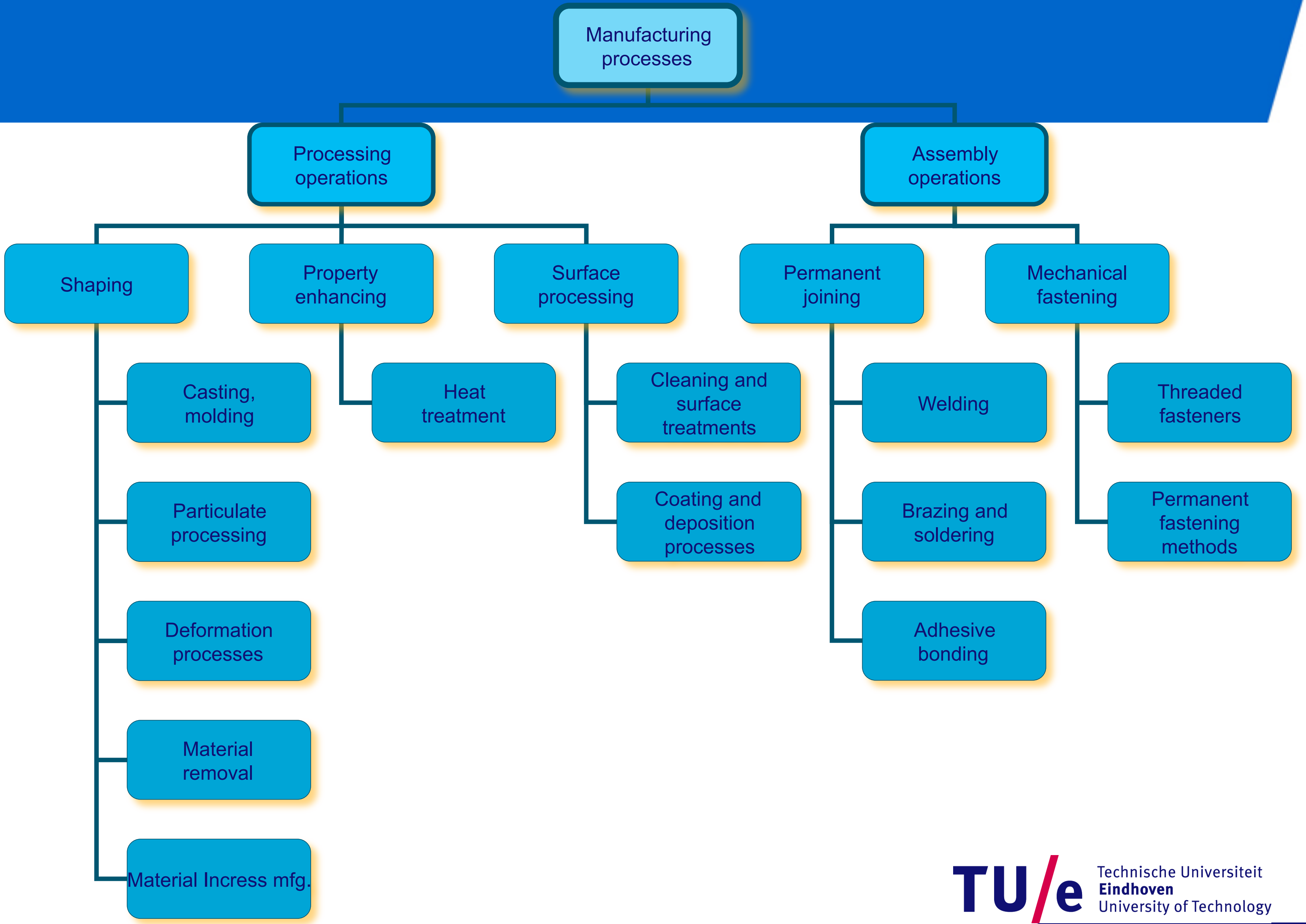
Engineering materials in manufacturing

- Different chemical composition of materials,
- Different mechanical and physical properties
- Thus consequences for manufacturing



Engineering materials

- Metals
  - Ferrous metals
    - Steel
    - Cast iron
  - Nonferrous metals
- Polymers
  - Thermoplast
  - Thermosetting
  - Elastomers
- Ceramics
  - Crystalline ceramics
  - Glasses
- Composites



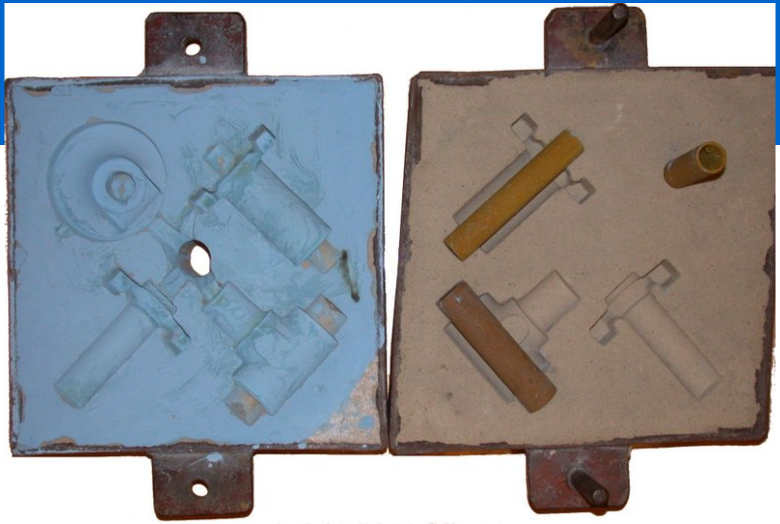
Manufacturing processes

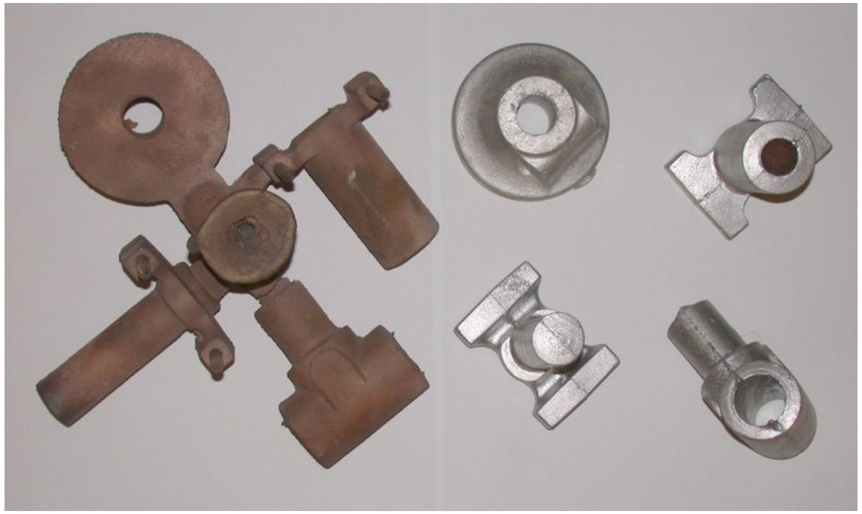
- Processing operations
  - Shaping
    - Casting, molding
    - Particulate processing
    - Deformation processes
    - Material removal
    - Material Incress mfg.
  - Property enhancing
    - Heat treatment
  - Surface processing
    - Cleaning and surface treatments
    - Coating and deposition processes
- Assembly operations
  - Permanent joining
    - Welding
    - Brazing and soldering
    - Adhesive bonding
  - Mechanical fastening
    - Threaded fasteners
    - Permanent fastening methods

Shaping processes

- Casting, molding and …:
  - Starting material is a heated liquid or semifluid

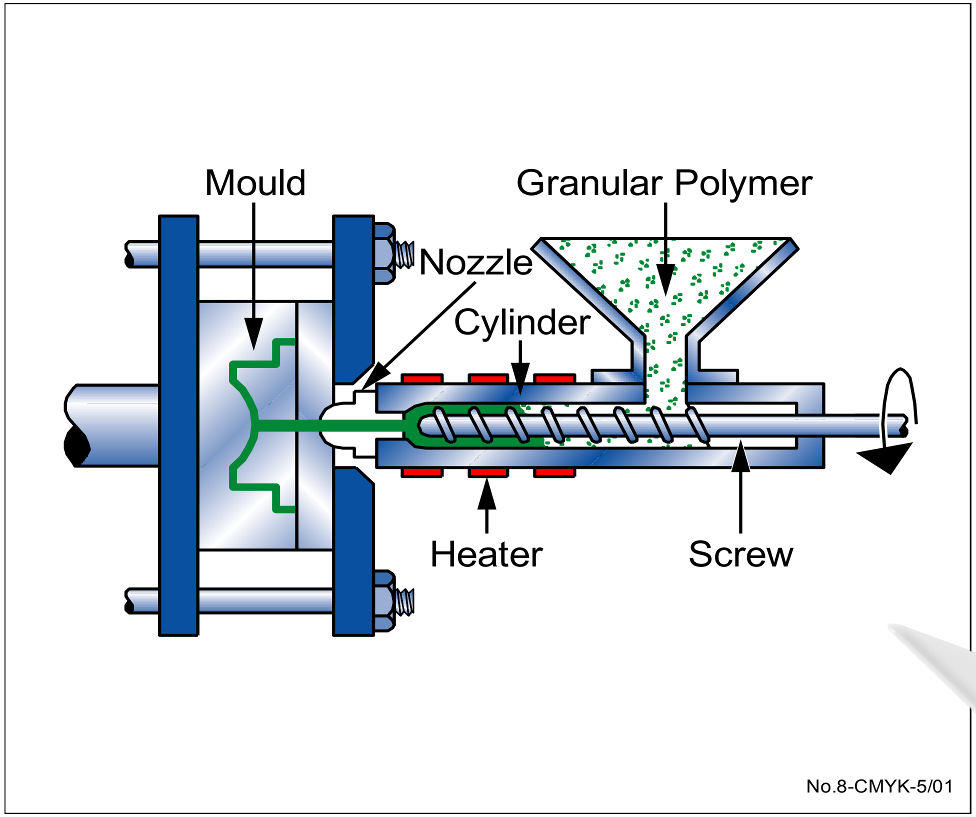
- Particulate processing:
  - Starting material is a powder which is formed and heated into the desired shape





Photo’s: www.wikipedia.org

Injection molding

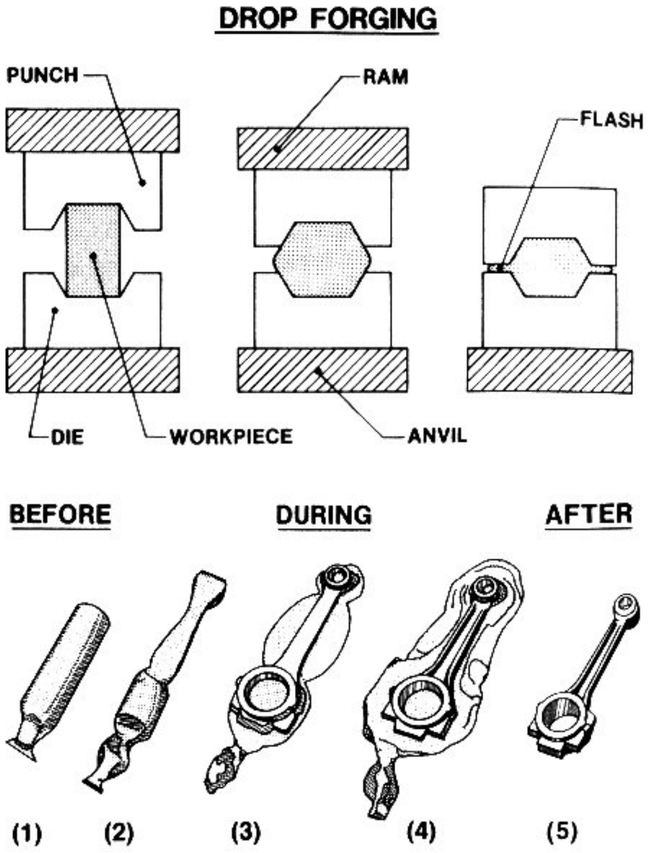


Shaping processes

- Deformation processes
  - Starting material is a ductile solid which is deformed to shape the part

- Material removal processes:
  - The starting material is a (brittle or ductile) solid from which material is removed.

Shaping processes: forging

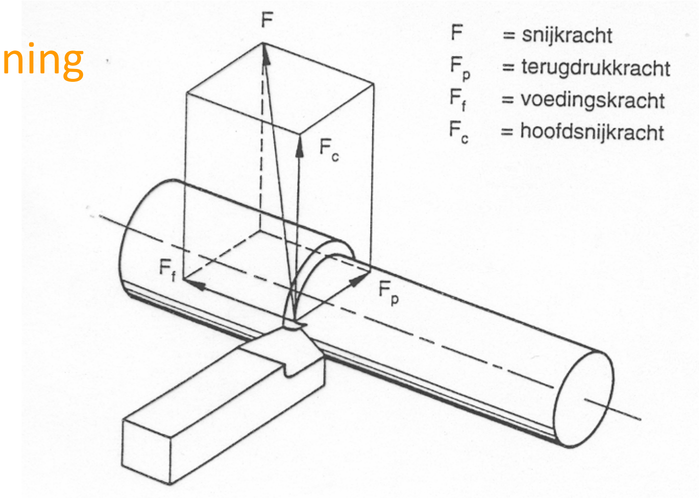


Metal stamping
& deformation

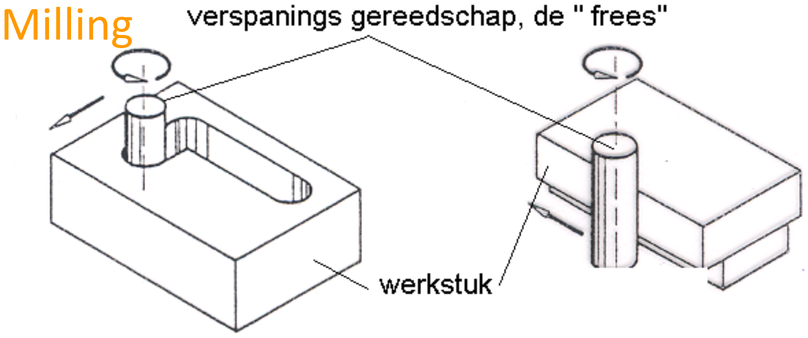
Photo’s: www.wikipedia.org

Shaping: material removal

Turning



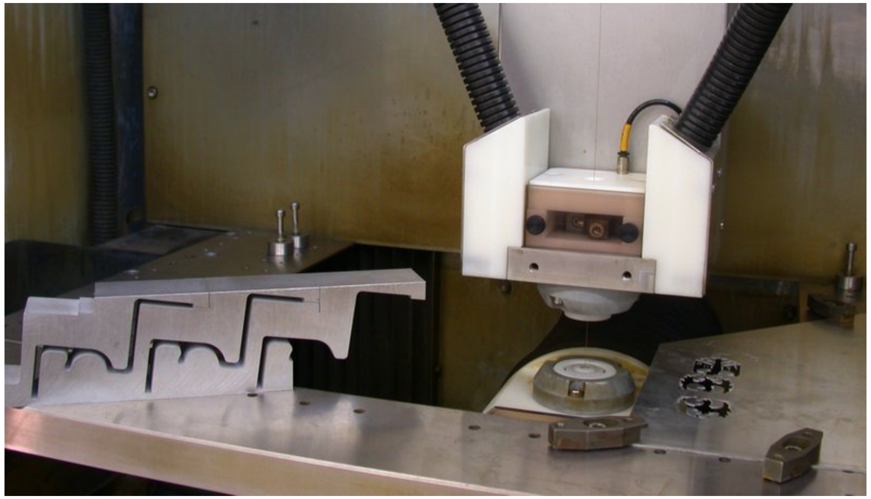
Milling

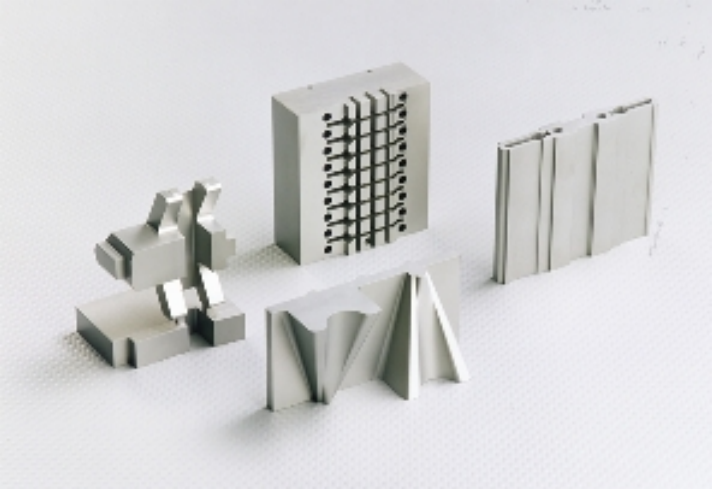


Lathe

Lens

Wire Electro Discharge Machining





Photo's: www.wikipedia.org

- Manufacturing processes
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    - Shaping
      - Casting, molding
      - Particulate processing
      - Deformation processes
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      - Material Incress Mfg.
    - Property enhancing
      - Heat treatment
    - **Surface processing**
      - Cleaning and surface treatments
      - Coating and deposition processes
  - Assembly operations
    - Permanent joining
      - Welding
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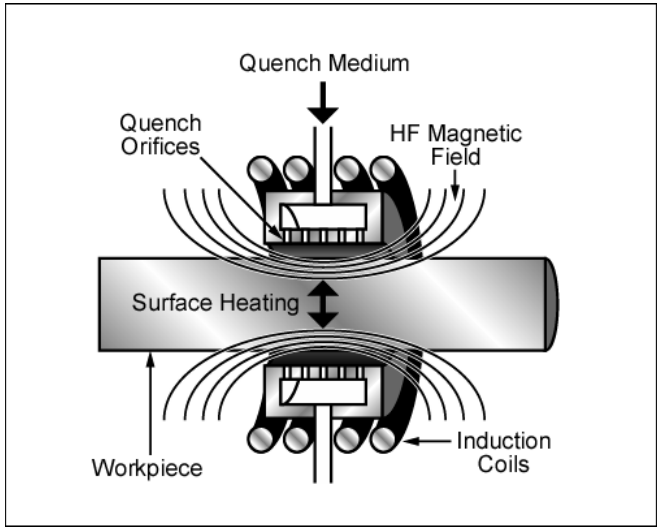
Surface processing

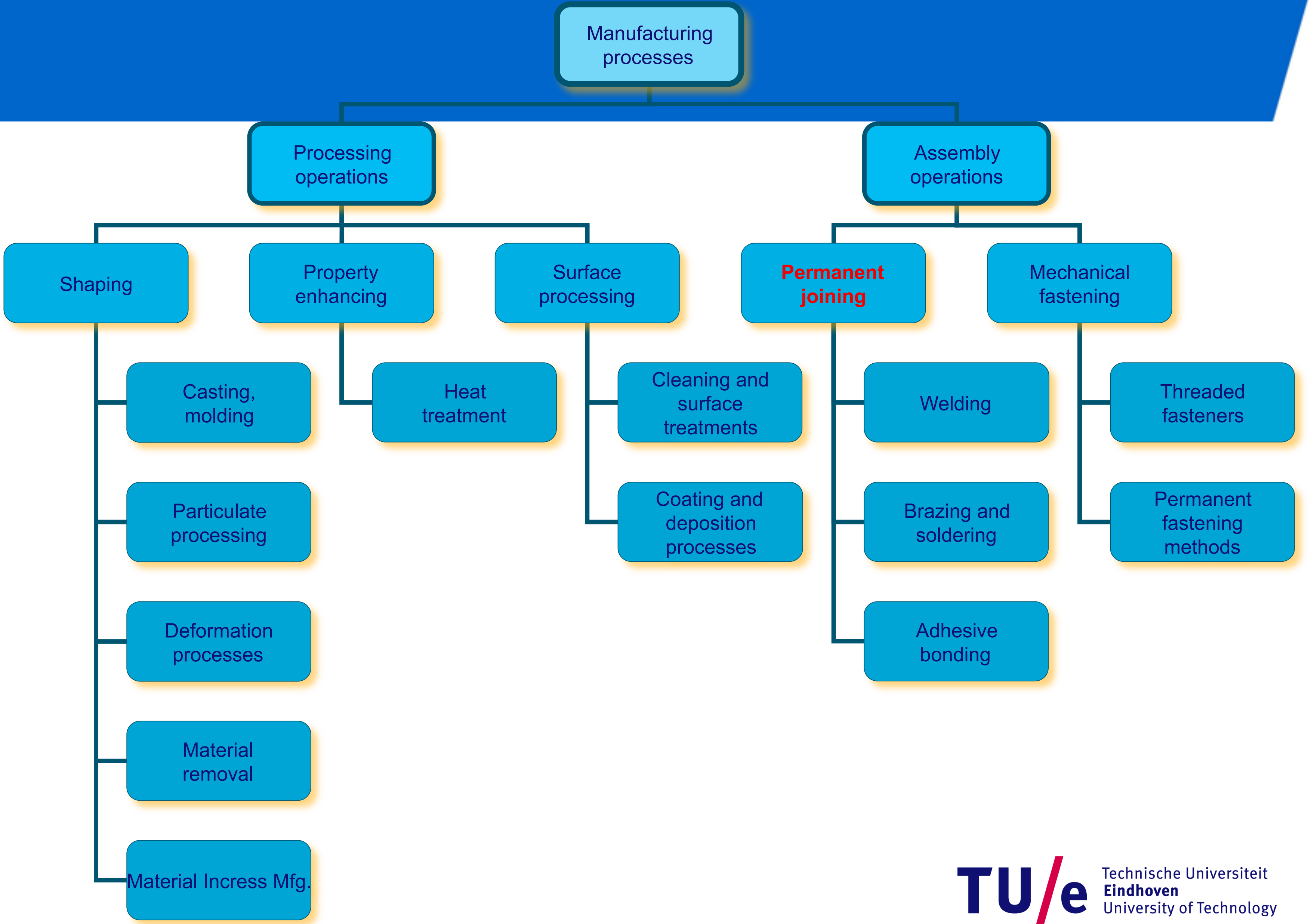
Enamel paint

Aluminum dyed
using anodisation



Surface induction hardening

Photo's: www.wikipedia.org


Manufacturing processes
Processing operations
Assembly operations
Shaping
Property enhancing
Surface processing
Permanent joining
Mechanical fastening
Casting, molding
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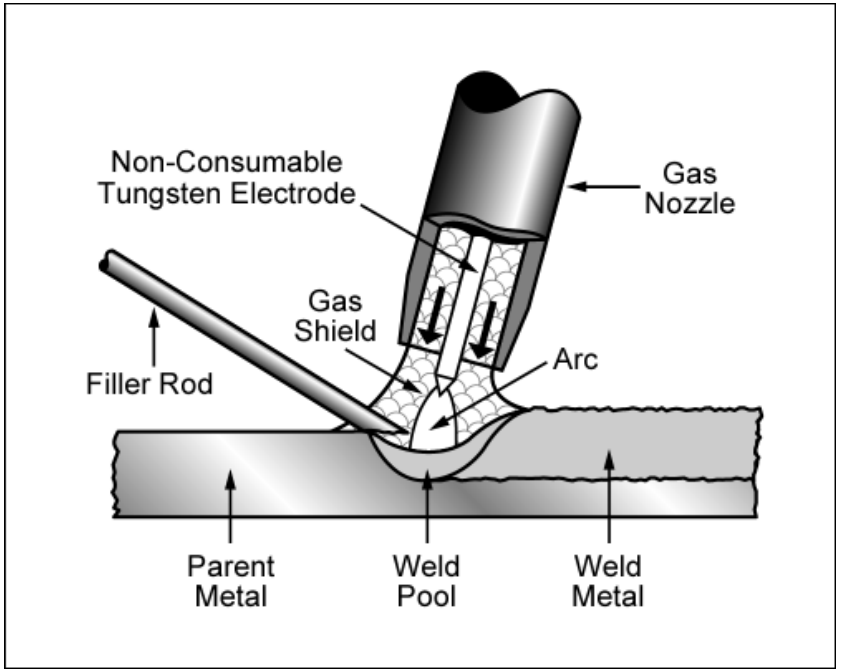
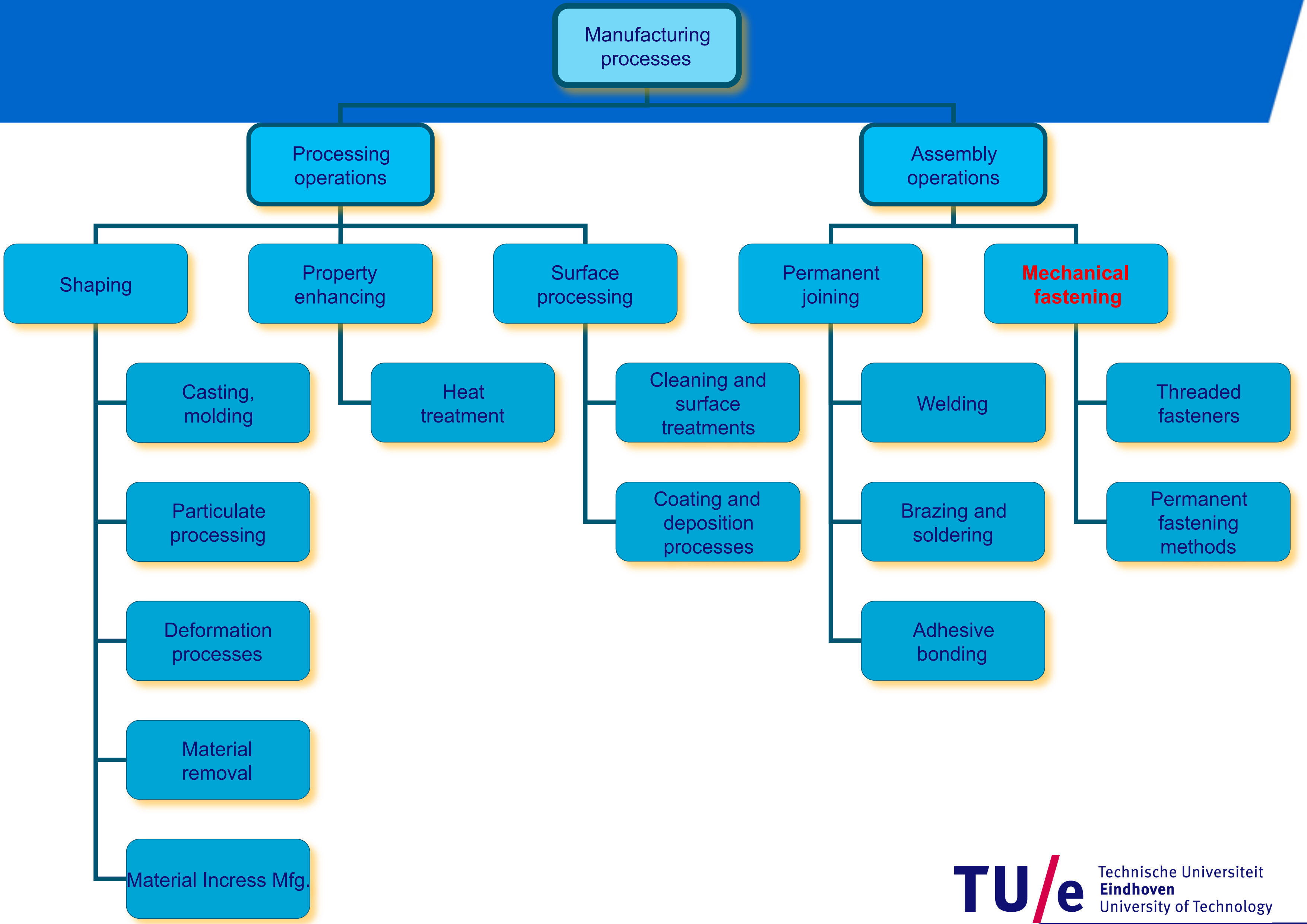
Permanent fastening methods

Tungsten inert-gas (TIG) welding



Tungsten inert-gas (TIG) welding, the third of the Big Three (the others are MMA and MIG) is the cleanest and most precise, but also the most expensive.



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    - **Mechanical fastening**
      - Threaded fasteners
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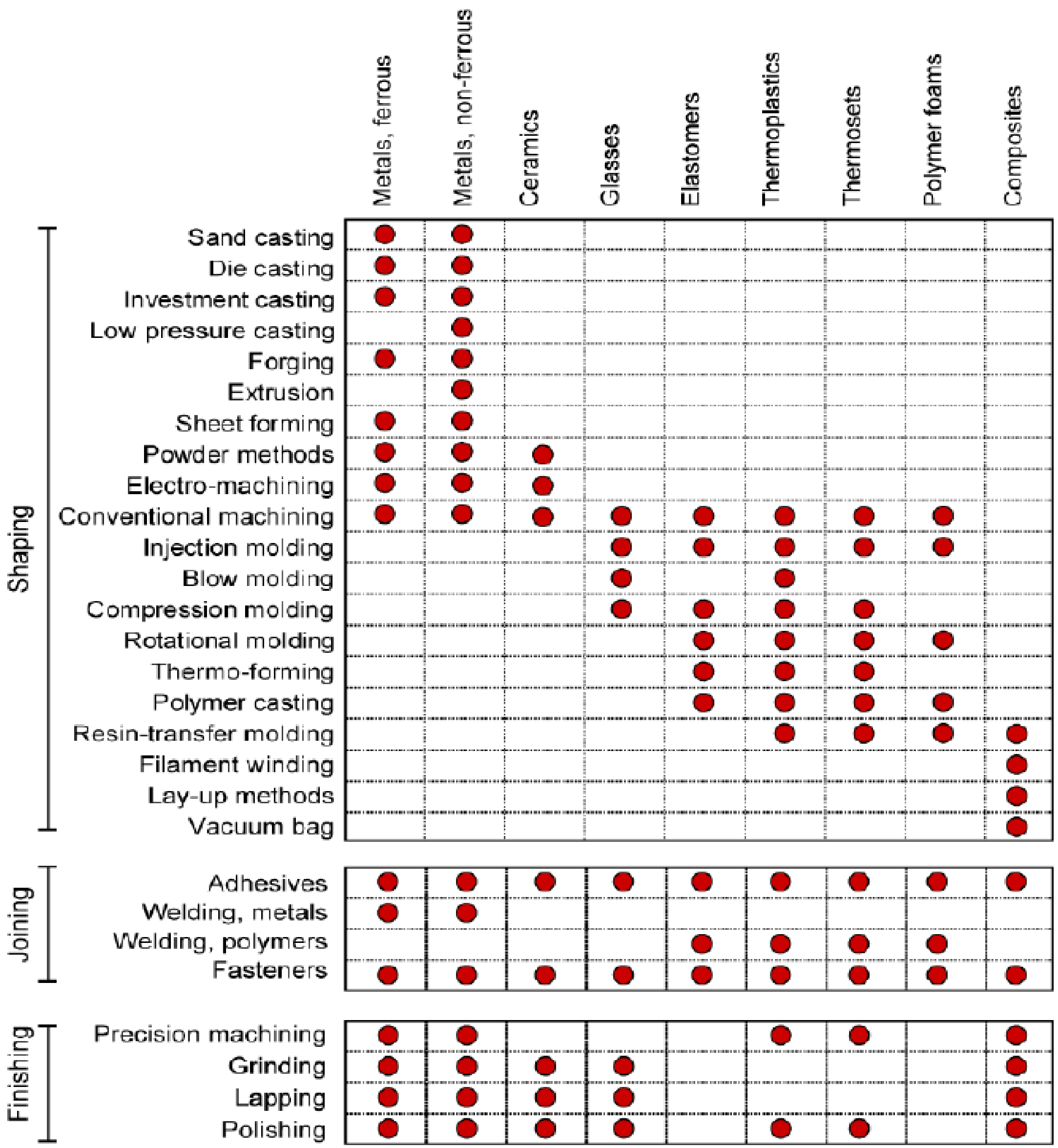
Mechanical fastening

Computer housing screw

Coulee dam generator
nut and screw

Photo's: www.wikipedia.org

Manufacturing processes & material combinations



		Metals, ferrous	Metals, non-ferrous	Ceramics	Glasses	Elastomers	Thermoplastics	Thermosets	Polymer foams	Composites
Shaping	Sand casting	●	●							
	Die casting	●	●							
	Investment casting	●	●							
	Low pressure casting		●							
	Forging	●	●							
	Extrusion		●							
	Sheet forming	●	●							
	Powder methods	●	●	●						
	Electro-machining	●	●	●						
	Conventional machining	●	●	●	●	●	●	●	●	
	Injection molding				●	●	●	●	●	
	Blow molding				●		●			
	Compression molding				●	●	●	●		
	Rotational molding					●	●	●	●	
	Thermo-forming					●	●	●		
	Polymer casting					●	●	●	●	
	Resin-transfer molding						●	●	●	●
	Filament winding									●
	Lay-up methods									●
	Vacuum bag									●
Joining	Adhesives	●	●	●	●	●	●	●	●	●
	Welding, metals	●	●							
	Welding, polymers					●	●	●	●	
	Fasteners	●	●	●	●	●	●	●	●	●
Finishing	Precision machining	●	●				●	●		●
	Grinding	●	●	●	●					●
	Lapping	●	●	●	●					●
	Polishing	●	●	●	●		●	●		●

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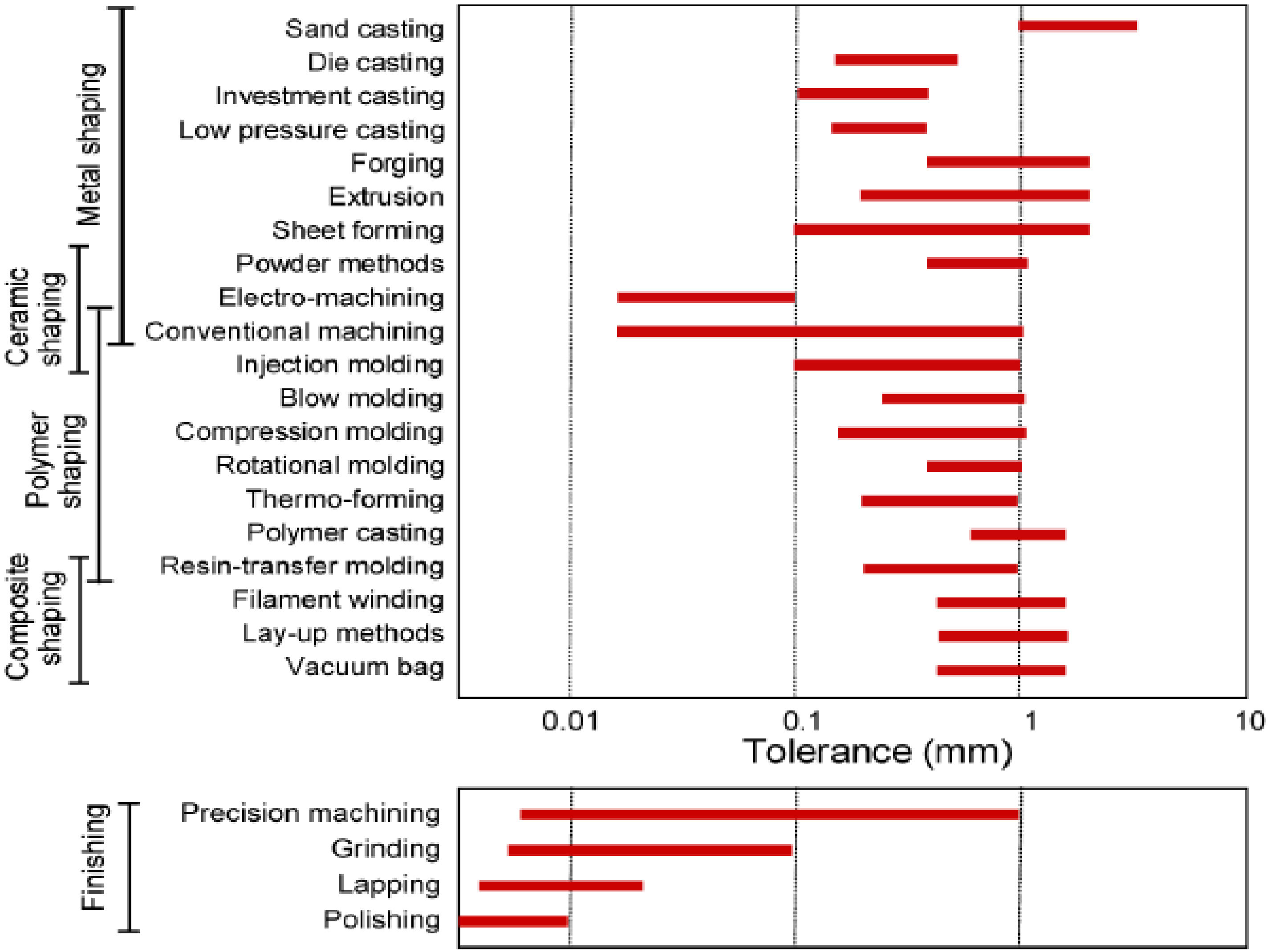
Metal shaping
Ceramic shaping
Polymer shaping
Composite shaping
Sand casting
Die casting
Investment casting
Low pressure casting
Forging
Extrusion
Sheet forming
Powder methods
Electro-machining
Conventional machining
Injection molding
Blow molding
Compression molding
Rotational molding
Thermo-forming
Polymer casting
Resin-transfer molding
Filament winding
Lay-up methods
Vacuum bag
0.01
0.1
1
10
Tolerance (mm)
Finishing
Precision machining
Grinding
Lapping
Polishing

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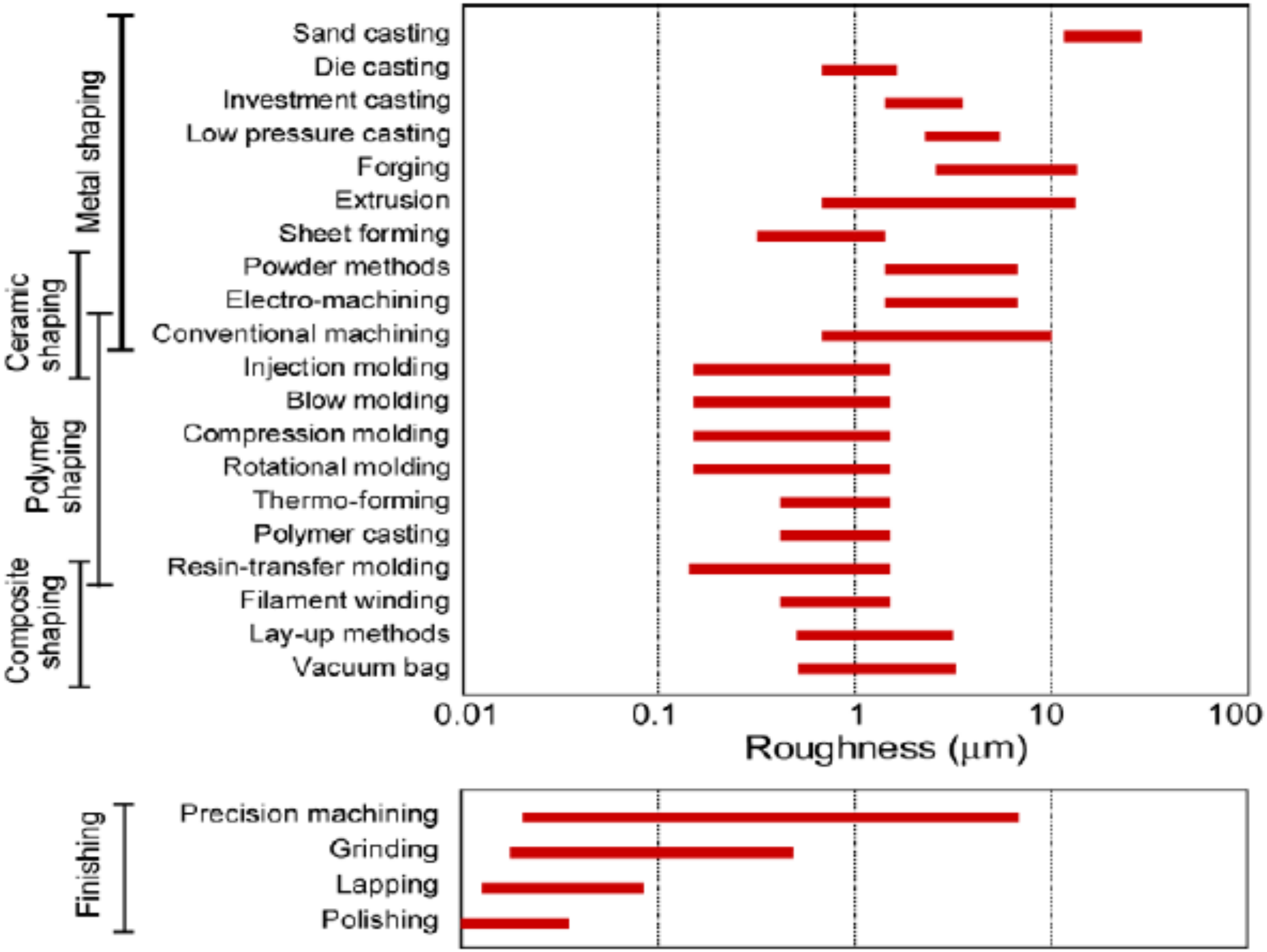
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Rotational molding
Thermo-forming
Polymer casting
Resin-transfer molding
Filament winding
Lay-up methods
Vacuum bag
0.01
0.1
1
10
100
Roughness (µm)
Finishing
Precision machining
Grinding
Lapping
Polishing

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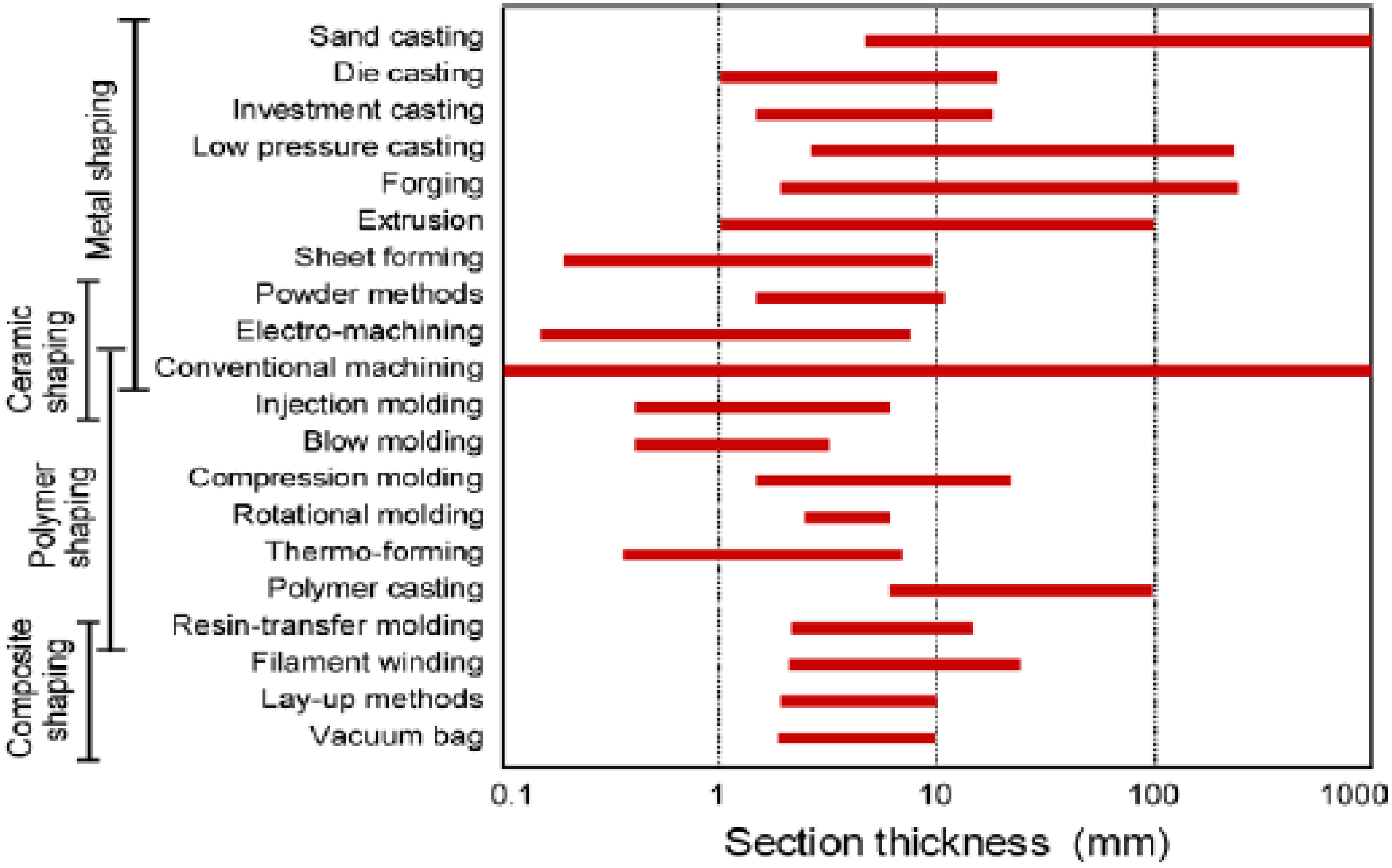
Levels of finish & applications

Finish (µm)	Process	Typical application
Ra=0.01	Lapping	Mirrors
Ra=0.1	Precision grinding or lap	High quality bearings
Ra=0.2-0.5	Precision grinding	Cylinders, piston, cams, bearings
Ra=0.5-2	Precision machining	Gears, ordinary machine parts
Ra=2-10	Machining	Light-loaded bearings
Ra=3-100	Unfinished castings	Non-bearing surfaces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Thermo-forming
Polymer casting
Resin-transfer molding
Filament winding
Lay-up methods
Vacuum bag
0.1
1
10
100
1000
Section thickness (mm)

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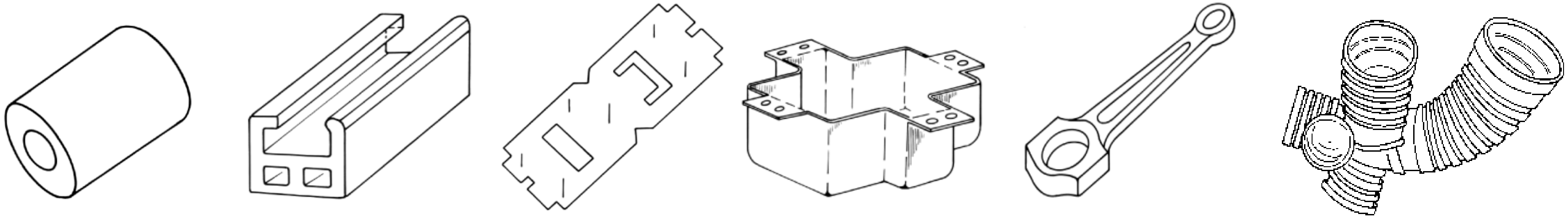
Shape categories:

- All shapes
  - Prismatic
    - Circular
    - Non-circular
  - Sheet
    - Flat
    - Dished
  - 3D
    - Solid
    - Hollow



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Feasible process / shape combinations

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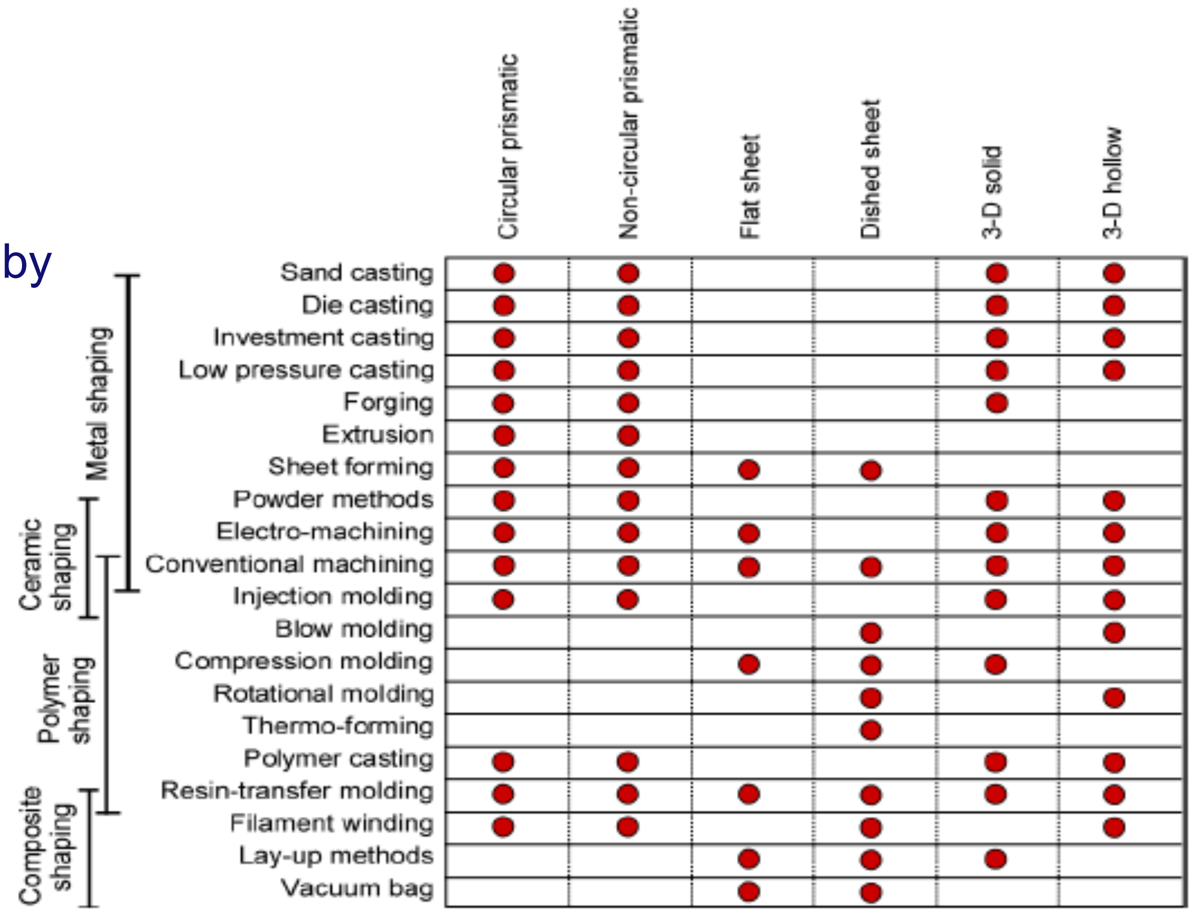
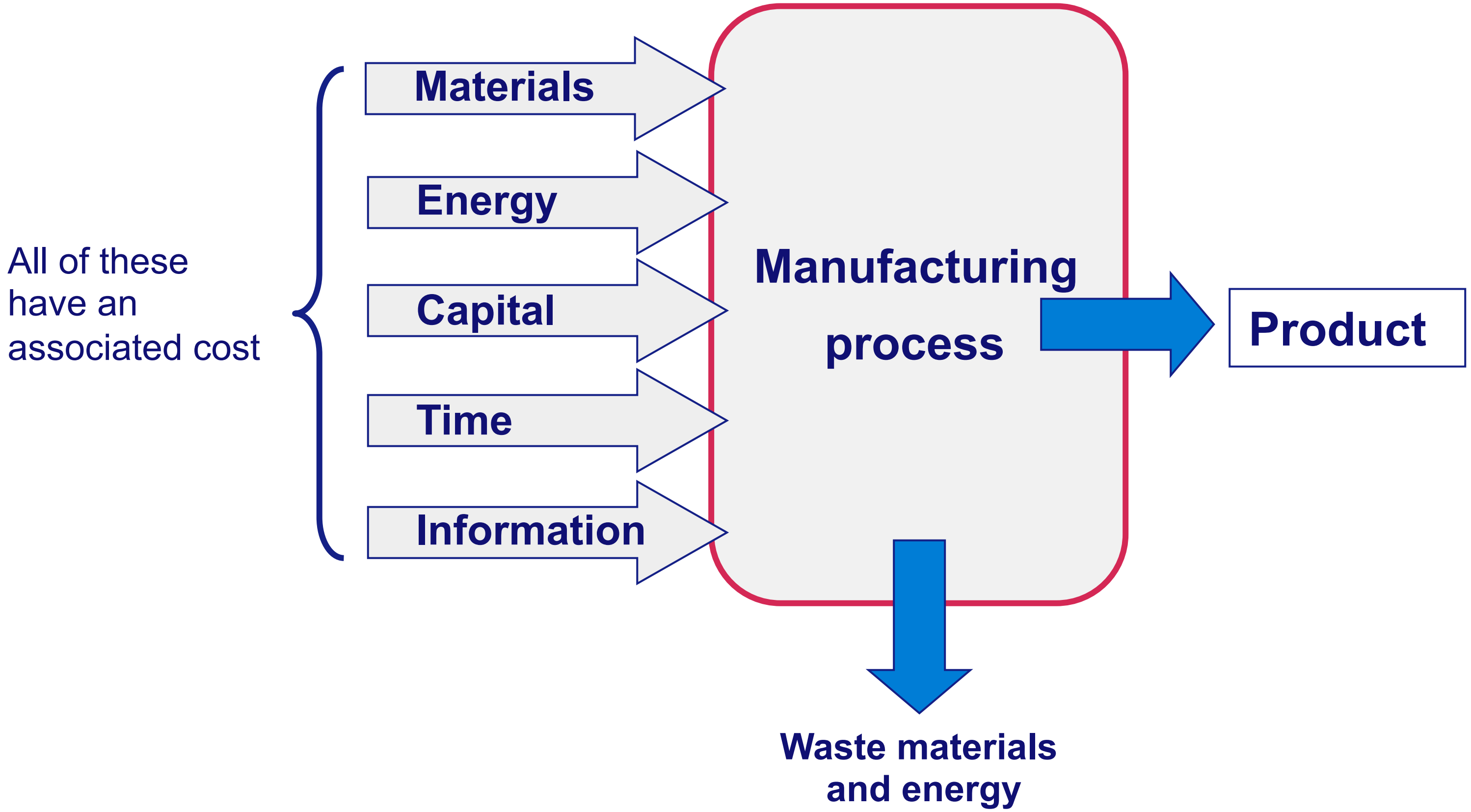


	Circular prismatic	Non-circular prismatic	Flat sheet	Dished sheet	3-D solid	3-D hollow
Sand casting	●	●			●	●
Die casting	●	●			●	●
Investment casting	●	●			●	●
Low pressure casting	●	●			●	●
Forging	●	●			●	
Extrusion	●	●				
Sheet forming	●	●	●	●		
Powder methods	●	●			●	●
Electro-machining	●	●	●		●	●
Conventional machining	●	●	●	●	●	●
Injection molding	●	●			●	●
Blow molding				●		●
Compression molding			●	●	●	
Rotational molding				●		●
Thermo-forming				●		
Polymer casting	●	●			●	●
Resin-transfer molding	●	●	●	●	●	●
Filament winding	●	●		●		●
Lay-up methods			●	●	●	
Vacuum bag			●	●		

Cost of product manufacturing



All of these
have an
associated cost

Materials

Energy

Capital

Time

Information

Manufacturing process

Product

Waste materials and energy

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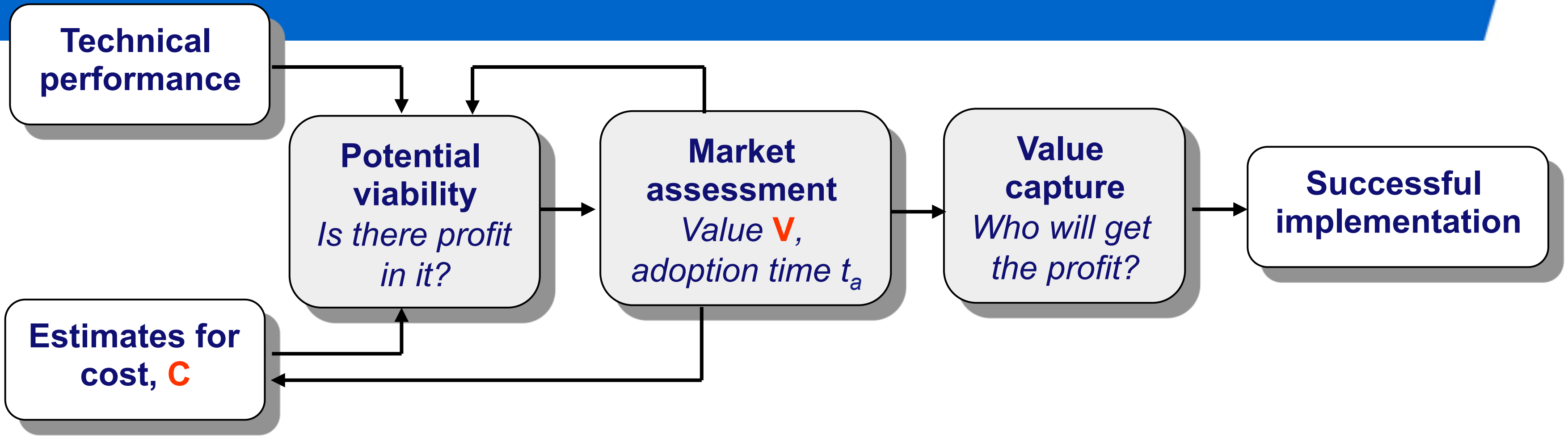

- But remember the **real requirement** is

Cost < Price < Value

C < P < V

Cost C = what it actually costs to make the part or product

Price P = the sum you sell it for

Value V = the worth the consumer puts on the product

"Not worth the price" **= P > V**

"Good value for money" **= P < V**

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Inputs to a generic cost estimator

Generic = can be applied to any process

Resource		Symbol	Unit
Materials including consumables		C_m	€/kg
Capital	cost of equipment cost of tooling	C_c C_t	€ €
Time (including labor) overhead rate		$\dot{C}_{oh}$	€/hr
Energy cost of energy		C_e	€/hr
Space, **admin.** a cost/hr		$\dot{C}_{s,a}$	€/hr
Information	R & D royalties, licenses	$\dot{C}_i$	€/hr

Lump into overhead rate $\dot{C}_{oh}$

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The cost per unit of output

Material costs C_m per kg, and a mass m is used per unit;
f is the scrap fraction (the fraction thrown away) $\Rightarrow \dfrac{m C_m}{1-f}$

Tooling C_t is "dedicated" -- it is written off against the number of parts to be made, n $\Rightarrow \dfrac{C_t}{n}$

Capital cost C_c of equipment is "non-dedicated"
It is written off against time, giving an hourly rate.
The write-off time is t_{wo} . The rate of production is $\dot{n}$ units/hour.
The load factor (fraction of time the equipment is used) is **L**. $\Rightarrow \dfrac{1}{\dot{n}}\left(\dfrac{C_c}{L.t_{wo}}\right)$

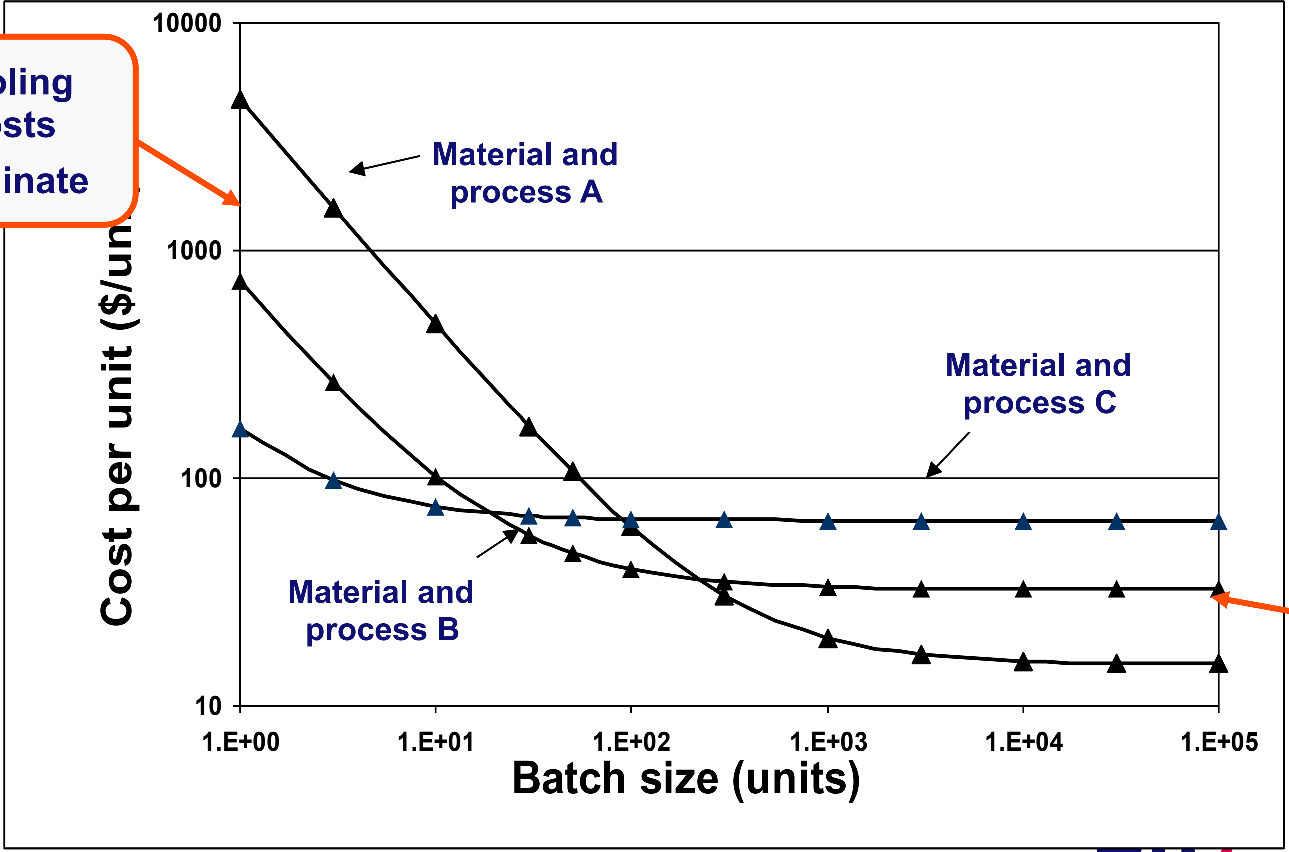
The gross **overhead rate** $\dot{C}_{oh}$ contributes a cost per unit of time that, like capital, depends on production rate $\dot{n}$ $\Rightarrow \dfrac{\dot{C}_{oh}}{\dot{n}}$

$$C = \overset{\substack{\text{Materials}\\ \downarrow}}{\left[\frac{m\,C_m}{1-f}\right]} + \overset{\substack{\text{Tooling}\\ \downarrow}}{\left[\frac{\sum(C_t)}{\underset{\substack{\uparrow\\ \text{Batch size}}}{n}}\right]} + \frac{1}{\underset{\substack{\uparrow\\ \text{Rate of production}}}{\dot{n}}}\left[\overset{\substack{\text{Capital, Labor, Information, Energy...}\\ \downarrow}}{\sum\left(\frac{C_c}{L.t_{wo}}\right)} + \dot{C}_{oh}\right]$$

Features of the cost model

Paraphrase as $$C = C_m^* + \frac{C_t^*}{n} + \frac{\dot{C}_{oh}^*}{\dot{n}}$$ (* = “total”)

Tooling costs dominate



Material and labor costs dominate

Meaning of “***economic batch size***”

Cost estimation examples (from CES EduPack)

- Machining product (10 parts)
  - Relative Tooling cost: low : < 1.000 €
  - Relative Equipment cost: medium: 10.000-100.000 €
  - Labor intensity: low : 30-300 hours/unit

- Injection molding product (50.000 parts)
  - Relative Tooling cost: very high 100.000 €
  - Relative Equipment cost: high: 100.000-1.000.000 €
  - Labor intensity: low : < 0.1 hours/unit

Example machining product

- Material cost per unit product:
  - Aluminum part: 1Kg, 1.2€/Kg
  - Scrap factor f = 0.6

$$C_1 = \frac{m \cdot C_m}{1-f} = \frac{1 \cdot 1.2}{1-0.6} = 3€$$

- Tooling cost per unit product:
  - Ct = tooling cost = 500 €
  - N= 1000 product per run
  - Nt = 10.000 products tool life

$$C_2 = \frac{C_t}{n}(1+\frac{n}{n_t}) = \frac{500}{1000}(1+\frac{1000}{10.000}) = 0.55€$$

Example machining product

- **Capital cost per unit product:**
  - **t_wo capital write off time: 5 years = 5*1600h**
  - **L = load factor = 0.5**
  - **$\dot{n}$ production rate/hour = 10**
  - **Cc= 50.000 €**

$$C_3 = \frac{1}{\dot{n}}\left(\frac{C_c}{L \cdot t_{wo}}\right) = \frac{1}{10}\left(\frac{50.000}{0.5 \cdot 5 \cdot 1600}\right) = 1.25€$$

- **Hourly overhead cost per unit product:**
  - $\dot{C}_{oh} = \dot{C}_{labor} + \dot{C}_{energy} + \ldots$ **: 80 €/hour**

$$C_4 = \frac{\dot{C}_{oh}}{\dot{n}} = \frac{80}{10} = 8€$$

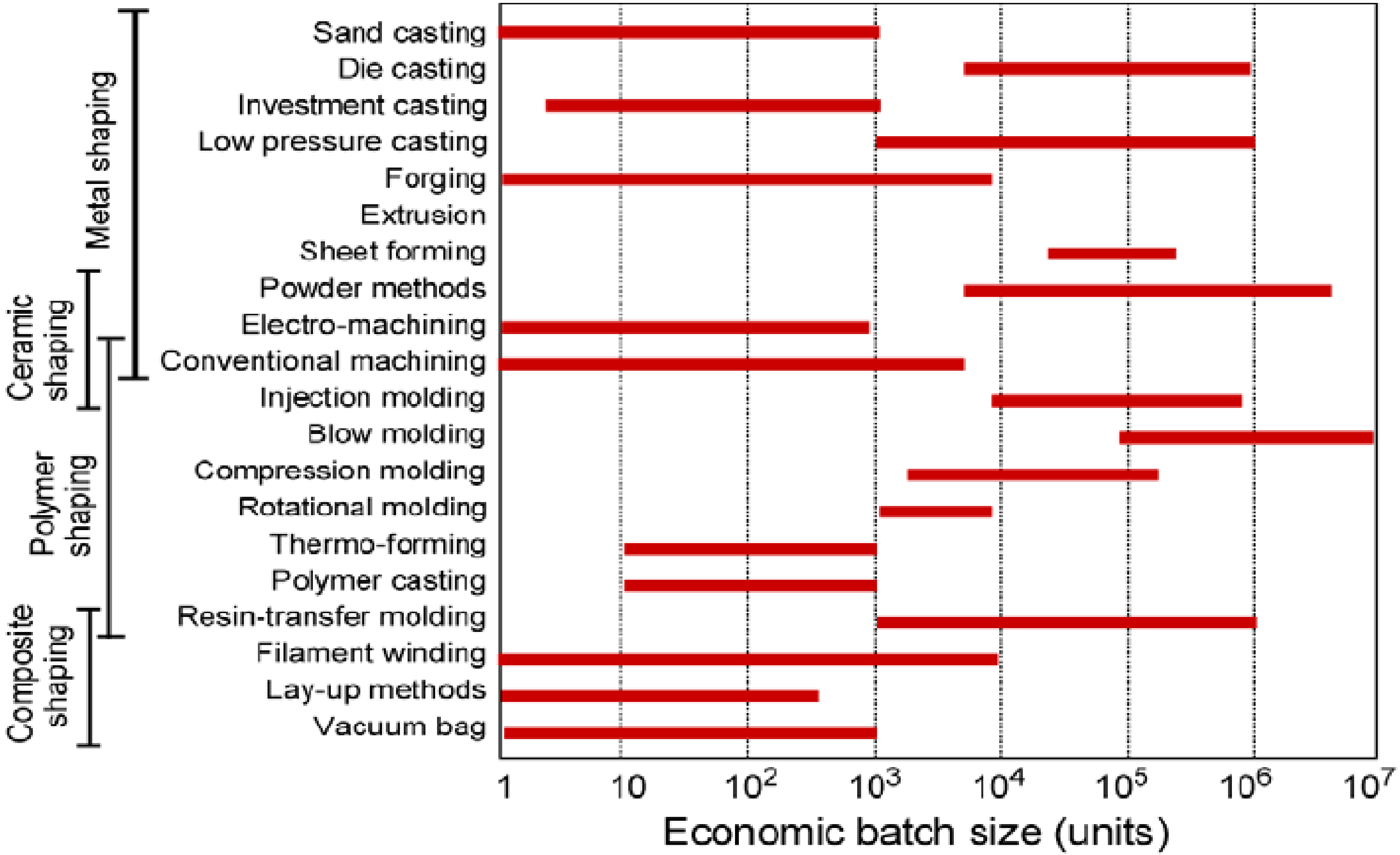
$$C_s = C_1 + C_2 + C_3 + C_4$$
$$= 3 + 0.55 + 1.25 + 8 = 12.80€$$

Product cost model revisited

$$C_s = \frac{m\cdot C_m}{1-f} + \frac{C_t}{n}\left(1+\frac{n}{n_t}\right) + \frac{1}{\dot{n}}\left(\frac{C_c}{L\cdot T_{wo}} + \dot{C}_{oh}\right)$$

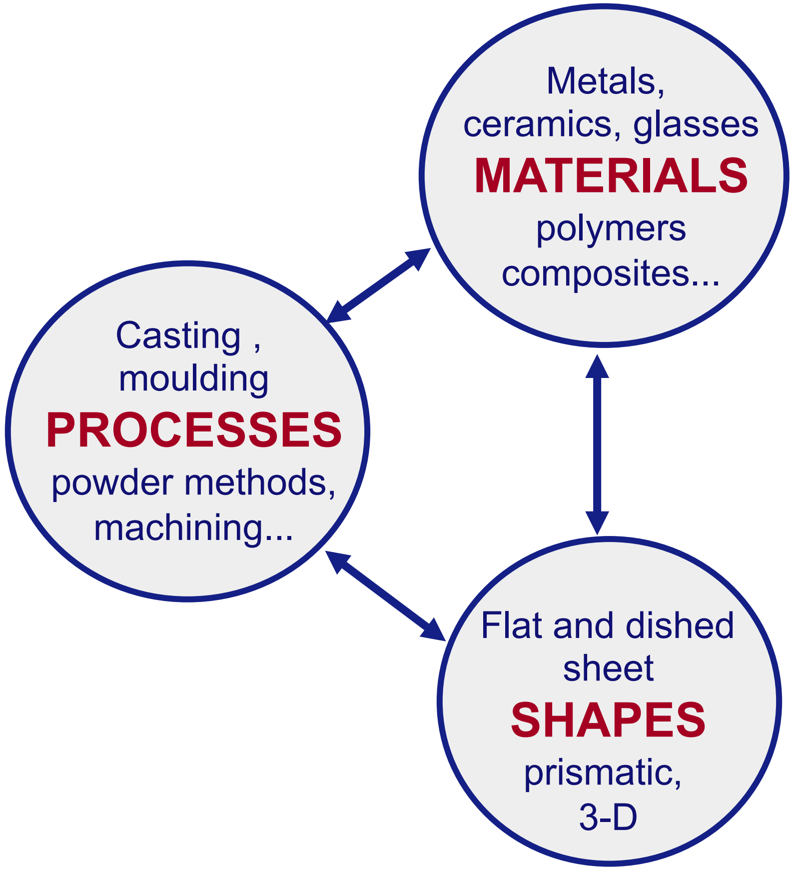
$$= C_{material} + \frac{C_{dedicated}}{n} + \frac{\dot{C}_{capital} + \dot{C}_{overhead}}{\dot{n}}$$

Economic batch size



M.F. Ashby

All products are combinations of: materials & processes & shapes

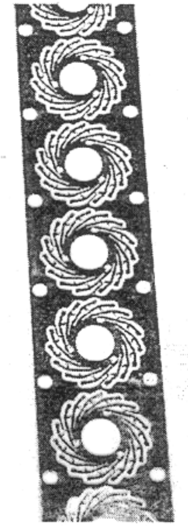


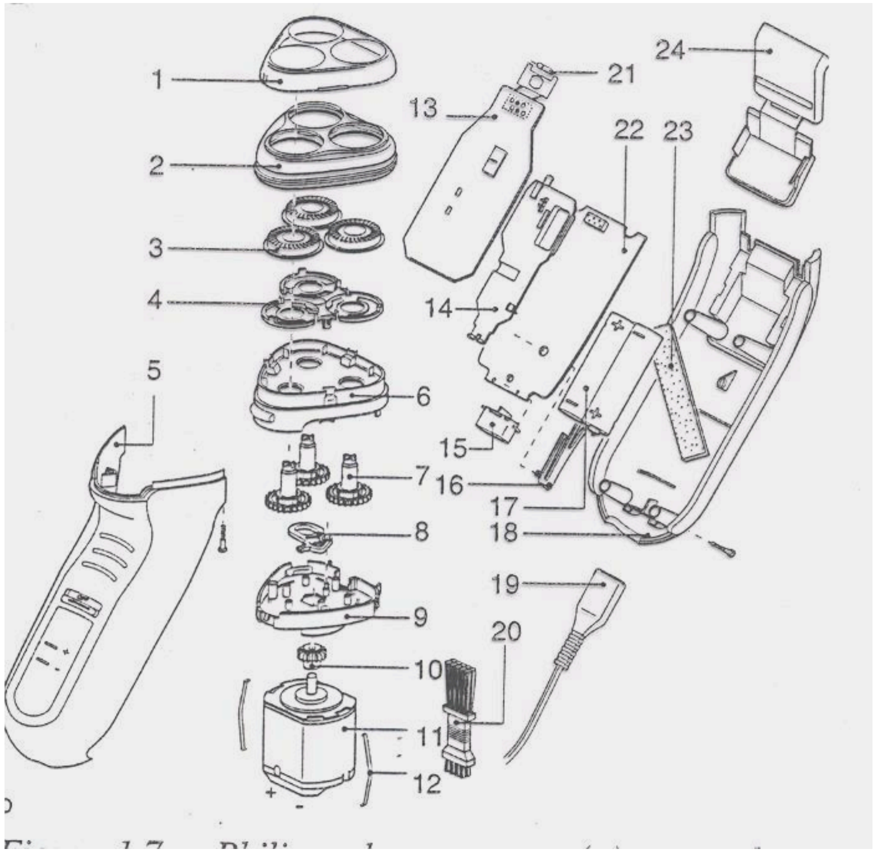
Metals,
ceramics, glasses
MATERIALS
polymers
composites...

Casting ,
moulding
PROCESSES
powder methods,
machining...

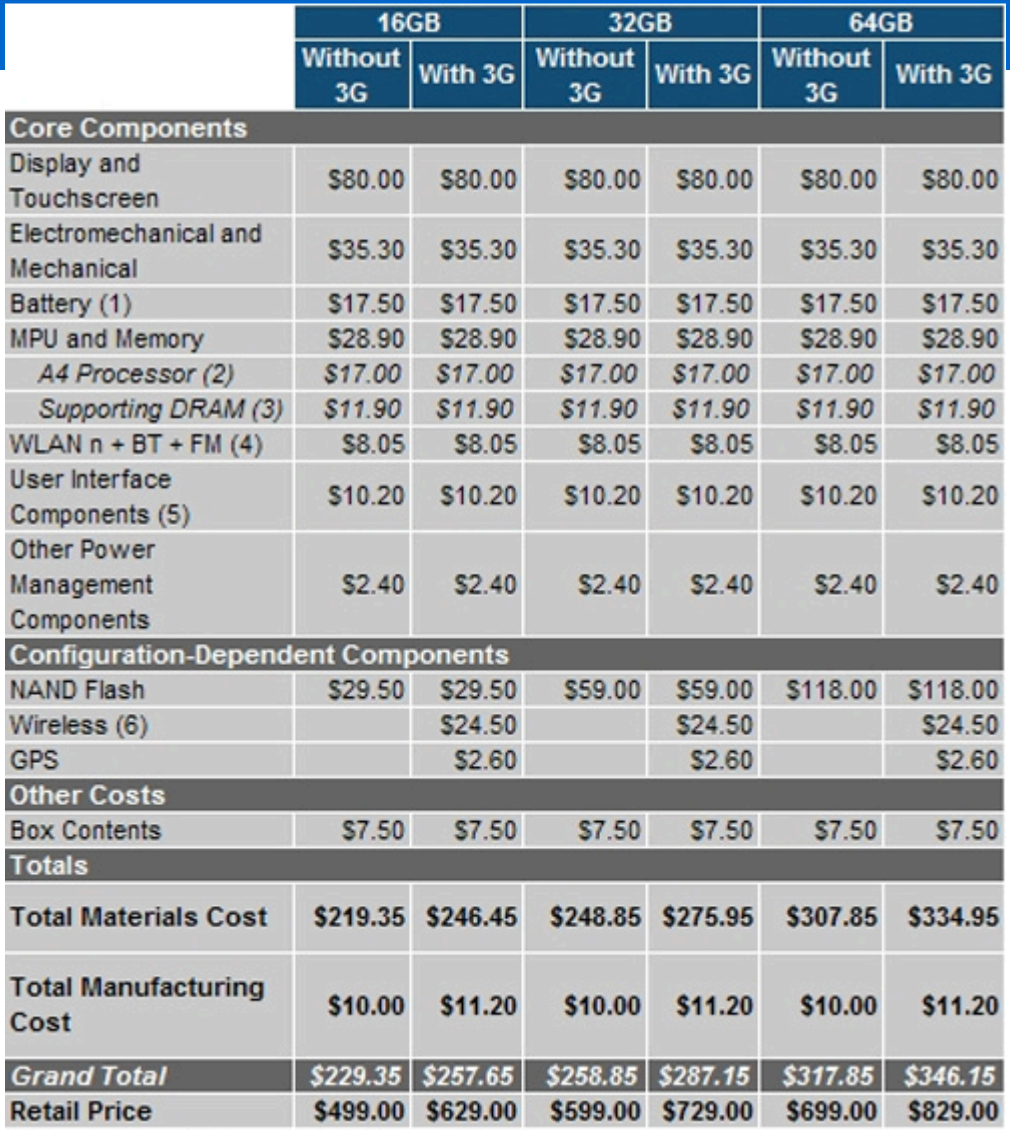
Flat and dished
sheet
SHAPES
prismatic,
3-D

Product: Shaver





Apple iPad cost breakdown



	16GB		32GB		64GB	
	Without 3G	With 3G	Without 3G	With 3G	Without 3G	With 3G
Core Components						
Display and Touchscreen	$80.00	$80.00	$80.00	$80.00	$80.00	$80.00
Electromechanical and Mechanical	$35.30	$35.30	$35.30	$35.30	$35.30	$35.30
Battery (1)	$17.50	$17.50	$17.50	$17.50	$17.50	$17.50
MPU and Memory	$28.90	$28.90	$28.90	$28.90	$28.90	$28.90
A4 Processor (2)	*$17.00*	*$17.00*	*$17.00*	*$17.00*	*$17.00*	*$17.00*
Supporting DRAM (3)	*$11.90*	*$11.90*	*$11.90*	*$11.90*	*$11.90*	*$11.90*
WLAN n + BT + FM (4)	$8.05	$8.05	$8.05	$8.05	$8.05	$8.05
User Interface Components (5)	$10.20	$10.20	$10.20	$10.20	$10.20	$10.20
Other Power Management Components	$2.40	$2.40	$2.40	$2.40	$2.40	$2.40
Configuration-Dependent Components						
NAND Flash	$29.50	$29.50	$59.00	$59.00	$118.00	$118.00
Wireless (6)		$24.50		$24.50		$24.50
GPS		$2.60		$2.60		$2.60
Other Costs						
Box Contents	$7.50	$7.50	$7.50	$7.50	$7.50	$7.50
Totals						
Total Materials Cost	**$219.35**	**$246.45**	**$248.85**	**$275.95**	**$307.85**	**$334.95**
Total Manufacturing Cost	**$10.00**	**$11.20**	**$10.00**	**$11.20**	**$10.00**	**$11.20**
Grand Total	***$229.35***	***$257.65***	***$258.85***	***$287.15***	***$317.85***	***$346.15***
Retail Price	**$499.00**	**$629.00**	**$599.00**	**$729.00**	**$699.00**	**$829.00**

Source - iSuppli Corporation February 2010

Apple iPhone 4 16Gb carries a BOM of $188

Preliminary Bill of Materials (BOM) Estimate for the 16Gbyte Version of the iPhone 4
(Costs in U.S. Dollars)*

Subsection	Part Description	Part Supplier/Part Details	Component Cost
Applications Processor	Applications Processor	Samsung A4 APL0398 45nm, PoP	$10.75
	DRAM Memory	SDRAM, 4Gb Mobile DDR, PoP Samsung K4XKG643GB (Samsung dies, 2 x 2Gb)	$13.80
	Misc. Applications Processor Components	Discretes, Passives, etc.	$0.50
Memory	Flash	Samsung NAND Flash 16GB MLC K9HDG08U5M-LCB0	$27.00
	Misc. Memory Components	Discretes, Passives, etc.	$0.30
Radio Frequency	Baseband	Infineon 337S3833 HSDPA/HSUPA/WCDMA/EDGE	$11.72
	Transceiver	Infineon 338S0626 Quad-Band GSM/Edge	$2.33
	Memory	Intel (Numonyx?) MCP 128Mb NOR Flash + 128Mb Mobile DDR (DDR is Elpida)	$2.70
	Power Mgmt.	n/a	
	PAM	Skyworks SKY77541-32 Transmit Module Quad-Band GSM/EDGE PAM + Antenna Switch	<included in Misc. Costs below>
	PAM	Skyworks SKY77459-17 Transmit Module Single-Band WCDMA/HSPA PAM + Duplexer	<included in Misc. Costs below>
	PAM	Skyworks SKY77452-20 Transmit Module Single-Band WCDMA/HSPA PAM + Duplexer	<included in Misc. Costs below>
	PAM	TriQuint TQM676091 Transmit Module Single-Band WCDMA/HSPA PAM + Duplexer	<included in Misc. Costs below>
	PAM	TriQuint TQM666092 Transmit Module Single-Band WCDMA/HSPA PAM + BAW Duplexer	<included in Misc. Costs below>
	FEM	n/a	
	SAW Module	Murata	<included in Misc. Costs below>
	Misc. RF Components	PAMs, Modules, Discretes, Passives, etc.	$8.25
Power Management	Main PM Device	Dialog D1815A 338S0867-A4 Main Pwr Mgmt	$2.03
	Misc. Power Mgmt.	Discretes, Passives, etc.	$1.90
Connectivity	WiFi/BT	Broadcom BCM4329 Module WLAN 02.11a/b/g/n, Bluetooth V2.1+EDR, FM/RDS/RBDS Rcvr	$7.80
	GPS	Broadcom BCM4750	$1.75
	Misc. Connectivity Components	Discretes, Passives, etc.	$0.80
Interface &Sensors	Touchscreen Controller	Texas Instruments 343S0499 (F761586C)	$1.23
	Audio CODEC	Cirrus Logic 343S0589 (CLI1495BO)	$1.15
	E-Compass	AKM AK8975 3-Axis	$0.70
	Accelerometer	ST Micro LIS331DLH 3-Axis	$0.65
	Gyroscope	ST Micro L3G4200D Digital 3-Axis	$2.60
	Misc. Interface & Sensor Components	Discretes, Passives, etc.	$3.80
Display/Camera	Display	3.5" Diag, LTPS LCD, 960x640 Pixels LG (or poss. TMD)	$28.50
	Touch Screen	Capacitive Glass, "Reinforced" Wintek or TPK/Balda	$10.00
	Camera	5MP Auto-Focus	$9.75
	Camera (secondary)	VGA Auto-Focus	$1.00
Battery	Battery	1400mAh	$5.80
Other	Mechanicals	Enclosure, Metals, Plastics, Hardware, etc.	$10.80
	Electro-Mechanicals	PCBs, Acoustics, Connectors, etc.	$14.40
	Misc.	Accessories, Literature, Box Contents	$5.50
TOTAL			**$187.51**

**Teardown costs account only for components and do not include other expenses such as manufacturing, software, royalties and licensing fees*

Source:
http://www.isuppli.com/

Technische Universiteit
Eindhoven
University of Technology

Topics to be studied:
per group 1 topic.

1. **Casting, Molding and related processes**
2. **Particulate processing for Metals and Ceramics + Surface Processing Operations + Electronics Manufacturing Technologies (Only: Processing of IC's)**
3. **Metal Forming and Sheet Metalworking**
4. **Material Removal Processes**
5. **Joining and Assembly Processes**

Apple iPhone 3G S,
Major components and cost drivers: $ 178.56

Apple iPhone 3G S Major Components and Cost Drivers
(US Dollars)

Manufacturer	Multi-Source Probability	Component Description	Cost
Toshiba	High	Flash Memory NAND, 16GB, MLC	$24.00
	High	Display Module 3.5" Diagonal, 16M Color TFT, 320 x 480 Pixels	$19.25
	Medium	Touch Screen Assembly Capacitive, Glass	$16.00
Samsung	Low	Application Processor ARM Core, Package-on-Package	$14.46
Infineon	Low	Baseband HSDPA/WCDMA/EDGE, Dual ARM926 and ARM7Core	$13.00
	Medium	Camera Module 3 Megapixel Auto-Focus	$9.55
Samsung (with Elpida die)	High	SDRAM - Mobile DDR 2Gb Package-on-Package (Mounted on Application Processor,	$8.50
Broadcom	Low	Bluetooth/FM/WLAN Single Chip, WLAN IEEE802.11b/g, Bluetooth V2.1+EDR, with FM and RDS/RBDS Receiver	$5.95
Numonyx	High	Memory MCP 128Mb NOR Flash and 512Mb Mobile DDR	$3.65
Infineon	Low	RF Transceiver Quad-Band GSM/EDGE, Tri-Band WCDMA/HSDPA, 130nm RF CMOS	$2.80
Infineon	Low	GPS Receiver Single Chip, 0.13um, with Integrated Front-End RF, PLL, PM, Correlator Engine and Host Control Interface	$2.25
Infineon	Low	Power IC RF Function	$1.25
Murata	Low	FEM Quad-Band GSM, Tri-Band UMTS Antenna Switch and Quad-Band GSM RX RF SAW Filters	$1.35
Dialog	Low	Power IC Application Processor Function	$1.30
Cirrus Logic	Low	Audio Codec Ultra Low Power, Stereo, with Headphone	$1.15
		Rest of Bill-of-Materials*	$48.00
		Total Bill-of-Materials	$172.46
		Manufacturing Costs*	$6.50
		Grand Total	$178.96

*Estimated Pending Complete Analysis

iSuppli Apple iPhone 3G S 16GB Teardown Analysis
Exploded View
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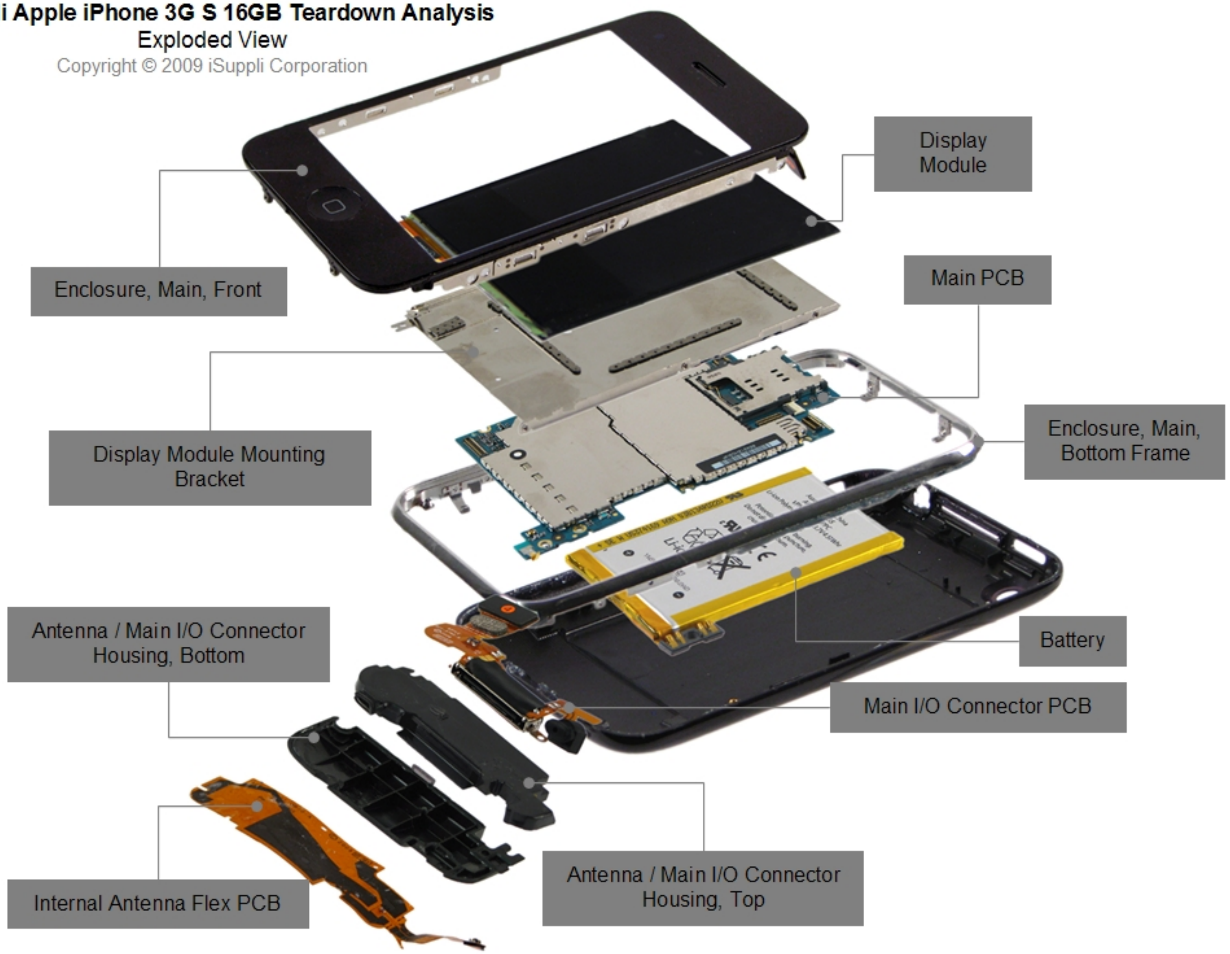

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