

Overview of CES EduPack 2009

Materials and Process Information

The screenshot shows the CES EduPack interface with a tree view on the left and a detailed view of 'Age-hardening wrought Al-alloys' on the right. The detailed view includes a table of properties:

General properties	Value	Unit
Density	2.563	2.943 g/cm ³
Price	2.54	3.28 USD/kg
Young's modulus	69	80 GPa
Shear modulus	25	28 GPa
Bulk modulus	64	75 GPa
Poisson's ratio	0.32	0.35
Yield strength (elastic limit)	95	110 MPa
Tensile strength	100	120 MPa
Compressive strength	95	110 MPa
Elongation	1	2%
Hardenability - Vickers	80	180 HV
Fatigue strength at 10 ⁷ cycles	57	210 MPa
Fracture toughness	21	35 MPa m ^{1/2}
Mechanical loss coefficient (tan delta)	1e-4	0.001
Thermal properties	Value	Unit
Modulus of elasticity	69	80 GPa

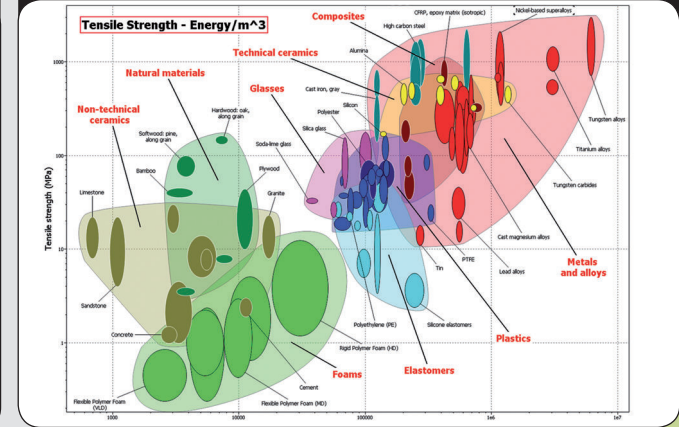
Three levels of database, from an introductory teaching resource to a comprehensive project tool covering 3,000 materials.

Science Notes

The screenshot shows the Science Notes section with two pages of text and a diagram of a tensile stress-strain curve. The diagram shows the yield strength σ_y , the elastic limit σ_e , and the ultimate tensile strength σ_u . The strain is labeled as $\epsilon = \Delta L / L_0$.

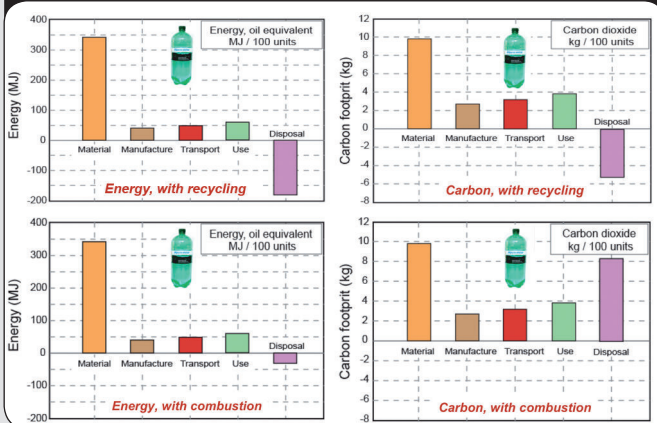
Textbook-style explanations with further reading references to books by Ashby, Askeland, Callister, Shackelford and more...

Interactive Materials Property Charts



Unique tools to compare and analyze properties and to select materials and processes.

Eco Audit Tool



Introduce key concepts in eco design and sustainability. Explore 'what if' design scenarios.

Specialist Databases



Editions for design, eco design, polymers, aerospace, bio engineering, architecture and the built environment.

Advanced Software



Use CES Constructor to build your own databases. Apply CES Selector and GRANTA MI for advanced teaching, research, and industry.

The screenshot shows the 'Search' tab of the GRANTA EduPack software. At the top, there are buttons for 'Browse', 'Search', 'Select', 'Print', and 'Search web'. Below these, a 'Choose data-table: materials, processes ...' section contains a 'New' button. Three stages are highlighted with red arrows:

- Graph stage:** Points to a bar chart with a vertical axis labeled 'Property'.
- Limit stage:** Points to a table of material properties with input fields for 'Min' and 'Max' values.
- Tree stage:** Points to a process tree diagram.

	Min	Max
Density	<input type="text"/>	<input type="text" value="2"/>
Modulus	<input type="text" value="200"/>	<input type="text"/>
Strength	<input type="text" value="100"/>	<input type="text"/>
T-conduction	<input type="text"/>	<input type="text" value="10"/>

```

graph LR
    Process((Process)) --- Shape[Shape]
    Shape --- Join[Join]
    Shape --- Surface[Surface]
    Shape --- Cast[Cast]
    Shape --- Deform[Deform]
    Shape --- Mold[Mold]
    Shape --- Composite[Composite]
    Shape --- Powder[Powder]
    Shape --- Prototype[Prototype]
  
```

GRANTA | CES 2009 EDUPACK

1 Getting Started with CES EduPack



Getting started with CES EduPack

These exercises give an easy way to learn to use the CES EduPack software.
The comprehensive CES Help file within the software gives more detailed guidance.

Thumbnail sketch of CES EduPack

The CES EduPack software has three Levels of Database.

	Coverage	Content
Level 1	Around 70 of the most widely used materials drawn from the classes: metals, polymers, ceramics, composites, foams, and natural materials. Around 70 of the most widely used processes.	A description, an image of the material in a familiar product, typical applications, and limited data for mechanical, thermal, and electrical properties, using rankings where appropriate.
Level 2	Around 100 of the most widely used materials. Around 110 of the most commonly used processes.	All the content of Level 1, supplemented by more extensive numerical data, design guidelines, ecological properties, and technical notes.
Level 3	The core database contains more than 3,000 materials, including those in Levels 1 and 2. Specialist editions covering aerospace, polymers, architecture, bio-materials, and eco-design are also available.	Extensive numerical data for all materials, allowing the full power of the CES selection system to be deployed.

When the software opens you are asked to choose a Level. Chose Level 1 to start with.

At each Level there are a number of Data Tables.

The most important are: Materials, Shaping Processes, Joining Processes, and Surface Treatment.

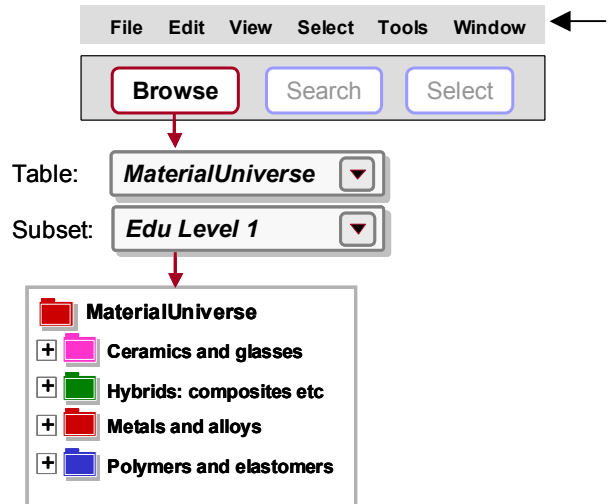
Each of the three levels can be interrogated by

- **BROWSING** Exploring the database and retrieving records via a hierarchical index.
- **SEARCHING** Finding information via a full-text search of records.
- **SELECTION** Use of powerful selection engine to find records that meet an array of design criteria.

CES EduPack does far more than this. But this is enough to get started.

BROWSING and SEARCHING

The DEFAULT on loading CES EduPack Levels 1 & 2 is LEVEL 1, MATERIALS UNIVERSE



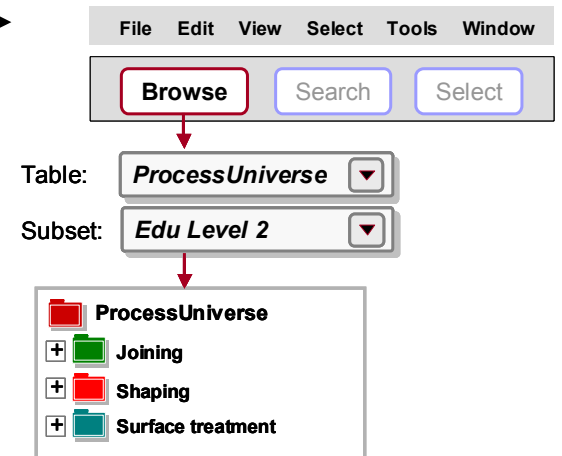
Exercise 1 BROWSE materials

- Find record for STAINLESS STEEL
- Find record for CONCRETE
- Find record for POLYPROPYLENE
- Explore POLYPROPYLENE record at LEVEL 2
- Find PROCESSES that can shape POLYPROPYLENE using the LINK at the bottom of the record

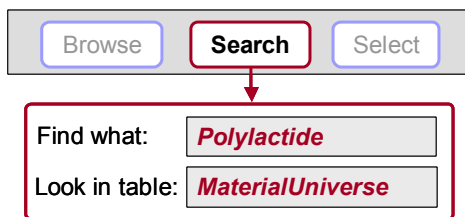
Exercise 2 BROWSE processes

Select LEVEL 2, ALL PROCESSES

- Find record for INJECTION MOLDING
- Find record for LASER SURFACE HARDENING
- Find record for FRICTION WELDING (METALS)
- Find MATERIALS that can be DIE CAST , using the LINK at the bottom of the record for DIE CASTING



Exercise 3 The SEARCH facility



- Find the material POLYLACTIDE
- Find materials for CUTTING TOOLS
- Find the process RTM

(Part of a material record and a process record are shown overleaf)

Part of a record for a material: polypropylene

Polypropylene (PP) (CH₂-CH(CH₃))_n

Polypropylene, PP, first produced commercially in 1958, is the younger brother of polyethylene - a very similar molecule with similar price, processing methods and application. Like PE it is produced in very large quantities (more than 30 million tons per year in 2000), growing at nearly 10% per year, and like PE its molecule-lengths and side-branches can be tailored by clever catalysis, giving precise control of impact strength, and of the properties that influence molding and drawing. In its pure form polypropylene is flammable and degrades in sunlight. Fire retardants make it slow to burn and stabilizers give it extreme stability, both to UV radiation and to fresh and salt water and most aqueous solutions.



General properties

Density	0.89	-	0.91	Mg/m ³
Price	1.102	-	1.61	USD/kg

Mechanical properties

Young's Modulus	0.896	-	1.55	GPa
Shear Modulus	0.31	-	0.54	GPa
Bulk modulus	2.5	-	2.6	GPa
Poisson's Ratio	0.40	-	0.42	
Hardness - Vickers	6.2	-	11.2	HV
Elastic Limit	20.7	-	37.2	MPa
Tensile Strength	27.6	-	41.4	MPa
Compressive Strength	25.1	-	55.2	MPa
Elongation	100	-	600	%
Endurance Limit	11.0	-	16.5	MPa
Fracture Toughness	3	-	4.5	MPa.m ^{1/2}
Loss Coefficient	0.025	-	0.044	

Thermal properties

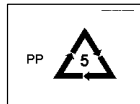
Thermal conductor or insulator?	Good insulator			
Thermal Conductivity	0.113	-	0.167	W/m.K
Thermal Expansion	122.4	-	180	µstrain/K
Specific Heat	1870	-	1956	J/kg.K
Melting Point	149.9	-	174.9	°C
Glass Temperature	-25.15	-	-15.15	°C
Maximum Service Temperature	82.85	-	106.9	°C
Minimum Service Temperature	-123.2	-	-73.15	°C

Electrical properties

Electrical conductor or insulator?	Good insulator			
Resistivity	3.3e22	-	3e23	µohm.cm
Dielectric Constant	2.2	-	2.3	
Power Factor	5e-4	-	7e-4	
Breakdown Potential	22.7	-	24.6	1000000*V/m

Design guidelines

Standard grade PP is inexpensive, light and ductile but it has low strength. It is more rigid than PE and can be used at higher temperatures. The properties of PP are similar to those of HDPE but it is stiffer and melts at a higher temperature (165 - 170 C). Stiffness and strength can be improved further by reinforcing with glass, chalk or talc. When drawn to fiber PP has exceptional strength and resilience; this, together with its resistance to water, makes it attractive for ropes and fabric. It is more easily molded than PE, has good transparency and can accept a wider, more vivid range of colors. PP is commonly produced as sheet, moldings fibers or it can be foamed. Advances in catalysis promise new co-polymers of PP with more attractive combinations of toughness, stability and ease of processing. Mono-filaments fibers have high abrasion resistance and are almost twice as strong as PE fibers. Multi-filament yarn or rope does not absorb water, will float on water and dyes easily.



Technical notes

The many different grades of polypropylene fall into three basic groups: homopolymers (polypropylene, with a range of molecular weights and thus properties), co-polymers (made by co-Polymerization of propylene with other olefines such as ethylene, butylene or styrene) and composites (polypropylene reinforced with mica, talc, glass powder or fibers) that are stiffer and better able to resist heat than simple polypropylenes.

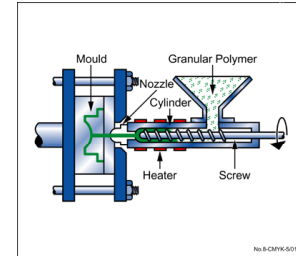
Typical uses

Ropes, general polymer engineering, automobile air ducting, parcel shelving and air-cleaners, garden furniture, washing machine tank, wet-cell battery cases, pipes and pipe fittings, beer bottle crates, chair shells, capacitor dielectrics, cable insulation, kitchen kettles, car bumpers, shatter proof glasses, crates, suitcases, artificial turf.

Part of a record for a process: injection molding

Injection molding

No other process has changed product design more than injection molding. Injection molded products appear in every sector of product design: consumer products, business, industrial, computers, communication, medical and research products, toys, cosmetic packaging and sports equipment. The most common equipment for molding thermoplastics is the reciprocating screw machine, shown schematically in the figure. Polymer granules are fed into a spiral press where they mix and soften to a dough-like consistency that can be forced through one or more channels ('sprues') into the die. The polymer solidifies under pressure and the component is then ejected.



Thermoplastics, thermosets and elastomers can all be injection molded. Co-injection allows molding of components with different materials, colors and features. Injection foam molding allows economical production of large molded components by using inert gas or chemical blowing agents to make components that have a solid skin and a cellular inner structure.

Physical Attributes

Mass range	0.01	-	25	kg
Range of section thickness	0.4	-	6.3	mm
Tolerance	0.2	-	1	mm
Roughness	0.2	-	1.6	µm
Surface roughness (A=v. smooth)	A			

Shape

Circular Prismatic	True
Non-circular Prismatic	True
Solid 3-D	True
Hollow 3-D	True

Economic Attributes

Economic batch size (units)	1e4	-	1e6
Relative tooling cost	very high		
Relative equipment cost	high		
Labor intensity	low		

Design guidelines

Injection molding is the best way to mass-produce small, precise, polymer components with complex shapes. The surface finish is good; texture and pattern can be easily altered in the tool, and fine detail reproduces well. Decorative labels can be molded onto the surface of the component (see In-mould Decoration). The only finishing operation is the removal of the sprue.

Technical notes

Most thermoplastics can be injection molded, although those with high melting temperatures (e.g. PTFE) are difficult. Thermoplastic based composites (short fiber and particulate filled) can be processed providing the filler-loading is not too large. Large changes in section area are not recommended. Small re-entrant angles and complex shapes are possible, though some features (e.g. undercuts, screw threads, inserts) may result in increased tooling costs. The process may also be used with thermosets and elastomers. The most common equipment for molding thermoplastics is the reciprocating screw machine, shown schematically in the figure. Polymer granules are fed into a spiral press where they mix and soften to a dough-like consistency that can be forced through one or more channels ('sprues') into the die. The polymer solidifies under pressure and the component is then ejected.

Typical uses

Extremely varied. Housings, containers, covers, knobs, tool handles, plumbing fittings, lenses, etc.

The economics

Capital cost are medium to high, tooling costs are usually high - making injection molding economic only for large batch sizes. Production rate can be high particularly for small moldings. Multi-cavity moulds are often used. Prototype moldings can be made using single cavity moulds of cheaper materials.

PROPERTY CHARTS

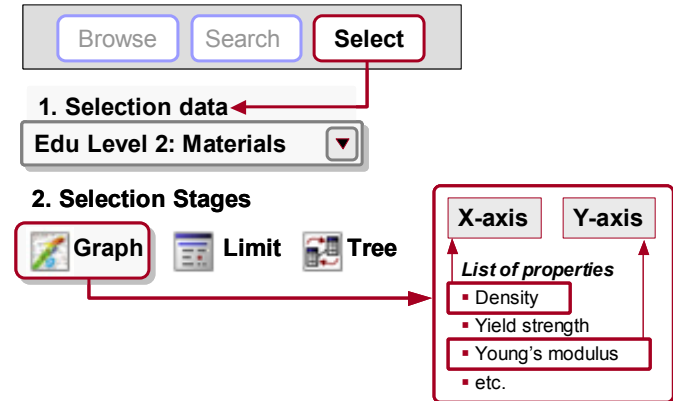
Exercise 4 Making PROPERTY CHARTS

- Select MaterialUniverse: LEVEL 2, MATERIALS
- Make a BAR CHART of YOUNG’S MODULUS (E)

*(Set y-axis to Young’s modulus; leave x-axis at <None>)
(Click on a few materials to label them; double-click to go to their record in the Data Table)*

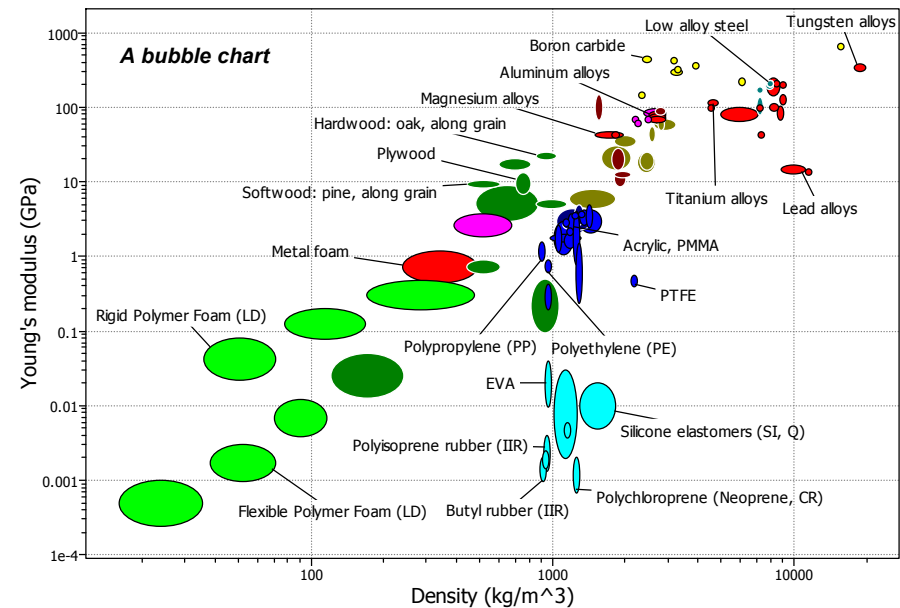
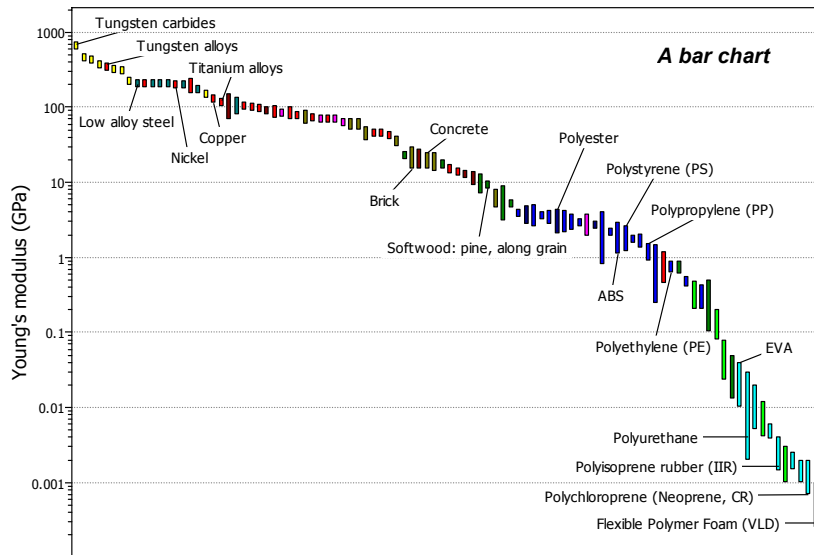
- Make a BUBBLE CHART of YOUNG’S MODULUS (E) against DENSITY (ρ)

*(Set both x-axis and y-axis; the default is a log-log plot)
(Materials can be labeled as before – click and drag to move the labels; use DEL to delete a label)*



DELETE THE STAGE

(Right click on stage in Selection Stages and select “Delete”)



SELECTION using a LIMIT STAGE

Exercise 5 Selection using a LIMIT stage

- Find materials with:

MAX. SERVICE TEMPERATURE > 200 °C

THERMAL CONDUCTIVITY > 25 W/m.k

ELECTRICAL CONDUCTOR = GOOD INSULATOR
OR INSULATOR?

(Enter the limits – minimum or maximum as appropriate – and click “Apply”)

(Results at Level 1 or 2: aluminum nitride, alumina, silicon nitride)

DELETE THE STAGE

1. Selection data

Edu Level 2: Materials

2. Selection Stages

Graph Limit Tree

Results	Ranking	
X out of 95 pass	Prop 1	Prop 2
Material 1	2230	113
Material 2	2100	300
Material 3	1950	5.6
Material 4	1876	47
etc...		

A Limit stage

Thermal properties

	Min.	Max	
Maximum service temperature	200		C
Thermal conductivity	25		W/m.K
Specific heat			J/kg.K





Electrical properties

Electrical conductor or insulator?

- Good conductor
- Poor conductor
- Semiconductor
- Poor insulator
- Good insulator

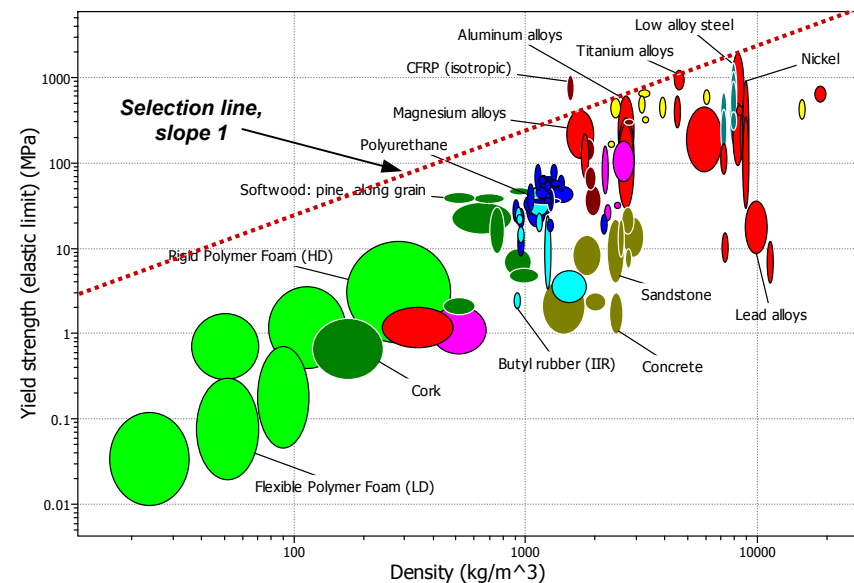
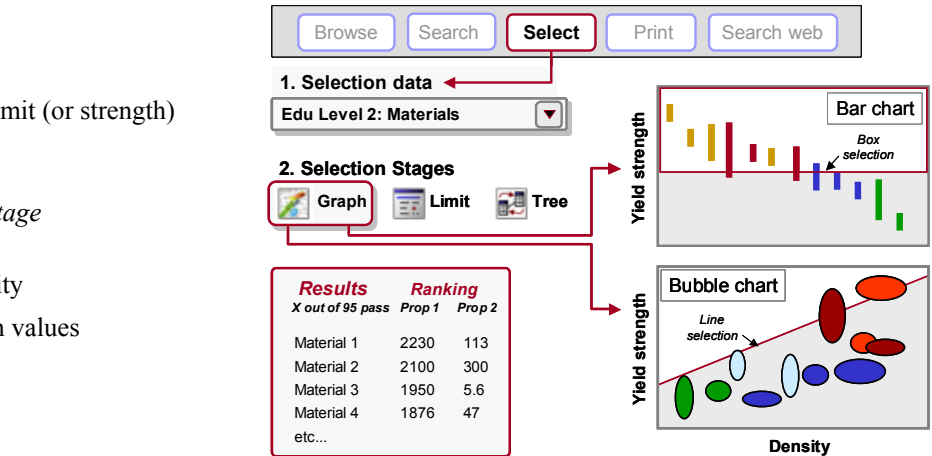
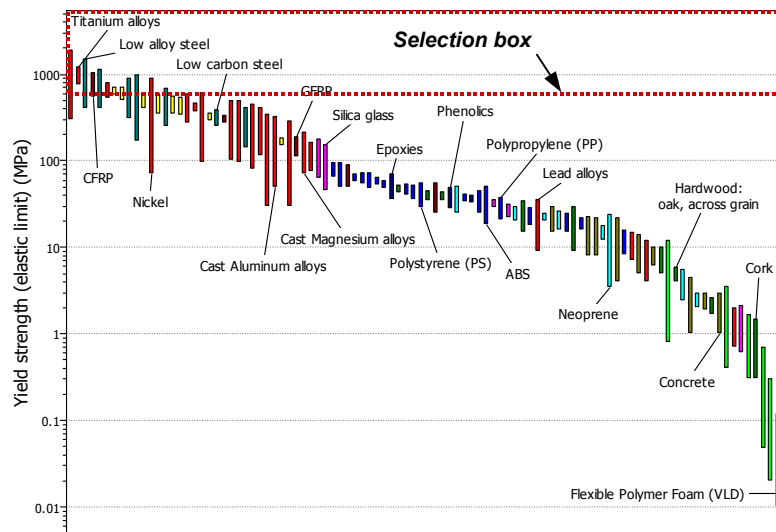
GRAPH SELECTION

Exercise 6 Selection with a GRAPH stage

- Make a BAR CHART of YIELD STRENGTH (σ_y) (plotted on the y-axis)
- Use a BOX SELECTION  to find materials with high values of elastic limit (or strength) (Click the box icon, then click-drag-release to define the box)
- Add, on the other axis, DENSITY (ρ) (Either: highlight Stage 1 in Selection Stages, right-click and choose Edit Stage from the menu; or double-click the graph axis to edit)
- Use a BOX SELECTION to find materials with high strength and low density
- Replace the BOX with a LINE SELECTION  to find materials with high values of the “specific strength”, σ_y / ρ (Click the gradient line icon, then enter slope: “1” in this case. Click on the graph + to position the line through a particular point. Click above or below the line  to select an area: above the line for high values of σ_y / ρ in this case. Now click on the line  and drag upwards, to refine the selection to fewer materials).

(Results at Level 1 or 2: CFRP (isotropic), Titanium alloys, Magnesium alloys, ...)

DELETE THE STAGE



TREE SELECTION

Exercise 7 Selection with a TREE Stage

- Find MATERIALS that can be MOLDED

(In Tree Stage window, select ProcessUniverse, expand “Shaping” in the tree, select Molding, and click “Insert”, then OK)

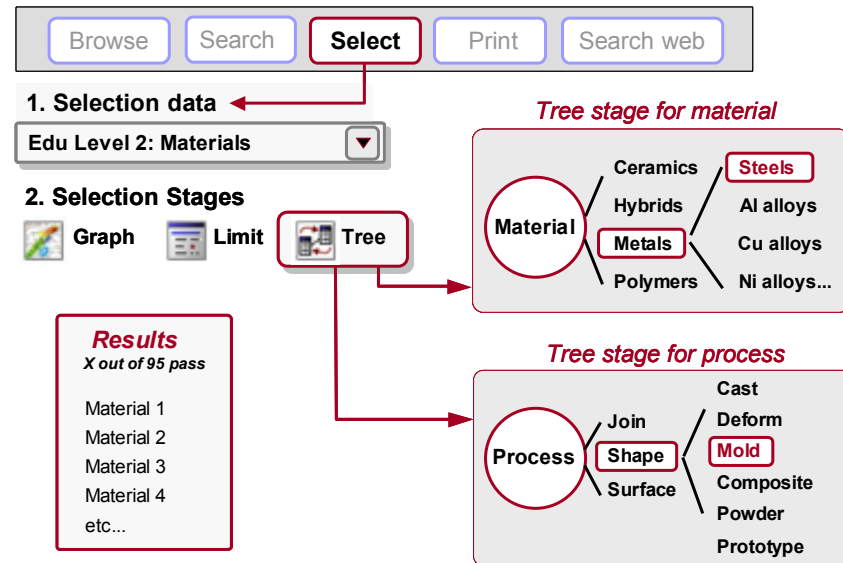
DELETE THE STAGE

- Find PROCESSES to join STEELS

(First change Selection Data to select Processes: LEVEL 2, JOINING PROCESSES)

(Then, in Tree Stage window, select MaterialUniverse, expand “Metals and alloys” in the tree, select Ferrous, and click “Insert”, then OK)

DELETE THE STAGE



GETTING IT ALL TOGETHER

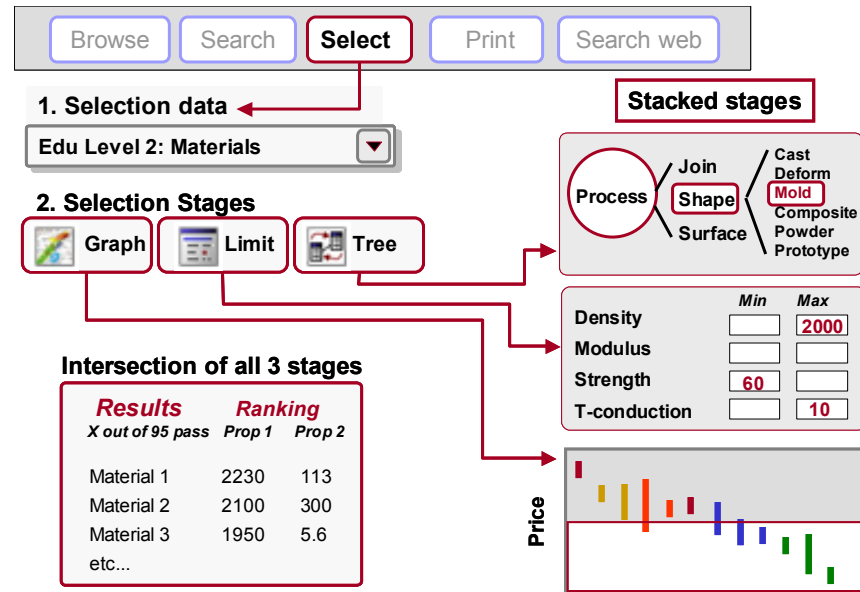
Exercise 8 Using ALL 3 STAGES together

Change Selection Data to select Materials:
Select LEVEL 2, MATERIALS

Find MATERIALS with the following properties

- DENSITY < 2000 kg/m³
- STRENGTH (Elastic limit) > 60 MPa
- THERMAL CONDUCTIVITY < 10 W/m.K
(3 entries in a Limit Stage)
- Can be MOLDED
(a Tree Stage: ProcessUniverse – Shaping – Molding)
- Rank the results by PRICE
(a Graph Stage: bar chart of Price)
(On the final Graph Stage, all materials that fail one or more stages are grayed-out; label the remaining materials, which pass all stages.)
The RESULTS window shows the materials that pass all the stages.)

(Results, cheapest first: PET, Epoxies, PMMA, ...)



Exercise 9 Finding SUPPORTING INFORMATION

(Requires Internet connection)

- With the PET record open, click on SEARCH WEB
(CES translates the material ID to strings compatible with a group of high-quality material and process information sources and delivers the hits. Some of the sources are open access, others require a subscriber-based password. The ASM source is particularly recommended.)

CLOSE THE DATASHEET

PROCESS SELECTION

Exercise 10 Selecting PROCESSES

Change Selection Data to select Processes:
Select LEVEL 2, SHAPING PROCESSES

Find PRIMARY SHAPING PROCESSES to make a component with:

- SHAPE = Dished sheet
- MASS = 10 – 12 kg
- SECTION THICKNESS = 4 mm
- ECONOMIC BATCH SIZE > 1000
(5 entries in a Limit Stage)
- Made of a THERMOPLASTIC
(a Tree Stage: MaterialUniverse – Polymers and elastomers – Polymers – Thermoplastics)

(Results: manual compression molding, rotational molding, thermoforming)

1. Selection data

Edu Level 2: Processes - Shaping

2. Selection Stages

Graph Limit Tree

Shape
Dished sheet

Physical attributes
Mass
Section thickness

Process characteristics
Primary shaping

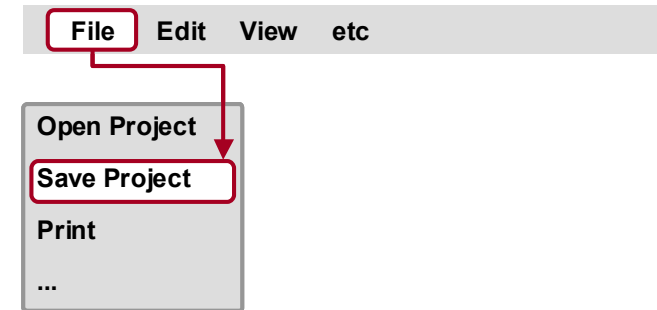
Economic attributes
Economic batch size

Material
Ceramics
Hybrids
Metals
Polymers
Thermoplastics
Thermosets

SAVING, COPYING, and REPORT WRITING

Exercise 11 Saving Selection Stages as a PROJECT

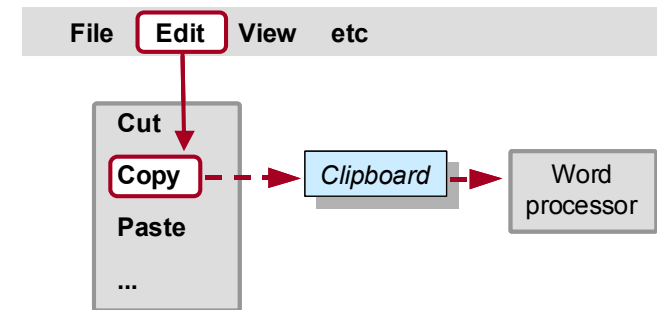
- SAVE the project – exactly as if saving a file in Word
(give it a filename and directory location; CES project files have the extension “.ces”)



Exercise 12 COPYING CES OUTPUT into a Document

Charts, Records, and Results lists may be copied (CTRL-C) and pasted (CTRL-V) into a word processor application

- Display a chart, click on it, then COPY and PASTE it into a document
- Double click a selected material in the Results window to display its datasheet, click on the datasheet, then COPY and PASTE it
- Click on the Results window, then COPY and PASTE it
- Try editing the document



(The datasheets in Exercise 3 and the selection charts in Exercises 4 and 6 were made in this way)

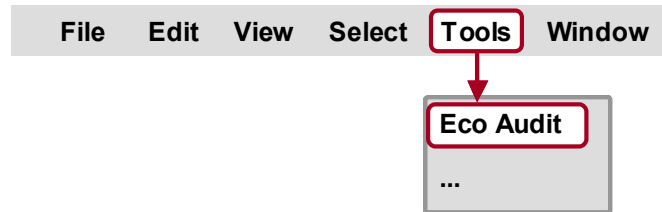
(Warning: There is a problem with WORD 2000: the image in the record is not transferred with the text. The problem is overcome by copying the image and pasting it separately into the WORD document as a DEVICE INDEPENDENT BITMAP.)

ECO AUDIT

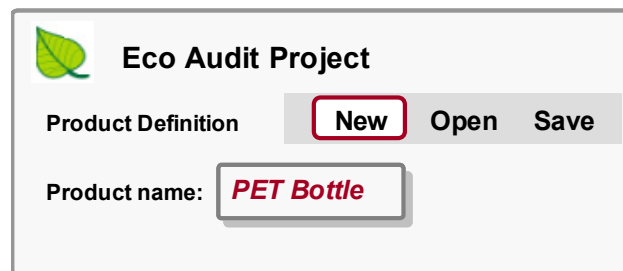
The Eco Audit Tool calculates the energy used and CO₂ produced during five key life phases of a product (material, manufacture, transport, use, and end of life) and identifies which is the dominant phase. This is the starting point for eco-aware product design, as it identifies which parameters need to be targeted to reduce the eco-footprint of the product.

Exercise 13 Eco Audit Project

A brand of bottled mineral water is sold in 1 liter PET bottles with polypropylene caps. A bottle weighs 40 grams; the cap 1 gram. Bottles and caps are molded, filled, and transported 550 km from the French Alps to England by 14 tonne truck, refrigerated for 2 days and then sold. The overall life of the bottle is one year.



Product Definition



1. Material, manufacture, and end of life

Bill of materials, primary processing techniques, and end of life

Quantity	Component name	Material	Recycle content	Primary process	Mass (kg)	End of life
1	Bottle	PET	0%	Molding	0.04	Recycle
		<ul style="list-style-type: none"> MaterialUniverse <ul style="list-style-type: none"> Ceramics and glasses Hybrids: composites etc Metals and alloys Polymers and elastomers <ul style="list-style-type: none"> Elastomers Polymers <ul style="list-style-type: none"> Thermoplastics <ul style="list-style-type: none"> PET 	<ul style="list-style-type: none"> 0% 100% 	<ul style="list-style-type: none"> Molding Extrusion 		<ul style="list-style-type: none"> Landfill Combust Downcycle Recycle Re-engineer Reuse
1	Cap	PP	0%	Molding	0.001	Recycle
1	Water				1	

2. Transport

Transportation from site of manufacture to point of sale

Stage name	Transport type	Distance (km)
Bottling plant to point of sale	14 tonne truck	550
		<ul style="list-style-type: none"> Sea freight Rail freight 14 tonne truck Air freight – long haul ...

3. Use

Product life and location of use

Product life: years

Country electricity mix: **United Kingdom** ▼

France

Germany

United Kingdom

...

Static mode

Energy used to refrigerate product at point of sale (average energy required to refrigerate 1 bottle at 4°C = 1 W)

Product uses the following energy:

Energy input and output: **Electric to mechanical (electric motors)** ▼

Power rating: **W** ▼

Usage: days per year

Usage: hours per day

Fossil fuel to thermal, enclosed system

Fossil fuel to electric

Electric to thermal

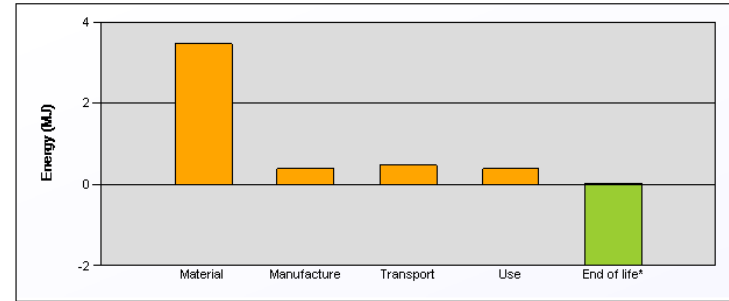
Electric to mechanical (electric motors)

...

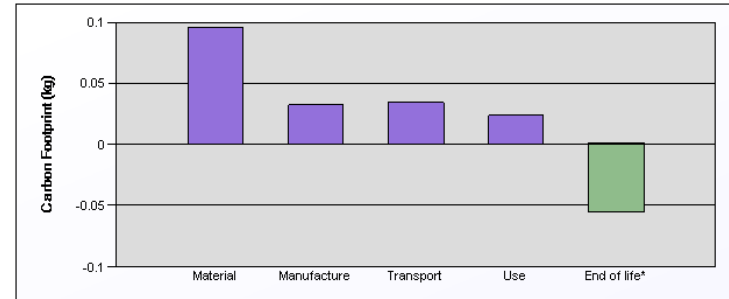
4. Report

[View Report](#)

Energy and Carbon Footprint Summary:



[Energy Details...](#)



[CO2 Details...](#)

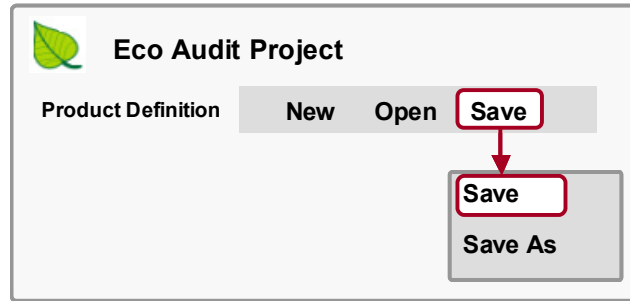
Phase	Energy (MJ)	Energy (%)	CO2 (kg)	CO2 (%)
Material	3.44	72.5	0.0958	50.9
Manufacture	0.402	8.5	0.0322	17.1
Transport	0.487	10.3	0.0344	18.3
Use	0.386	8.1	0.0241	12.8
End of life (collection & sorting)	0.0287	0.6	0.00172	0.9
Total	4.75	100	0.188	100
End of life (potential saving/burden)	-2	-42.1	-0.0555	-29.5
Total (including end of life saving/burden)	2.75		0.133	

(Result: Material is the dominant life phase ⇒ Focus on minimizing embodied energy and/or mass of bottle to reduce eco-footprint of product)

Change the “End of life” option to “Combust” and note the different impacts on the end of life Energy & CO₂

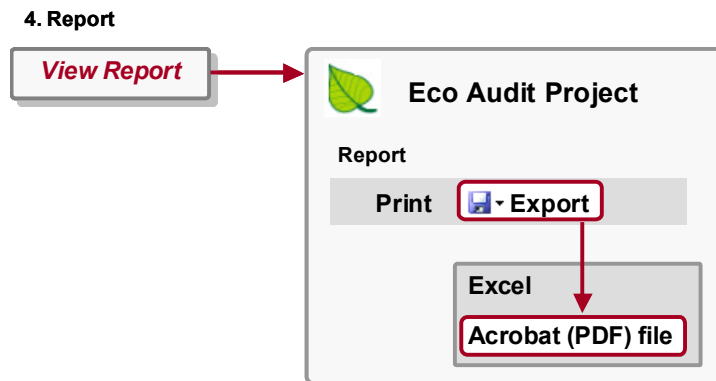
Exercise 14 Saving Eco Audit Product Definition

Eco audit projects do not form part of a selection project and need to be saved separately



- SAVE the product definition – (give it a filename and directory location; CES Eco Audit product files have the extension “.prd”)

Exercise 15 Saving/Exporting Eco Audit Report



- GENERATE the eco audit report
- EXPORT the eco audit report as a PDF

(Note: You will require Microsoft Excel or a PDF reader such as Adobe Reader to view the exported eco audit report)

Appendices

Toolbars in CES EduPack

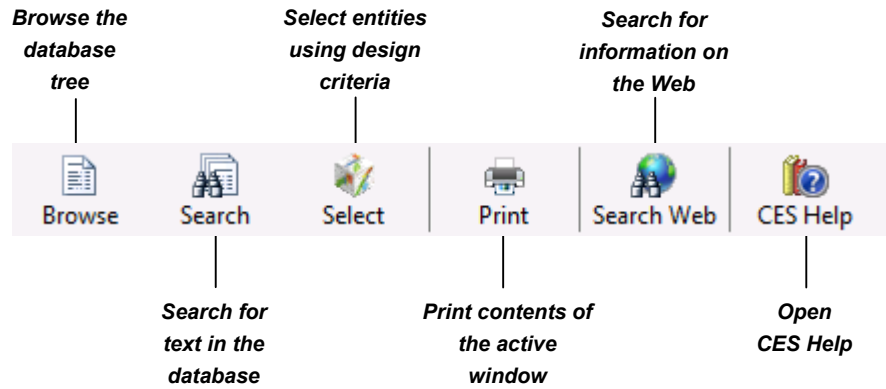


Figure A1. The Standard toolbar in CES EduPack

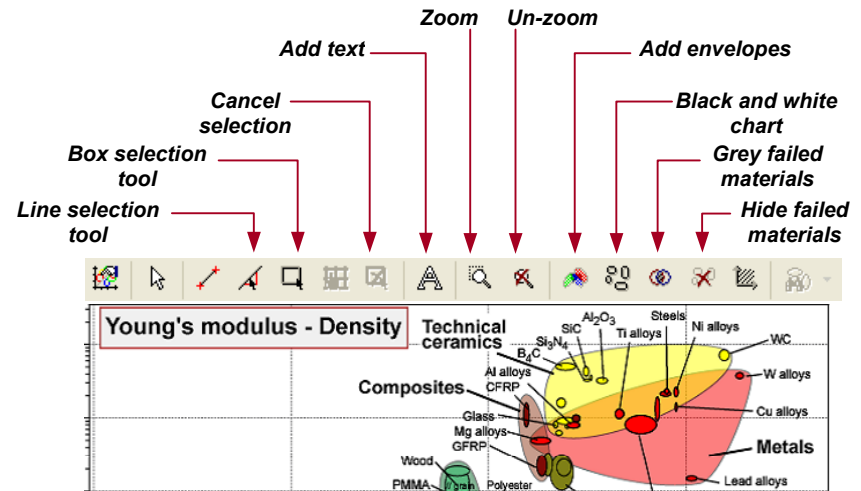


Figure A2. The Graph Stage toolbar in CES EduPack

Physical constants and conversion of units

Absolute zero temperature	-273.2°C
Acceleration due to gravity, g	9.807m/s ²
Avogadro's number, N _A	6.022 x 10 ²³
Base of natural logarithms, e	2.718
Boltzmann's constant, k	1.381 x 10 ⁻²³ J/K
Faraday's constant k	9.648 x 10 ⁴ C/mol
Gas constant, \bar{R}	8.314 J/mol/K
Planck's constant, h	6.626 x 10 ⁻³⁴ J/s
Velocity of light in vacuum, c	2.998 x 10 ⁸ m/s
Volume of perfect gas at STP	22.41 x 10 ⁻³ m ³ /mol

Angle, θ	1 rad	57.30°
Density, ρ	1 lb/ft ³	16.03 kg/m ³
Diffusion Coefficient, D	1 cm ² /s	1.0 x 10 ⁻⁴ m ² /s
Energy, U	See opposite	
Force, F	1 kgf	9.807 N
	1 lbf	4.448 N
	1 dyne	1.0 x 10 ⁻⁵ N
Length, ℓ	1 ft	304.8 mm
	1 inch	25.40 mm
	1 Å	0.1 nm
Mass, M	1 tonne	1000 kg
	1 short ton	908 kg
	1 long ton	1107 kg
	1 lb mass	0.454 kg
Power, P	See opposite	
Stress, σ	See opposite	
Specific Heat, Cp	1 cal/gal.°C	4.188 kJ/kg.°C
	Btu/lb.°F	4.187 kg/kg.°C
Stress Intensity, K _{Ic}	1 ksi $\sqrt{\text{in}}$	1.10 MN/m ^{3/2}
Surface Energy γ	1 erg/cm ²	1 mJ/m ²
Temperature, T	1°F	0.556°K
Thermal Conductivity λ	1 cal/s.cm.°C	418.8 W/m.°C
	1 Btu/h.ft.°F	1.731 W/m.°C
Volume, V	1 Imperial gall	4.546 x 10 ⁻³ m ³
	1 US gall	3.785 x 10 ⁻³ m ³
Viscosity, η	1 poise	0.1 N.s/m ²
	1 lb ft.s	0.1517 N.s/m ²

Conversion of units – stress and pressure*

	MPa	dyn/cm ²	lb.in ²	kgf/mm ²	bar	long ton/in ²
MPa	1	10 ⁷	1.45 x 10 ²	0.102	10	6.48 x 10 ⁻²
dyn/cm ²	10 ⁻⁷	1	1.45 x 10 ⁻⁵	1.02 x 10 ⁻⁸	10 ⁻⁶	6.48 x 10 ⁻⁹
lb/in ²	6.89 x 10 ⁻³	6.89 x 10 ⁴	1	703 x 10 ⁻⁴	6.89 x 10 ⁻²	4.46 x 10 ⁻⁴
kgf/mm ²	9.81	9.81 x 10 ⁷	1.42 x 10 ³	1	98.1	63.5 x 10 ⁻²
bar	0.10	10 ⁶	14.48	1.02 x 10 ⁻²	1	6.48 x 10 ⁻³
long ton/in ²	15.44	1.54 x 10 ⁸	2.24 x 10 ³	1.54	1.54 x 10 ²	1

Conversion of units – energy*

	J	erg	cal	eV	Btu	ft lbf
J	1	10 ⁷	0.239	6.24 x 10 ¹⁸	9.48 x 10 ⁻⁴	0.738
erg	10 ⁻⁷	1	2.39 x 10 ⁻⁸	6.24 x 10 ¹¹	9.48 x 10 ⁻¹¹	7.38 x 10 ⁻⁸
cal	4.19	4.19 x 10 ⁷	1	2.61 x 10 ¹⁹	3.97 x 10 ⁻³	3.09
eV	1.60 x 10 ⁻¹⁹	1.60 x 10 ⁻¹²	3.38 x 10 ⁻²⁰	1	1.52 x 10 ⁻²²	1.18 x 10 ⁻¹⁹
Btu	1.06 x 10 ³	1.06 x 10 ¹⁰	2.52 x 10 ²	6.59 x 10 ²¹	1	7.78 x 10 ²
ft lbf	1.36	1.36 x 10 ⁷	0.324	8.46 x 10 ¹⁸	1.29 x 10 ⁻³	1

Conversion of units – power*

	kW (kJ/s)	erg/s	hp	ft lbf/s
kW (kJ/s)	1	10 ⁻¹⁰	1.34	7.38 x 10 ²
erg/s	10 ⁻¹⁰	1	1.34 x 10 ⁻¹⁰	7.38 x 10 ⁻⁸
hp	7.46 x 10 ⁻¹	7.46 x 10 ⁹	1	15.50 x 10 ²
Ft lbf/s	1.36 x 10 ⁻³	1.36 x 10 ⁷	1.82 x 10 ⁻³	1

* To convert row unit to column unit, multiply by the number at the column row intersection, thus 1MPa = 1 bar

This is one of six CES EduPack teaching resource books. All are available free of charge to users with a maintained CES EduPack license.

Book 1: Getting Started with CES EduPack

Book 2: Material and Process Selection Charts

Book 3: Useful Approximate Solutions for Standard Problems

Book 4: PowerPoint Lectures

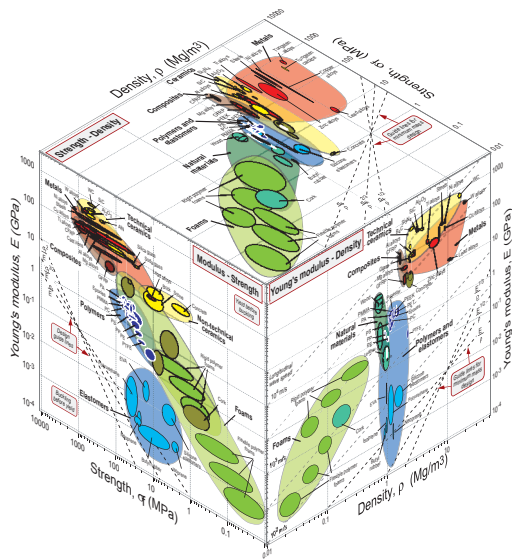
Book 5: Projects Using CES EduPack

Book 6: Exercises with Worked Solutions

Granta's CES EduPack is the world's leading teaching resource for materials and processes.

The complete EduPack includes the EduPack software and databases, a choice of 4 textbooks from Professor Mike Ashby, and a range of other resources including advice, lectures, projects, exercises, and handouts. Download resources from www.grantadesign.com/education/.

GRANTA MI and CES Selector are Granta's industrial products for materials information management and materials selection.



GRANTA
MATERIAL INSPIRATION

www.grantadesign.com • info@grantadesign.com • Granta Design Limited • Cambridge UK

UK/Int'l T +44 1223 518895
F +44 1223 506432

USA T (800) 241-1546
F (216) 274-9812

France T 08 00 76 12 90
F 01 53 01 69 66

Germany T 0800 182 5026
F 01805 4820 151 002

© Copyright Granta Design Ltd.

