CES EduPack

USER'S MANUAL

Granta Design Limited

CES EduPack User's Manual
Release 4

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Contents

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When referring to this *User's Manual* in publications, the bibliographic reference is:

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Chapter 1 Introduction

1.1 Read this First!

The CES EduPack is a powerful tool. It is centered on the CES EduPack software, supported by textbooks, and by teaching resources - lectures, projects, and exercises - that you can download (password protected) from www.grantadesign.com/education/ .

The CES EduPack software enables users to search, browse, and analyze data contained in CES databases and to apply a systematic methodology for selecting entities to optimize performance, based on design specifications. The CES EduPack software can be used to view and analyze reference databases provided by Granta Design Limited.

The reference databases provided by Granta are described in Chapter 4 of this manual. Each database consists of a number of data 'tables' that are linked together in a relational structure to provide a powerful engineering data management and selection environment. They contain unique sets of high quality data, developed by Granta's specialist database team, in conjunction with Cambridge University Engineering Department and some third-party data providers.

The main aim of this manual is to help users get *up and running* with the software and to introduce: the type and level of data stored in the databases, and the capabilities of the selection tools. However, in order to benefit from the full power of the package you should also refer to the following: the white papers available from CES Help and the teaching resources website; and the text books 'Material Selection in Mechanical Design' by Prof. Mike Ashby (explaining the selection methodology in detail) and 'Materials: Engineering, Science, Processing and Design' by Ashby, Shercliff and Cebon.

1.2 About this Manual

This manual contains five Chapters:

Chapter 1 Introduction
provides information about this manual and on obtaining help.

Chapter 2 Installation
gives step-by-step instructions on how to install single–user and multi-user copies of CES EduPack.

Chapter 3 Teaching Materials
describes how CES EduPack can be used to teach material and process selection.

Chapter 4 CES EduPack Databases
describes the contents of the CES EduPack educational databases.

Chapter 5 Getting Started with CES EduPack
provides a brief overview of the facilities of CES EduPack in tutorial format.

1.3 Tutorials and Reference Information

Information on getting started with the CES EduPack software can be found in Chapter 5 of this manual.

A comprehensive set of tutorials on use of the software as well as reference information about all aspect of the software can be found in the online *Help* system, accessible via the CES Help button on the CES EduPack toolbar.

The 'CES Help' contains a wealth of information about the system, including: details of the selection methodology, tables of material indices, solutions to standard engineering problems, material and process case studies, and a glossary of attributes names, etc.

Chapter 2 Installation

2.1 Introduction

This part of the User's Manual provides instructions for registering and installing your copy of the CES EduPack system.

2.1.1 System Requirements

In order to run the CES EduPack software, your personal computer (PC) must have the Windows® operating system (CES EduPack is developed and optimized for Windows Vista; the software is expected to function on compatible versions of Windows such as XP) and should have at least a Pentium II processor (or equivalent) with 512MB of RAM, 500–800MB of free hard disk space, SVGA graphics (256 color, 800x600), and a mouse or compatible pointing device. An Internet connection is required for running the Web-based searching facilities.

You may need Administrator Rights to install the software.

For 'All Editions', the server will require 3GB of free hard disk space, and 1GB of RAM is recommended.

The CES EduPack software makes use of version 3.0 of the Microsoft .NET Framework and a Microsoft Visual Studio runtime. These must be available prior to the installation. The CES EduPack installation will offer to install these components automatically if they cannot be detected on your computer. However, should you encounter any installation difficulties, the components can be installed manually and are supplied with the software in the 'support' folder.

2.1.2 License Options

The CES EduPack License Agreement specifies the number of 'seats' or 'users' (students). This is the number of computers on which the software may be installed, or the number of unique users (students) the software may be used with each year.

If the License is for a *Single Seat*, then the software may be installed on *one personal computer* only. Installation on more than one computer or installation on a network drive is forbidden under the terms of the License.

If the License is for *Multiple Seats*, the software may be installed on the number of *computers* specified on the License Agreement. Note that such installations may use a network drive to store a single common copy of the database.

If the License is for *Multiple Users* (students), the software may be installed on any personal computer for use by students and instructors covered by the License Agreement.

The enrollment based license also allows installation on the personal computers of the students and instructors on the courses named in the License Agreement.

2.1.3 Configuration

For a single-seat license, the program must be installed on the hard disk drive of a PC. With multiple-seat/user (student) licenses (e.g. *lab* license or *enrollment* license), the program must be installed on each PC. In network installations, this can be done using the 'netsetup' program which is supplied with the software. Each networked PC must have access to some 'writeable' file space, either on a local hard disk or on a network file server. Network installations are discussed in Section 2.5.

All CES EduPack databases are installed by the installation procedure described in the following sections. Additional CES EduPack databases can be purchased and installed in the same way.

2.2 Running the Setup Program

If you have installed a previous or evaluation copy of CES EduPack, it is recommended that you un-install this before installing your licensed copy.

CES EduPack uses a *Setup* program similar to those of many other Windows applications. You can proceed through the stages of installation by clicking *once* with the left mouse button on the **Next** button. You can stop the installation process whenever a **Cancel** or **Exit Setup** button is displayed.

Insert the disk in your CD-ROM drive.

The Setup program should run by itself. If it does not, try one of the following actions:

Open Windows Explorer and double-click on the file Setup.exe on your CD-ROM drive.

or use the Windows 'Run' command as follows:

From the Windows Start menu, select the 'Run' command.

This will open the Windows 'Run' dialog box.

Click in the Open field in the Run dialog box, then type E:\Setup

where E:\ is the location of the Setup.exe file (your CD–ROM drive).

Click once on *OK.*

If one of the above procedures has been successful, after a few seconds, you should see the Welcome dialog box.

Click on the *Next* > button.

2.3 Registering Your Copy of CES EduPack

To register your copy of CES EduPack, enter the relevant details for your Name, Company and registration key. A Name is required. Your registration key is provided on the License Agreement card that accompanied the software. If you have an enrolment based license you do not need to enter the registration key.

Enter your Name and Company details.

Enter your registration key (located on your License Agreement card) by typing it in the field provided.

Click once on the *Next >* **button to confirm the registration information and continue with the setup procedure.**

The License Agreement screen will appear. The License Agreement is a legally binding agreement between you and Granta Design Limited. The same License Agreement text appears on the License Card. For 'Customer' details, the 'Site' and any special conditions, please see the hard copy License Card.

IF YOU CLICK ON THE ***I Agree*** BUTTON, YOU AGREE TO BE BOUND BY THE TERMS OF THE LICENSE AGREEMENT AS SPECIFIED ON THE LICENSE AGREEMENT SCREEN AND ON THE LICENSE CARD.

Once you have read the license agreement, you can proceed with installing CES EduPack:

Click once on the *I Agree* **button, if you agree to be bound by the terms of the License Agreement.**

2.4 Installation

Next specify the type of installation (stand-alone or network) and enter the location where the software is to be installed.

For stand-alone installation, on a single PC, click on the 'Stand Alone' button. If you wish to install the software on a network of PCs, select the 'Network Server' button.

The default installation location is a directory named 'C:\Program Files\CES EduPack'. You do not have to create the default directory beforehand, the setup program will create it for you.

If you wish to change the destination location for your copy of CES EduPack:

> **Click once on the *Browse* button on the 'Choose Destination Location' dialog box. Select a folder in the 'Select Destination Directory' dialog and then click once on *OK*.**

When you are happy with the destination,

> **Click once on the *Next* > button.**

The 'Choose Databases' dialog will appear. This screen enables you to choose between various database options: for example, the Level 1 and 2 databases are available in French as well as English.

> **Choose the database option you wish to install and click once on the *Next* > button.**

You should see the Start Installation dialog box.

> **Click on the *Next* > button in this dialog box to perform the installation.**

If you wish to alter any of the installation settings, click the **Cancel** button and begin the installation process again.

A 'thermometer' indicator will inform you of the progress of the installation.

When *Setup* has finished, a dialog box will appear with the message 'CES EduPack has been successfully installed.'

> **Click on *OK* to exit the installation program.**

The program will return control to Windows.

The installation process will make a Start Menu Program group named 'CES EduPack', which will contain the icons for the CES EduPack components.

To begin using the CES EduPack, go to the *Start* menu > *All Programs* > *CES EduPack*.

To uninstall CES EduPack, use Add or Remove Programs in the Control Panel.

Note that the CES Constructor software is *not* automatically distributed with every CES EduPack system. It will only be available if you have purchased a research license.

2.5 Multiple Seat/User Installations

This section provides information about options for multiple-seat/user (student) installations of CES EduPack. It assumes that you have some experience with setting up Windows programs to run on networks.

Many universities deploy 'All Editions' of the CES EduPack across the campus network. If you would like further assistance with this, please contact Granta (support@grantadesign.com).

Multiple-seat/user copies of CES EduPack can be installed in two possible ways. In both cases it is necessary to perform an installation *on every machine* on which the software is to be used.

(i) CES EduPack can be installed individually on the hard disk drive of every machine on which it will be used, i.e. like a single-user installation. In this case, you should follow the installation instructions described in the previous sections, and install the software into a folder on the local hard disk.

(ii) The software can be installed in a folder on a network drive. In this case, you should follow the installation instructions described in the previous sections, but install the software into a folder on a network drive that is read-accessible to all PCs on the network. The netsetup program can then be run on each PC on the network to install the relevant 'client' components of the software.

In both cases, users will require some file space with 'write' access, for saving CES EduPack output and project files.

2.5.1 Example

You are an educational user and have purchased a lab license. All of the 20 PCs in the lab are networked to a file server. The hard disk drive of each PC is the '*C*' drive. The network drive '*F*' can be read by the networked PCs. Only the system administrator has write access to this drive.

The system administrator runs the setup program and performs a network installation to the folder 'F:\CES Selector'. Then on each of the 20 PCs in the network, the administrator runs the *netsetup.exe* program 'F:\CES Selector\netsetup.exe'. This will install program files and dll's to the local machine, but the database will be accessed from the server location.

A user of CES EduPack at one of the networked PCs must have read permission for the *F* drive and write permission to a folder on the network or on the PC they are currently using, for output of CES EduPack files (e.g. C:\Users).

Note: CES EduPack requires certain system libraries (dll's) to run. If a compatible version of these files is not found on the user's machine, and the machine is running Windows NT, then the user will need to have Administrator rights to install the software – or the installation may fail.

Chapter 3 Teaching Materials

3.1 Introduction: Teaching Materials to Students of Engineering, Science, and Design

There are two main approaches to teaching materials. The traditional science-driven approach, that starts at the atom and gradually builds up an understanding of the structure and performance of a material before applying it to a design. The inverse of this is the design-driven approach. This starts with a design, the specification of design requirements and the identification of candidate materials, before drilling-down to the underlying structure and science of the material (see Figure 3-1).

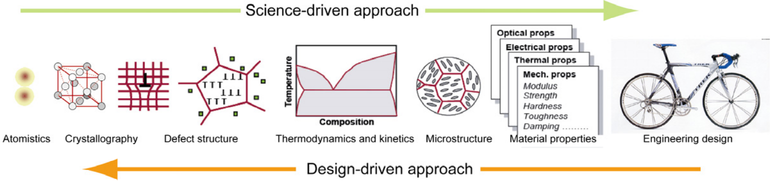


Figure 3-1. Two alternative approaches (simplified) to the teaching of materials

CES EduPack is able to support both of these teaching approaches. In the design-driven case, for example, the student can drill-down to the underlying science of a material to understand why a particular material is suitable for their application. In the science-driven case, the EduPack can be used to demonstrate what the science means in terms of material performance. For example, a plot of materials properties (e.g. Young's modulus vs. density) can be used to show how materials with different bond types occupy different areas in the property space.

In addition, CES EduPack complements a range of teaching methods, including: classroom-based, project-based, problem-based, and self-teaching techniques. This level of flexibility has resulted in many universities and colleges using the CES EduPack as a central resource for all their materials teaching.

3.2 The CES EduPack Teaching Resources

The CES EduPack consists of the following components:

(i) CES EduPack Software, with a range of licensing options.

(ii) A suite of databases, spanning three levels: Level 1, suitable for an introductory (e.g. first year) course, Level 2, providing more information, but limited to records for the more common materials and processes, and Level 3, a range of specialist databases allowing comprehensive projects and real-life materials selection studies.

(iii) A range of supporting texts, for example, 'Materials: Engineering, Science, Processing and Design' Ashby, M. Shercliff, H. and Cebon, D. (Butterworth Heinemann, Oxford, 2007).

(iv) In-depth science notes explaining the underlying science of materials and properties. These also provide references to a broad range of standard materials texts.

(v) A set of White Papers and resource books with advice, lectures, projects, exercises, and handouts. These are available to download from:
http://www.grantadesign.com/userarea/teachingresource/
(Login required – the password is provided in the cover letter for your EduPack shipment, or available by contacting Granta Design.)

For the latest information, please see:

http://www.grantadesign.com/education/

Chapter 4 CES EduPack Databases

4.1 The EduPack Materials Data Tables for Education

Materials information is stored at three levels of coverage and detail, summarized in Table 4-1. Level 1 is adapted to an introductory materials course, Level 2 to an intermediate course, and Level 3 to advanced and professional teaching and training.

	Material coverage	Nature of 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.

Table 4-1. The coverage and content of the three levels of database

Level 1 contains records for around 70 of the most widely used material classes. Records at Level 2 contain all the information presented at Level 1 for around 100 of the most widely used materials, augmented with additional numeric data and text for design guidelines, ecological properties, and technical notes. Level 3, with vastly greater material coverage, lists detailed numeric properties and rankings for over 3,000 materials.

The taxonomy of the database follows the hierarchical structure of Figure 4-1. This is easily understood, can be limited initially to 70 or so "commodity" classes of materials (as it is in Level 1), or expanded to include the full portfolio of over 3,000 members (Level 3).

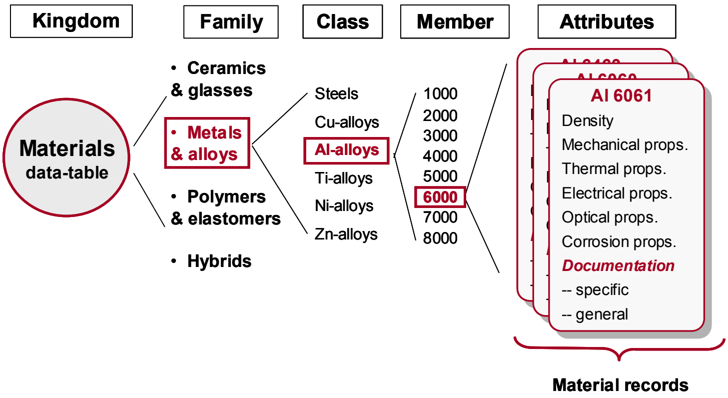


Figure 4-1. The taxonomy of the MATERIALUNIVERSE as used in the database

Chapter 5, Exercise 3 shows a typical Level 1 record; it is for Polypropylene, PP. It starts with a description and an image of a product containing the material – a good way of displaying its characteristics. The numeric attributes that come next are described by ranges spanning their spread. Electrical resistance and optical transparency are given as a ranking ("good or poor conductor or insulator", for instance), because this is easier to understand and use than a numeric value for resistivity or transparency (numeric values are given at Levels 2 and 3). The record concludes with a list of applications.

Each material record is linked to records in other CES EduPack data tables: Processes; References, Producers, and so forth. These links can be used as part of the selection process: you can, for example select materials that can be formed by a particular process using the links to the Process tables.

All the records are complete. Where data are not available, sophisticated estimation methods have been used to bracket them, allowing design concepts to be explored even when data are sparse.

4.2 The EduPack Process Data Tables for Education

4.2.1 Contents of the Shaping Data Table

Chapter 5, Exercise 3 presents a typical record from the Level 1 Shaping Process Table: it is for 'Injection molding'. A schematic and a short description illustrate how the process works. This is followed by a listing of numeric attributes, stored as ranges indicating the range of capability of the process. Economic attributes are characterized by rankings "low", "medium", "high" or A, B, C. The shape-classes that the process can make are listed as Logical properties. The record also includes a lot of text information.

Links to the Material data tables enable selection of processes on the basis of the materials they can form. Links to the References table provides sources of data and further information: essential in reaching a final selection.

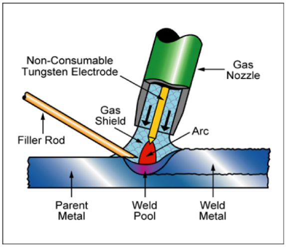
Level 2 shaping records contain all the information shown at Level 1, supplemented by additional data, design guidelines, technical, and environmental notes. At Level 3 the number of shaping records increases from 30 to 131.

4.2.2 Contents of the Joining Data Table

Figure 4-2 presents a typical record from the Level 2 Joining Process Table: it is for 'Gas tungsten arc (TIG) welding'. The layout is the same as that for Shaping. As before, Level 2 provides more detail for the records of Level 1; Level 3 expands the number of records from 23 to 53 records.

Gas tungsten arc (TIG)

TUNGSTEN-INERT GAS (TIG) welding is a heavy-duty welding process (others are MMA and MIG) is the cleanest and most precise, but also the most expensive. In one regard it is very like MIG welding: an arc is struck between a non-consumable tungsten electrode and the work piece, shielded by inert gas (argon, helium, carbon dioxide) to protect the molten metal from contamination. But, in this case, the tungsten electrode is not consumed because of its extremely high melting temperature. Filler material is supplied separately as wire or rod. TIG welding works well with thin sheet and can be used manually, but is easily automated. Both penetration and deposition rates are much less than those of MIG welding, but precise control of the weld is easier.



Function
Electrically conductive True
Thermally conductive True
Watertight/airtight True
Demountable False
Service temperature regime Limited by parent material

Process Characteristics
Discrete True
Continuous True

Economic Attributes
Relative tooling cost low
Relative equipment cost medium
Labor intensity low

Materials to be joined
Metals True

Joint geometry
Lap True
Butt True
Sleeve True
Scarf True
Tee True

Recommended Loading
Tension True
Compression True
Shear True
Bending True
Torsion True

Design guidelines
Because the heating is de-coupled from the filler supply, greater control of weld conditions is possible. Thus, TIG welding is used for thin plate and for precision assemblies, made of almost any metal. Clean surfaces and well-prepared joints are important. It's principally used for thin sections and precisely made joints.

Technical notes
TIG welding produces very high quality welds on metals such as aluminum, magnesium, titanium, stainless steel, and nickel; cast iron and mild steel are also easily welded. The arc is started by a high frequency AC discharge to avoid contaminating the tungsten electrode; it is subsequently maintained by a DC current or a square wave AC current, which gives greater control of penetration.

Typical uses
TIG welding is one of the most commonly used processes for dedicated automatic welding in the automobile, aerospace, nuclear, power generation, process plant, electrical and domestic equipment markets.

The economics
The equipment is more expensive and less portable than torch, and a higher skill level is required of the operator. But the greater precision, the wide choice of metals that can be welded and the quality of the weld frequently justify the expense.

The enviro**nment**
TIG welding requires the same precautions as any other arc welding process: ventilation to prevent inhalation of fumes from the weld pool, and visors or colored goggles to protect the operator from radiation.

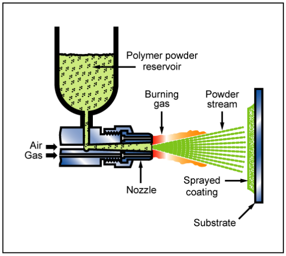
Figure 4-2. Part of a typical record from the Level 2 Joining Process Table

4.2.3 Contents of the Surface Treatment Data Table

Figure 4-3 is a typical record from the Level 2 Surface Treatment Table: it is for 'Polymer powder coating'. The layout is the same as that for Shaping and Joining. As before, Level 2 provides more detail for the records of Level 1; Level 3 expands the number of records from 24 to 46 records.

Polymer powder coating

ELECTROSTATIC POWDER COATING is an efficient, widely used process for applying decorative and protective finishes to metallic or conducting components. The powder is a mixture of finely ground pigment and resin that is sprayed through a negatively charged nozzle onto a surface to be coated. The charged powder particles adhere to the surface of the electrically grounded component. The charge difference attracts the powder to the component at places where the powder layer (which is insulating) is thinnest, building up a uniform layer and minimizing powder loss. The component is subsequently heated to fuse the layer into a smooth coating in a curing oven. The result is a uniform, durable coating of high quality and attractive finish. Powder coating is the fastest growing finishing technology in North America, representing over 10% of all industrial finishing. In polymer flame coating, a thermoplastic in powder form (80-200 μm) is fed from a hopper into a gas-air flame that melts the powder and propels it onto the surface to be coated. The process is versatile, can be mechanized or operated manually, and can build up coatings as thick as 1 mm. A wide range of thermoplastic powders can be used and the process is cheap. The disadvantages: line-of-sight deposition, and surface finish that is inferior to other processes.
In **FLUIDISED BED COATING** the component, heated to 200 - 400 C, is immersed for 1 to 10 seconds in a tank containing coating powder, fluidized by a stream of air at 0.1 - 0.5 atmospheres. The hot component melts the particles, which adhere to it, forming a thick coating with excellent adhesion.
In **ELECTROSTATIC BED COATING** the bed is similar but the air stream is electrically charged as it enters the bed. The ionized air charges the particles as they move upward, forming a cloud of charged particles. The grounded component is covered by the charged particles as it enters the chamber. No preheating of the component is required but a subsequent hot curing is necessary. The process is particularly suitable for coating small objects with simple geometries.



Physical Attributes

Curved surface coverage	Good			
Coating thickness	125	-	1000	μm
Coating rate	10	-	30	μm/s
Processing temperature	46.85	-	186.9	°C
Surface hardness	10	-	16	Vickers
Surface roughness (A=v. smooth)			B	

Economic Attributes

Relative tooling cost	low
Relative equipment cost	medium
Labor intensity	low

Process Characteristics

Discrete	True

Function of Treatment

Corrosion Protection (aqueous)	True
Corrosion Protection (organics)	True
Friction control	True
Thermal Insulation	True
Electrical Insulation	True
Aesthetics	True
Colour	True
Reflectivity	True

Typical uses
Automotive industry: wheels, bumpers, hubcaps, door handles, decorative trim and accent parts, truck beds, radiators, filters, numerous engine parts. Appliances: front and side panels of ranges and refrigerators, washer tops and lids, dryer drums, air-conditioner cabinets, water heaters, dishwater racks, cavities of microwave ovens; powder coating has replaced porcelain enamel on many washer and dryer parts. Architecture: frames for windows and doors and modular furniture. Consumer products: lighting fixtures, antennas, electrical components, golf clubs, ski poles and bindings, bicycles, computer cabinets, mechanical pencils and pens

Figure 4-3. Part of a typical record from the Level 2 Surface Treatment Table

4.3 Use of the Database

The data-tables and selection engine of the CES EduPack are designed to allow great freedom in the way it is used.

The **Browse** and **Search** functions in the software can be used to explore the world of materials and processes. The descriptions in the database provide useful qualitative knowledge. The material properties can be used very effectively as a resource for other subjects: structural engineering or heat transfer calculations for example. Particular utility can be obtained by following the links between records in the database... For example, to find out which processes can be used to shape a particular material or which materials can be joined by a particular process.

The online documentation system, CES Help, contains 33 fully-worked, interactive case studies on materials selection and 13 on shaping process selection. (These case studies are best performed with the Level 3 database). Examining these is a good way to explore the range of methods for materials selection.

5 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. A complete set of exercises is available to download from www.grantadesign.com.

5.1 Thumbnail Sketch of CES EduPack

The CES EduPack software has three Levels of Database as shown in Table 4-1. At each Level there are a number of Data Tables. The most important are: **Materials**, **Shaping Processes**, **Joining Processes**, and **Surface Treatments**.

Each of the three levels can be interrogated by

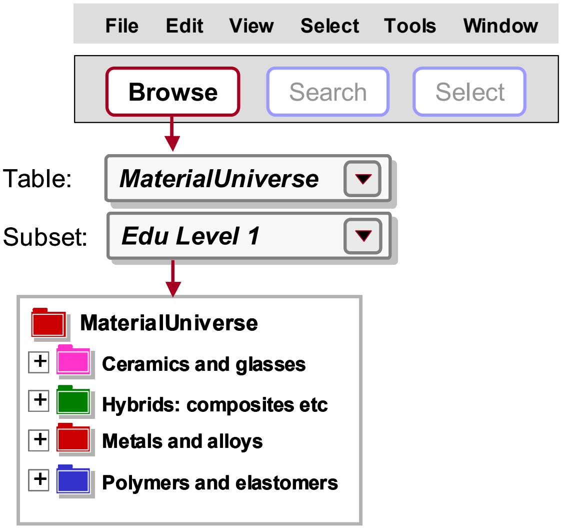
- BROWSING Exploring the database and retrieving records via a hierarchical index.
- SEARCHING Finding information via a full-text search of records.
- SELECTION Use of powerful selection engine to find records that meet an array of design criteria.

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

5.2 Browsing and Searching

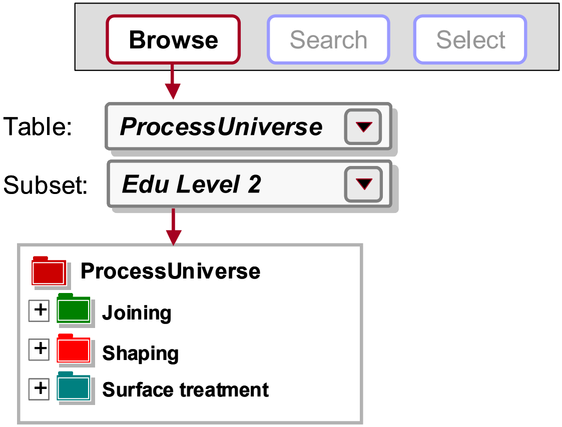
The DEFAULT on loading CES EduPack Levels 1 & 2 is LEVEL 1, MATERIALS UNIVERSE

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

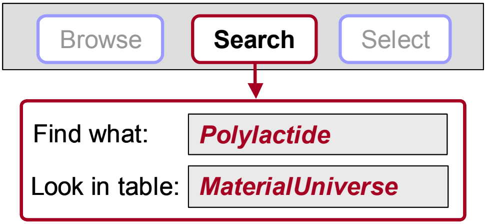
Exercise 2 Browse Processes



Browse ProcessUniverse: 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 next)

Part of a record for a material: polypropylene

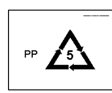
Polypropylene (PP) (CH2-CH(CH3))n

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.

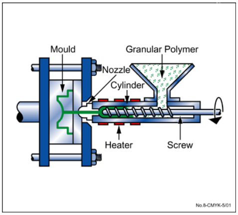


Technical notes
The many different grades of polypropylene fall into three basic groups: homopolymers (polypropylene, with a range of molecular weights and thus properties), co-polymers (made by co-Polymerization of propylene with other olefines such as ethylene, butylene or styrene) and composites (polypropylene 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
Injection molded products appear in every sector of product
consumer products, business, industrial, computers,
medical and research products, toys, cosmetic packaging and
equipment. The most common equipment for molding thermoplastics is
reciprocating screw machine, shown schematically in the figure.
granules are fed into a spiral press where they mix and soften to a
like consistency that can be forced through one or more channels
into the die. The polymer solidifies under pressure and the component
then ejected.
Thermoplastics, thermosets and elastomers can all be injection molded.
injection allows molding of components with different materials, colors
features. Injection foam molding allows economical production of
molded components by using inert gas or chemical blowing agents to
components that have a solid skin and a cellular inner

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.
surface finish is good; texture and pattern can be easily altered in the tool, and fine detail reproduces
Decorative labels can be molded onto the surface of the component (see In-mould Decoration). The only
operation is the removal of the sprue.

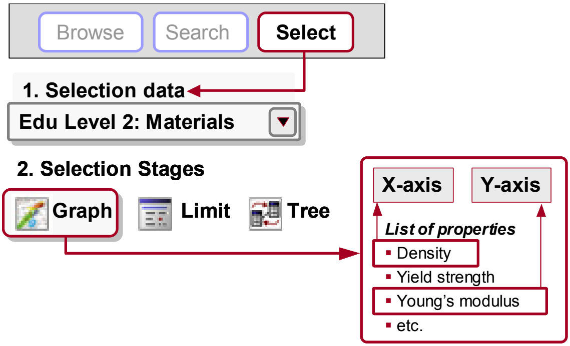
Technical notes
Most thermoplastics can be injection molded, although those with high melting temperatures (e.g. PTFE)
difficult. Thermoplastic based composites (short fiber and particulate filled) can be processed providing the
loading is not too large. Large changes in section area are not recommended.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

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

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

5.3 Property Charts

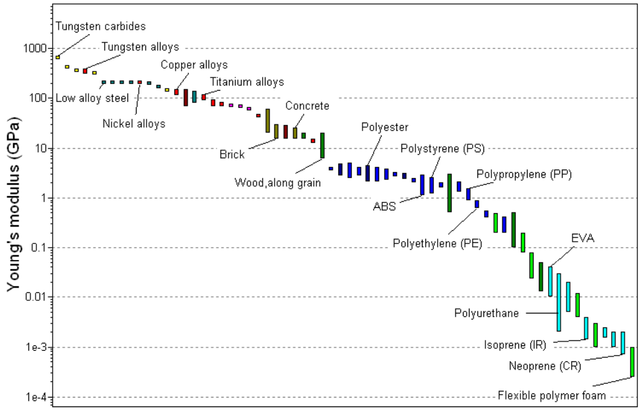
Exercise 4 Making Property Charts



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>)

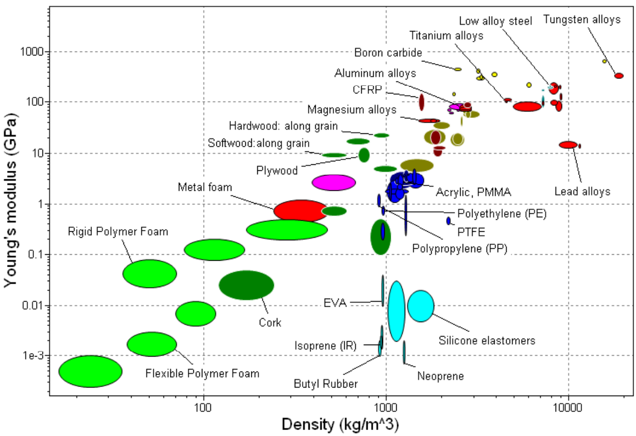


(Click on a few materials to label them; double-click to go to their record in the Data Table)

- 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)

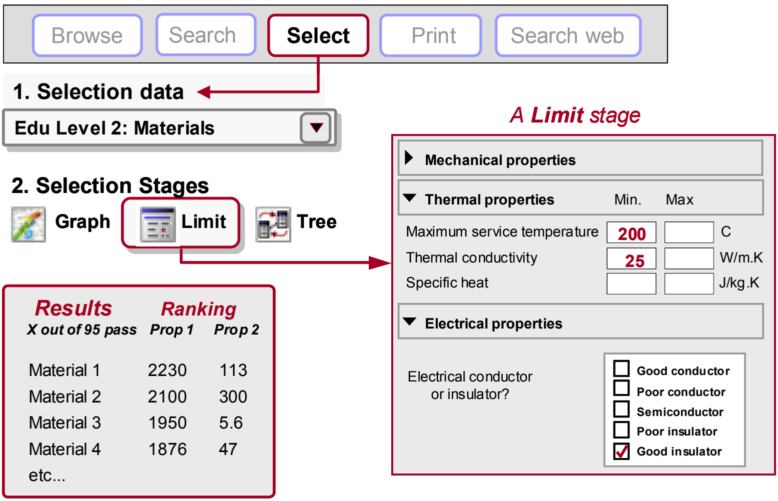


DELETE THE STAGE

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

5.4 Selection using a Limit Stage

Exercise 5 Selection with a Limit Stage



- Find materials with

MAX. SERVICE TEMPERATURE	> 200 °C
THERMAL CONDUCTIVITY	> 25 W/m.k
ELECTRICAL CONDUCTOR OR INSULATOR?	= GOOD INSULATOR

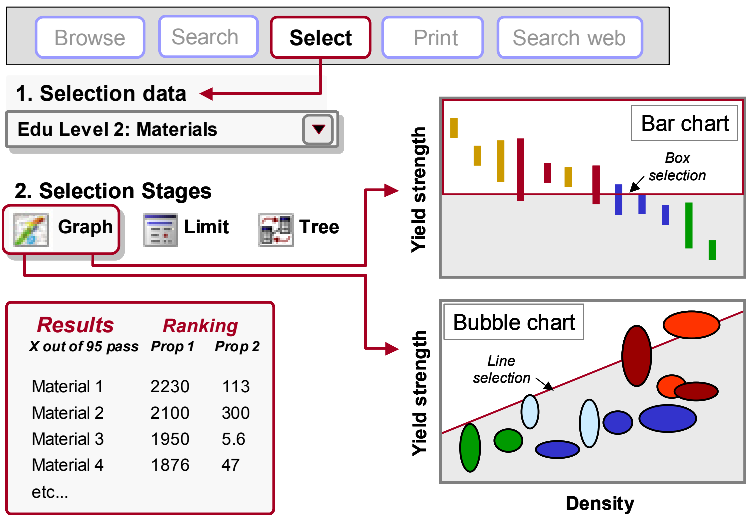
(Enter the limits – minimum or maximum as appropriate – and click "Apply")

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

DELETE THE STAGE

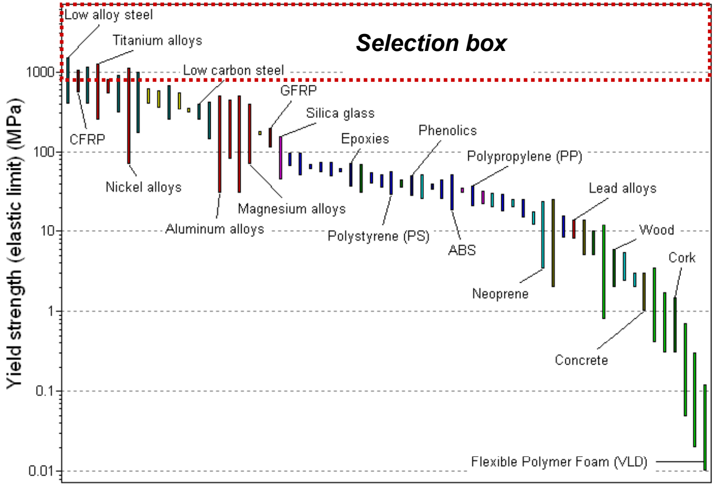
5.5 Graph Selection

Exercise 6 Selection with a Graph Stage



- Make a BAR CHART of YIELD STRENGTH (σ_y) (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

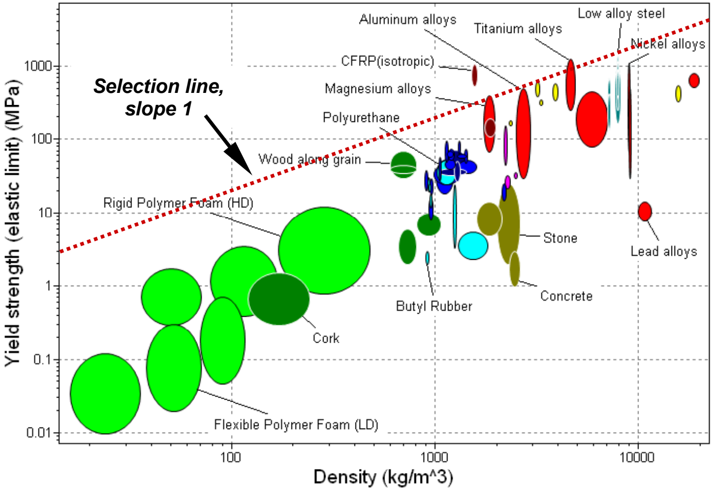
- Replace the BOX with a LINE SELECTION to find materials with high values of the "specific strength", σ_y / ρ

(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.)

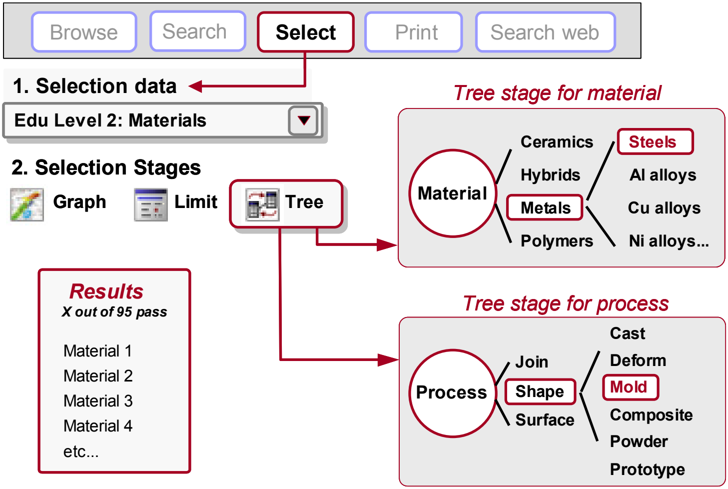


(Results at Level 1 or 2: CFRP (isotropic), Titanium alloys, Magnesium alloys)

DELETE THE STAGE

5.6 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

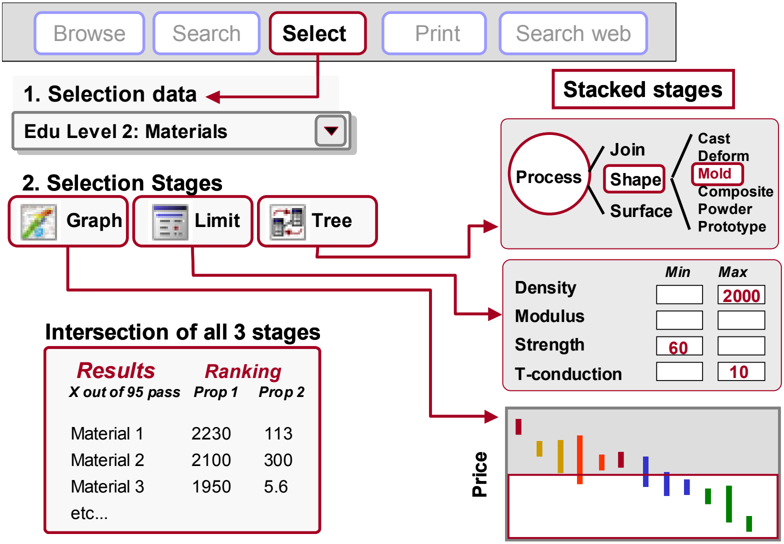
(First change Selection Data to select Processes: LEVEL 2, JOINING PROCESSES)

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

DELETE THE STAGE

5.7 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/m^3
- 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)

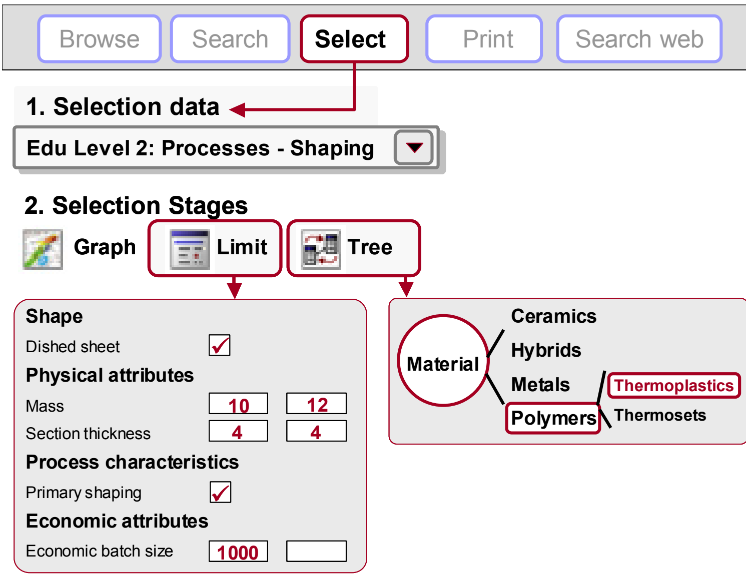
With the PET record open, click on SEARCH WEB

(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

5.8 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)

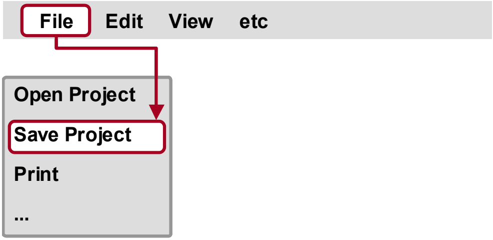
- Made of a THERMOPLASTIC

(a Tree Stage: MaterialUniverse – Polymers and elastomers – Polymers – Thermoplastics)

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

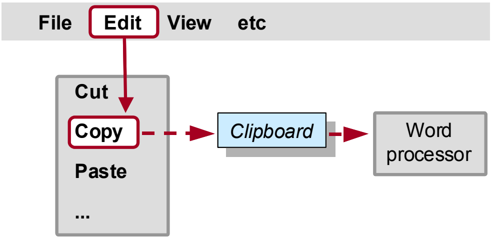
5.9 Saving, Copying, and Report Writing

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.)

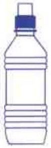
(Warning: There is a problem with WORD 2000: the image in the record is not transferred with the text. The problem is overcome by copying the image and pasting it separately into the WORD document as a DEVICE INDEPENDENT BITMAP.)

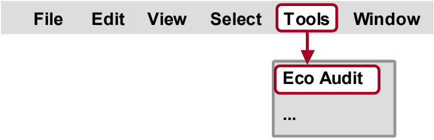
5.10 Eco Audit

The Eco Audit Tool calculates the energy used and CO_2 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.

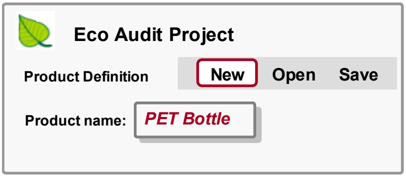
Exercise 13 Eco Audit Project

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.



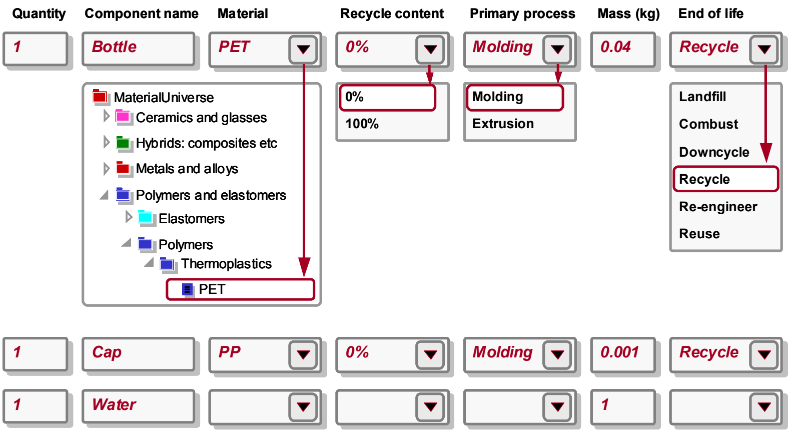


Product Definition



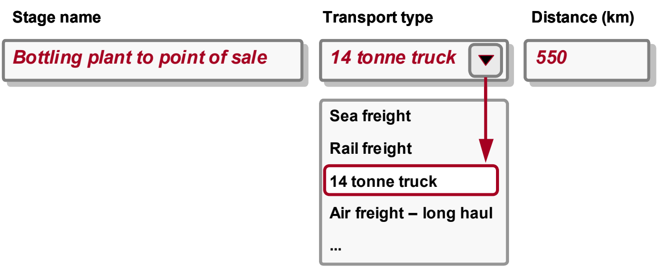
1. Material, manufacture, and end of life

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



2. Transport

Transportation from site of manufacture to point of sale

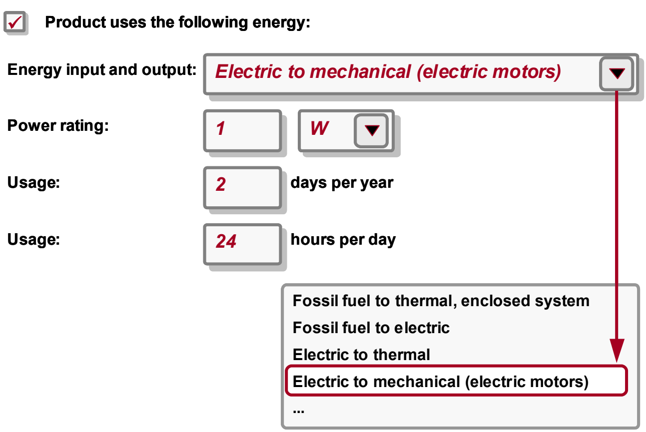


3. Use

Product life and location of use

Static mode

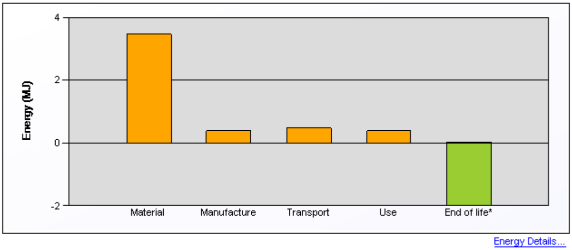
Energy used to refrigerate product at point of sale (average energy required to refrigerate 1 bottle at 4°C = 1 W)

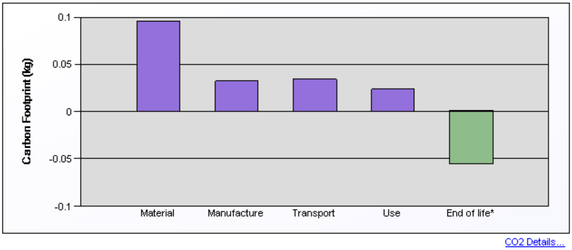


4. Report

View Report

Energy and Carbon Footprint Summary:





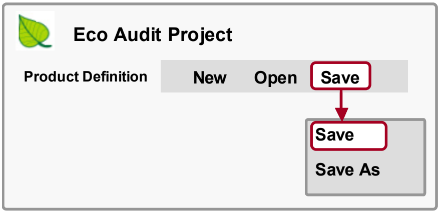
Phase	Energy (MJ)	Energy (%)	CO2 (kg)	CO2 (%)
Material	3.44	72.5	0.0958	50.9
Manufacture	0.402	8.5	0.0322	17.1
Transport	0.487	10.3	0.0344	18.3
Use	0.386	8.1	0.0241	12.8
End of life (collection & sorting)	0.0287	0.6	0.00172	0.9
Total	**4.75**	**100**	**0.188**	**100**
End of life (potential saving/burden)	-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 & CO_2

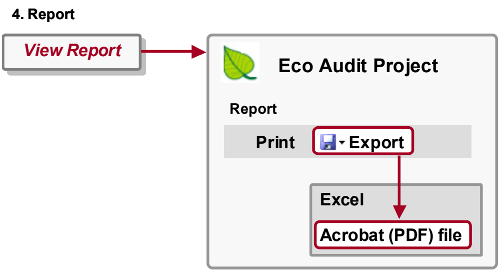
Exercise 14 Saving Eco Audit Product Definition

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

Appendix A Toolbars

CES EduPack

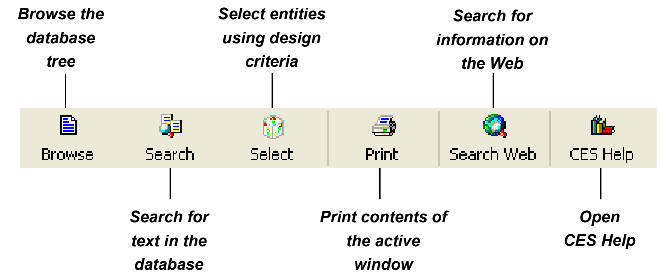


Figure A1. The Standard toolbar in CES EduPack

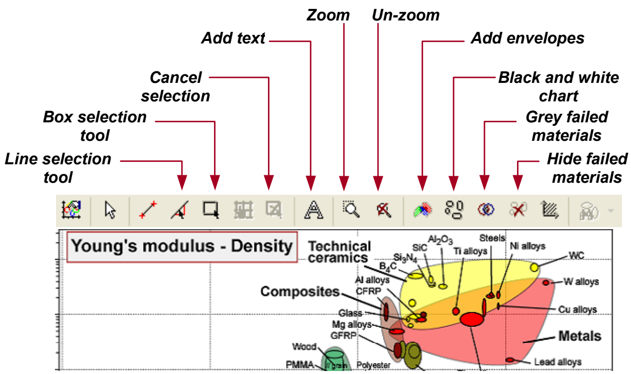


Figure A2. The Graph Stage toolbar in CES EduPack

Appendix B General Information

File Types

Projects

*.gdb	Granta Database file
*.ces	CES EduPack Project file (text)
*.cet	Selection Template file
*.prd	Eco Audit Product Definition file

Currency File

currency.csv

Options for Preferred Currency and Units

	Database Options	
Settings	**Preferred Currency**	**Preferred Unit System**
<**Automatic**>	The Regional Setting from the operating system for currency is used to view data. The regional setting is specified after 'Automatic' e.g. <Automatic - GBP>.	The Regional Setting from the operating system for unit system is used to view data. The regional setting is specified after 'Automatic' e.g. '<Automatic - Metric>'.
<**None**>	Data is displayed using the units stored in the database. Currency data is displayed using the default Currency (see *Database Properties* dialog).	Data is displaying using the units stored in the database. Attribute data is displayed using the unit for the attribute definition (see *Table Properties* dialog).
Named Setting	Named currency is used to display data e.g. 'US Dollar (USD)'.	Named unit system is used to display data e.g. 'Metric'.

Appendix C Conversion of Units

Physical constants and conversion of units

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

Angle, θ	1 rad	57.30°
Density, ρ	1 lb/ft^3	16.03 kg/m^3
Diffusion Coefficient, D	1cm^3/s	1.0 x 10^{-4}m^2/s
Energy, U	See opposite	
Force, F	1 kgf 1 lbf 1 dyne	9.807 N 4.448 N 1.0 x 10^{-5}N
Length, ℓ	1 ft 1 inch 1 Å	304.8 mm 25.40 mm 0.1 nm
Mass, M	1 tonne 1 short ton 1 long ton 1 lb mass	1000 kg 908 kg 1107 kg 0.454 kg
Power, P	See opposite	
Stress, σ	See opposite	
Specific Heat, C_p	1 cal/gal.°C Btu/lb.°F	4.188 kJ/kg.°C 4.187 kg/kg.°C
Stress Intensity, K_{1c}	1 ksi √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 1 Btu/h.ft.°F	418.8 W/m.°C 1.731 W/m.°C
Volume, V	1 Imperial gall 1 US gall	4.546 x 10^{-3}m^3 3.785 x 10^{-3}m^3
Viscosity, η	1 poise 1 lb ft.s	0.1 N.s/m^2 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	1.45×10^2	0.102	10	6.48×10^{-2}
dyn/cm^2	10^{-7}	1	1.45×10^{-5}	1.02×10^{-8}	10^{-6}	6.48×10^{-9}
lb/in^2	6.89×10^{-3}	6.89×10^4	1	703×10^{-4}	6.89×10^{-2}	4.46×10^{-4}
kgf/mm^2	9.81	9.81×10^7	1.42×10^3	1	98.1	63.5×10^{-2}
bar	0.10	10^6	14.48	1.02×10^{-2}	1	6.48×10^{-3}
long ton/ in^2	15.44	1.54×10^8	2.24×10^3	1.54	1.54×10^2	1

Conversion of units – energy*

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

Conversion of units – power*

	kW (kJ/s)	erg/s	hp	ft lbf/s
kW (kJ/s)	1	10^{-10}	1.34	7.38×10^2
erg/s	10^{-10}	1	1.34×10^{-10}	7.38×10^{-8}
hp	7.46×10^{-1}	7.46×10^9	1	15.50×10^2
Ft lbf/s	1.36×10^{-3}	1.36×10^7	1.82×10^{-3}	1

* To convert row unit to column unit, multiply by the number at the column row intersection, thus 1 MPa = 10 bar.