ChE 413
Chemical Engineering Product Design

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EPFL

Lecture 2

Selection of top idea for product design

EPFL

Review: Essential, Desirable and Useful Needs

🔴 Essential needs (must have)

The product must melt snow.

It must be non-corrosive.

It must be applied in short time (e.g., when flight is waiting for takeoff)

🟡 Desirable needs (should have)

The product is non-carcinogenic.

It is non-flammable.

It is easily recycled.

🟢 Useful needs (nice to have)

The product is inexpensive.

It is water miscible.

It is available from multiple suppliers.

It should not have odor.

Converting needs into specifications

Turning vague customer needs into measurable engineering specifications

- Write complete chemical reactions for any steps involved.
- Make central mass and energy balances.
- Estimate any important process rates.

Needs to **Specification** to **Ideas** to **Selection**

Ideas : What different products could satisfy these needs?

Sort the ideas in to a few (3-5) categories to remove redundancy

Selection : Which ideas are most promising?

Manufacture : How can we make the product? What are its final specifications?

Sorting Ideas

Example: Product ideas for a new laundry detergent that can cause less pollution

1. Wash without soap.
2. Throw the clothes away.
3. Use less soap and less water.
4. Use a more effective soap.
5. Add enzymes to detergents.
6. Add dead cells to detergents.
7. Add live cells to detergents.
8. Mop up dirt with particles.
9. Use specific chemical interactions.
10. Improve the washing machine.
11. Recycle the soap.
12. Filter bigger detergent particles.
13. Make larger micelles.
14. Make emulsions out of the soap.
15. Grow microbes on dirty clothes.
16. Attach soap to particles, facilitating recycle.
17. Imitate dry cleaner agents.
18. Use a fine adsorbent.
19. Cook clothes under N_2.
20. Air out clothes as washing substitute.
21. Prevent soiling with antistatic coatings.
22. Wash until semi-clean.
23. Remove odor without removing dirt.
24. Wash with base, converting sweat compounds into soap.
25. Split objectives of clean, color-fast, and odor.
26. Ultrafilter dirty water.
27. Imitate dry cleaning.
28. Get a new dry-cleaning solvent.
29. Make a home dry cleaner which is sealed.
30. Use supercritical CO_2 for dry cleaning.
31. Use another supercritical solvent.
32. Wash with Fuller's Earth.
33. Dry clean with chlorine-free solvents.
34. Grind the clothes up and remake them.
35. Recycle the surfactant using a pH change.
36. Recycle the surfactant exploiting its cloud point.
37. Make a detergent which precipitates on command.
38. A detergent which forms many phases.
39. Wash clothes with dry shampoo.
40. Clean ultrasonically.
41. Shine with a UV light (to sterilize?).
42. Use pressure waves.
43. Cook clothes in high-pressure water.
44. Freeze clothes; shake off dirt.
45. Calcine dry shampoo to make it pure.
46. Adsorb detergent in clay.
47. Use ultrafiltration.
48. Dry cleaning recycle is distillation.
49. Flocculant aid for detergent.

Sorting Ideas

Example: New laundry detergent

- Remove redundancy
- Eliminate irrelevant ideas
- Sort remaining ideas into categories
  - Which categories?
    the material will tell you!
  - Around 4-5 main headings (to start with).
  - 2-3 subheadings as needed.

I. New soap
II. New washer design
III. Improved dry cleaning
IV. New directions

6. Add dead cells to detergents.
7. Add live cells to detergents.

I. New soap (4, 9, 11, 37)
  A. Chemistry
    1. Base (24)
    2. Powders (8, 16, 18, 32, 39, 46)
    3. Biochemical (5, 6, 7, 15)
    4. Emulsions (14)
  B. Easier to recycle (48)
    1. Size (12, 13, 14, 16, 26, 47)
    2. Temperature (36, 38, 45)
    3. pH (35)
    4. Other chemistry (49)

II. New washer design (3, 10)
  A. More mechanical energy
  Ultrasonic and pressure waves (40, 42)
  B. Thermal energy
    1. Cooking (43)
    2. Freezing (44)
  C. Light (41)

III. Improved dry cleaning (1, 27, 28, 48)
  A. Altered equipment
    1. Sealed (29)
    2. Supercritical (30, 31)
  B. New solvents (33)
    1. Gases (19, 20)
    2. Liquids (30)

IV. New directions
  A. Disposable clothing (2, 34)
  B. Soil-resistant clothing (21)
  C. Altered mores (22, 23, 25)

Sorting Ideas

- *Example: Ideas for a pollution-preventing ink*

A printing company uses methylene chloride (CH_2Cl_2) ink for personal checks and for cleaning presses with solvent-soaked rags. While effective, the solvent evaporates in air during cleaning—posing health and environmental risks—and the contaminated rags are now classified as hazardous waste, making disposal costly. The company needs a less harmful, more sustainable alternative. Some ideas for this are below.

Can you Sort these ideas into ~4 categories?

1. Don't use a solvent.
2. Switch solvents.
3. Clean the press with robots.
4. Change the press.
5. Use an electrostatic ink.
6. Use a laser printer instead of the current design.
7. Change ink chemistry.
8. Recycle all of the solvent.
9. Clean the press with a high-pressure spray.
10. Extract the solvent from the rags used to clean the press.
11. Do the whole process in a clean room.
12. Isolate all equipment.
13. Clean the press less often.
14. Clean the press in a fume hood.
15. Print more checks at a time.
16. Mix the current solvent, methylene chloride, with other solvents.
17. Have workers wear a self-contained breathing apparatus.
18. Use a solvent mixture.
19. Use a solvent which dissolves the ink.
20. The solvent in the ink should differ from the cleaning solvent.
21. Use a non-volatile solvent.
22. Use partial cleaning of specific components of the press.
23. Steam clean the press.
24. Clean the press with air.
25. Put the press in a car wash.
26. Clean the press by brushing.
27. Clean the press by burning.
28. Make the lithography more like a jet printer.
29. Don't use checks.
30. Use a disposable press.
31. Use oil to trap the solvent.
32. Make checks by photocopying.

1. Ideas: sorting ideas

- *Example: Ideas for a pollution-preventing ink:*

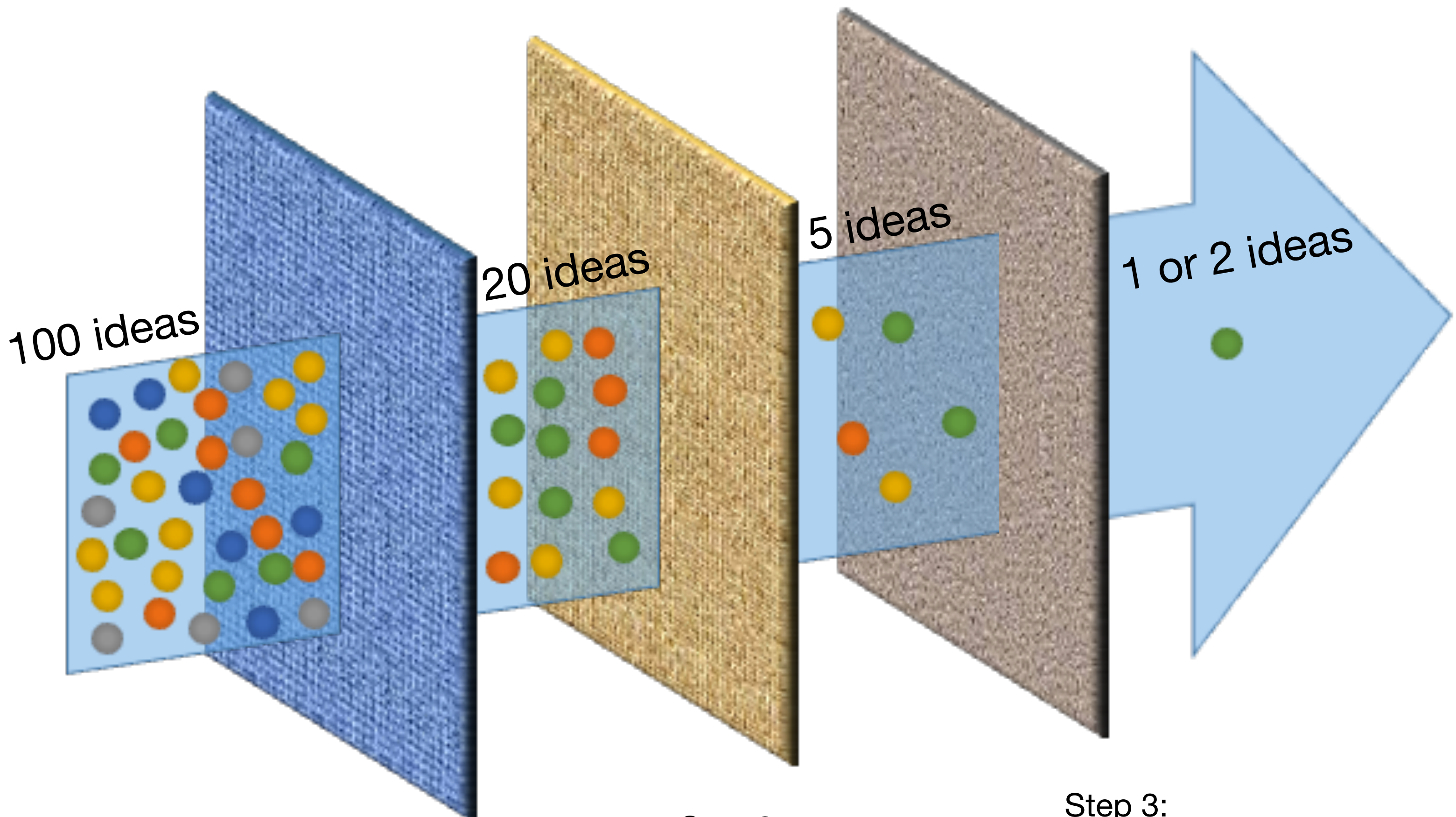
I. *Improve current printing process*

II. *Change the solvent operation*

III. *Solvent-free ink chemistry (1, 7)*

IV. *Don't use checks (29)*

Screening ideas until final selection



Step 1:
Remove redundant, folly, and inconsistent ideas

Step 2:
Evaluate ideas using **selection matrix technique** with approximations

Step 3:
Reapply **selection matrix technique** with detailed calculations and consider risk factors

Screening ideas: Matrix selection technique

First, choose the most important factors by which we want to evaluate the product. These factors will often include at least some of the following (this is just a guide):

(1) ***Scientific maturity*****:** We will prefer designs based on scientific knowledge which we already have and understand.

(2) ***Engineering ease*****:** We will prefer designs which imply straightforward engineering like that already used in established manufacturing.

(3) ***Risk:*** We do not want to take unnecessary chances. At least, we want to know what our chances of success are.

(4) ***Relative cost*****:** We may want a rough estimate of the relative cost of our ideas.

(5) ***Safety*****:** We want to identify which products are inherently safer or more dangerous than our benchmark.

(6) ***Low environmental impact:*** We will tend to choose products which cause less pollution.

Your list may have other important subjective factors from your needs list, e.g., “the product should be quiet” or “the product should be comfortable”. More on this towards the end of the lecture.

Screening ideas: Matrix selection technique

After the key factors are identified, we need to assign weighting factors to them. These weighting factors should be normalized:

$$\sum_{i=0}^{n} \omega_i = 1$$

With these weighting factors in hand, we now evaluate the key ideas in our outline on the basis of some scale. The easiest scale ranges from a low score of one to a high score of ten.

Assign scores in each category from 1 to 10 to the benchmark product/idea first, and then rate the other products relative to this benchmark.

(the *benchmark* can be an existing product with the greatest market share, or it may be what we hope we can make as the best of the existing type of product)

The final score for each product/idea, *j*, is then given by: $Score(j) = \sum_{i=0}^{n} \omega_i s_{ij}$

Deciding weighing for key factors

This is tricky. General recommendation is

1. To link weights to customer needs

Essential → higher weights (e.g., 25-35%).

Desirable → medium (15-25%).

Useful → low (5-15%).

2. Higher weights to deal-breakers

For example, safety, regulatory compliance, environmental impact, depending on product.

3. Make a sensitivity analysis of weighing factors

Change the weighting factors within sensible limits to see if this alters our rank ordering of the ideas.

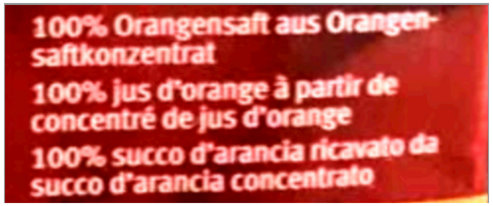
Screening ideas: Matrix selection technique

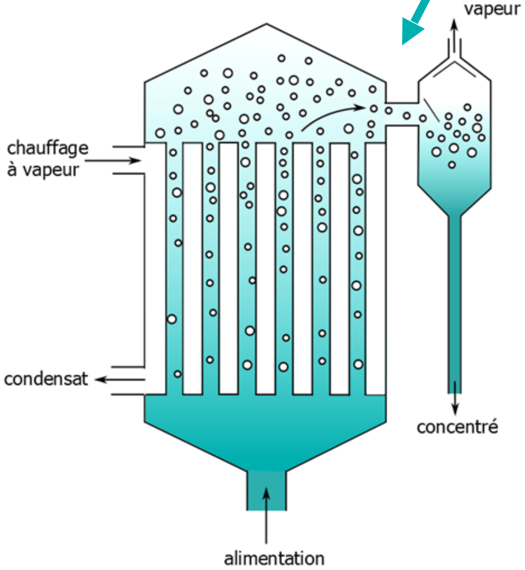
- *Example: concentrating orange juice*

Removal of water (concentration)

Frozen for storage and transport

Adding water and flavors





Vacuum Evaporation

Your company wants to explore alternatives for this process. After the first step of idea screening, two ideas remain:

(1) Reverse osmosis, and

(2) a hybrid technique with some vacuum evaporation and some reverse osmosis.

Screening ideas: Matrix selection technique

- *Example: concentrating orange juice*

Your company wants to explore alternatives for this process. After the first step of idea screening, two ideas remain:

(1) Reverse osmosis, and

(2) a hybrid technique with some vacuum evaporation and some reverse osmosis.

The core design team decide on 4 key factors:
(1) Technical maturity, (2) engineering ease, (3) relative cost, and (4) quality (taste)

High weightage is given to cost and quality which are essential for this product.

Criterion	Weighting factor	Vacuum evaporation	Reverse osmosis	Hybrid
Technical maturity	***0.15***	9	6	7
Engineering ease	***0.15***	9	6	8
Relative cost	***0.35***	3	9	6
Product quality (taste)	***0.35***	5	8	7
		6.5	**7.25**	**7.0**

Screening ideas: Matrix selection technique

This process is imperfect, how can it be improved?

First method: careful choice of the benchmark

Try to choose a different benchmark after a first round of assessments (e.g., highest market share product, best possible product, etc.)

Second method: check your scores against those of other interested experts

Ask lead users of current products, or other experts outside of core group to also make the assessment

Third method: make a sensitivity analysis of the weighting factors

change the weighting factors within sensible limits to see if this alters our rank ordering of the ideas

Screening ideas: Matrix selection technique

This process is imperfect, how can it be improved?

A serious problem: the “1-10” rating scale assumes that each aspect can be scored on a linear scale!

This is approximately true only when the products are similar, changed in only minor ways. The assumption of linearity is generally untrue in three obvious cases:

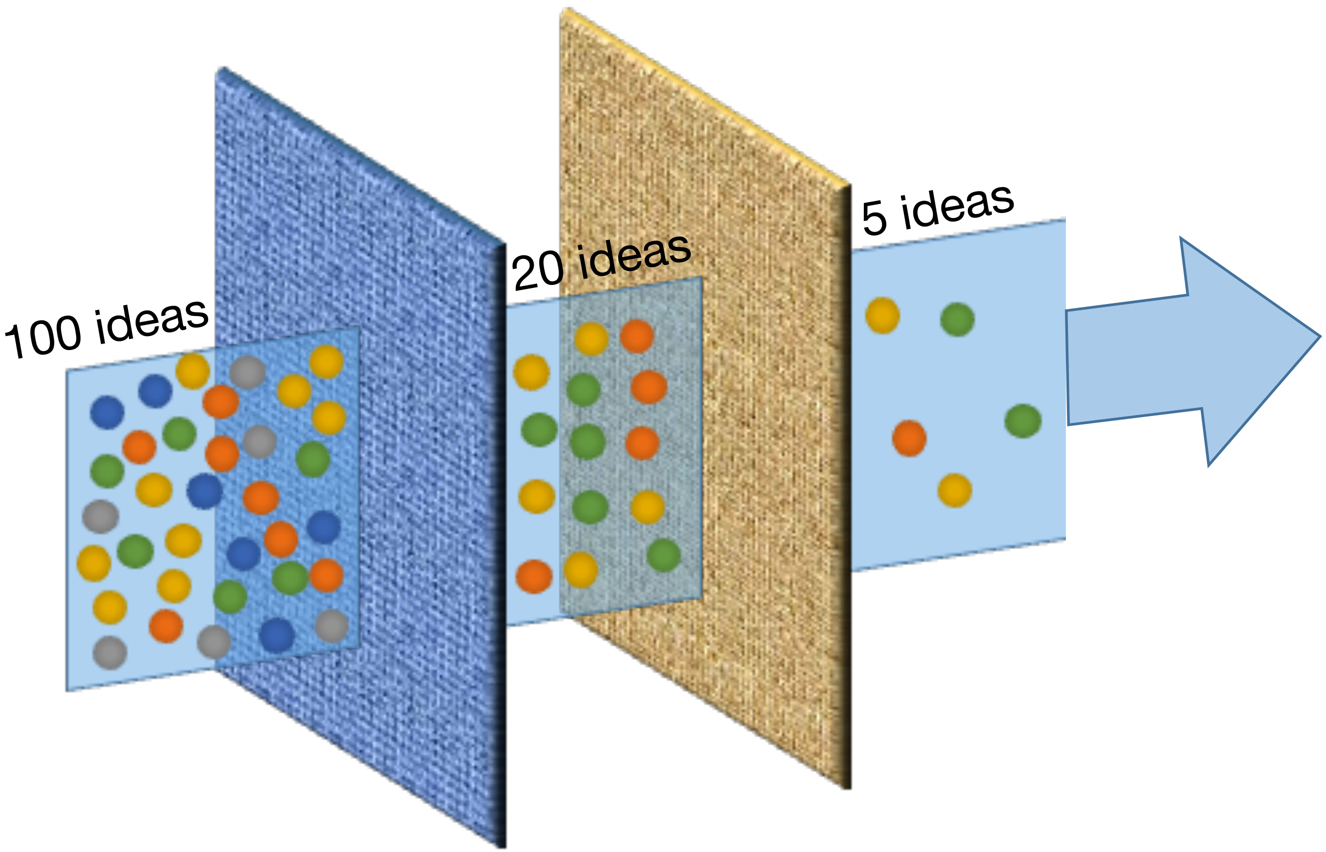
(1) *The criterion is binary*. For a home air purifier, the product might be judged too noisy or quiet, with nothing in between.

(2) *The product will not work.* For an olefin–paraffin separation, the top scoring hollow-fiber membrane product depends on making the membrane selective, which may not be possible.

(3) *The product changes the market.* This implies an innovation which is so good that all other criteria are irrelevant.

Screening ideas: Matrix selection technique

Use the rough matrix screening technique to rank the 20 (or so) ideas and choose the top 5 for further development



These ideas require an in-depth assessment!

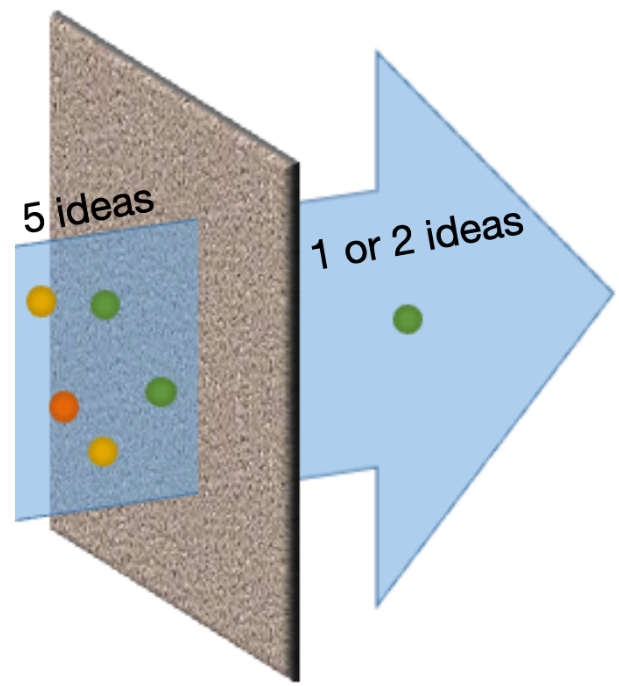
Selecting the top idea

- We now want to select the best ideas for further development. In most cases, we will want to select from five or fewer possibilities, simply because the *amount of work required for further development is substantial*.

- we can identify two separate situations:

    1. we can compare products using only technical criteria drawn from chemistry and engineering relying on thermodynamics and/or kinetic estimations or data.

    2. we must compare products not only on a technical basis, but also using more subjective criteria, like “comfort” and “safety.”



Screening a large list of ideas

- *Example : Ideas for a pollution-preventing ink:*

I. *Improve current printing*
  - A. Change press (4)
    - 1. Isolate press (3, 11, 12, 14, 17)
    - 2. Use laser printer (6)
    - 3. Use photocopying (32)
  - B. Change cleaning
    - 1. Less often (13, 15)
    - 2. Other solvents (9, 23, 24, 25)

II. *Use a new solvent*
  - A. Change CH_2Cl_2 operation
    - 1. Recycle (8)
      - (i) Extract (10)
      - (ii) Spin dry (new)
    - 2. Burn (27)
    - 3. Freeze (new)
  - B. Replacement of CH_2Cl_2 (2, 20)
    - 1. Non-volatile solvent (21)
    - 2. Oil as solvent (31)
    - 3. Solvent mixtures (16, 18)

III. *Solvent-free ink chemistry (1, 7)*
  - A. Electrostatic ink (5)
  - B. “Solvent which dissolves ink” (19)

IV. *Don’t use checks (29)*

e.g. after Step 1 and 2, only these ideas remain

Selecting the top idea – example 1

- Using thermodynamic principles

- *Example : Ideas for a pollution-preventing ink:*

II. *Use a new solvent*

B. Replacement of CH_2Cl_2 (2, 20)

1. Non-volatile solvent (21)
2. Oil as solvent (31)
3. Solvent mixtures (16, 18)

We clearly need a solvent with suitable properties to dissolve the pigment (or dye)

➢ Solubility parameters!

$$\mu_2 = \mu_2^0 + RT \ln x_2 + \omega x_1^2$$

μ_2 is the chemical potential of the product solute (dye)
ω is an activity parameter
x_1 and x_2 are the mole fractions of the solvent and the product

$$\omega = \overline{V}_2 \left(\delta_1 - \delta_2\right)^2$$

$\overline{V}_2$ is the molar volume of the product solute
δ_i are solubility parameters

Selecting the top idea – example 1

- *Example (from lecture 1): Ideas for a pollution-preventing ink:*

Formula	Substance	V (cm^3/mol)	δ (cal$^{1/2}$/cm$^{3/2}$)
	HALOGENATED SOLVENTS		
C_6F_{14}	Perfluoro-*n*-hexane	205	5.9
C_7F_{16}	Perfluoro-*n*-heptane	226	6.0
C_6F_{12}	Perfluorocyclohexane	170	6.1
$(C_4F_9)_3N$	Perfluoro tributylamine	360	5.9
$C_2Cl_3F_3$	1,1,2-Trichloro,1,2,2- trifluoroethane	120	7.1
CH_2Cl_2	Methylene chloride	64	9.8
$CHCl_3$	Chloroform	81	9.2
CCl_4	Carbon tetrachloride	97	8.6
$CHBr_3$	Bromoform	88	10.5
CH_3I	Methyl iodide	63	9.9
CH_2I_2	Methylene iodide	81	11.8
C_2H_5Cl	Ethyl chloride	74	8.3
C_2H_5Br	Ethyl bromide	75	8.9
C_2H_5I	Ethyl iodide	81	9.4
$C_2H_4Cl_2$	1,2-Dichloroethane (ethylene chloride)	79	9.9
$C_2H_4Cl_2$	1,1-Dichloroethane (ethylidene chloride)	85	9.1
$C_2H_4Br_2$	1,2-Dibromoethane	90	10.2
$C_2H_3Cl_3$	1,1,1-Trichloroethane	100	8.5
	ALIPHATIC HYDROCARBONS		
C_5H_{12}	*n*-Pentane	116	7.1
	2-Methylbutane (isopentane)	117	6.8
	2,2-Dimethyl propane (neopentane)	122	6.2
C_6H_{14}	*n*-Hexane	132	7.3
C_7H_{16}	*n*-Heptane	148	7.4
C_8H_{18}	*n*-Octane	164	7.5
	2,2,4-Trimethylpentane	166	6.9
$C_{16}H_{34}$	*n*-Hexadecane	294	8.0
C_6H_{12}	Cylohexane	109	8.2
C_7H_{14}	Methylcyclohexane	128	7.8
C_6H_{12}	l-Hexene	126	7.3
C_8H_{16}	l-Octene	158	7.6
C_6H_{10}	1,5-Hexadiene	118	7.7

Formula	Substance	V (cm^3/mol)	δ (cal$^{1/2}$/cm$^{3/2}$)
	AROMATIC HYDROCARBONS		
C_6H_6	Benzene	89	9.2
C_7H_8	Toluene	107	8.9
C_8H_{10}	Ethylbenzene	123	9.9
	o-Xylene	121	9.0
	m-Xylene	123	8.8
	p-Xylene	124	8.8
C_8H_8	Styrene	116	9.3
$C_{10}H_8$	Naphthalene	123	9.9
	INORGANICS		
Br_2	Bromine	51	11.5
I_2	Iodine	59	14.1
S_8	Sulfur	135	12.4
P_4	Phosphorus	70	13.1
CCl_4	Carbon tetrachloride	97	8.6
$SiCl_4$	Silicon tetrachloride	115	7.6
$SnCl_4$	Stannic chloride	118	8.7
WF_6	Tungsten hexafluoride	88	8.0
$Si(CH_3)_4$	Silicon tetramethyl	136	6.2

Toxicity ranking

Ethylbenzene < Naphthalene < Methylene chloride < Methyl iodide

Selecting the top idea – example 2

- Using Kinetics arguments to refine and select.
  - Rates of the chemical reactions by which raw materials become the desired products (implies experimental data or some rough estimation)
  - Mass transfer rates
  - Heat transfer rates

Example: A cup of coffee at the perfect temperature

Your product should be an improved coffee cup that keeps the coffee at the ideal drinking temperature (51-53°C) for a longer time. The cup should have a volume of 200 cm^3 with a total surface area (top, bottom and sides) of 200 cm^2.

Generating ideas, sorting them and your initial matrix evaluation leaves three top ideas:

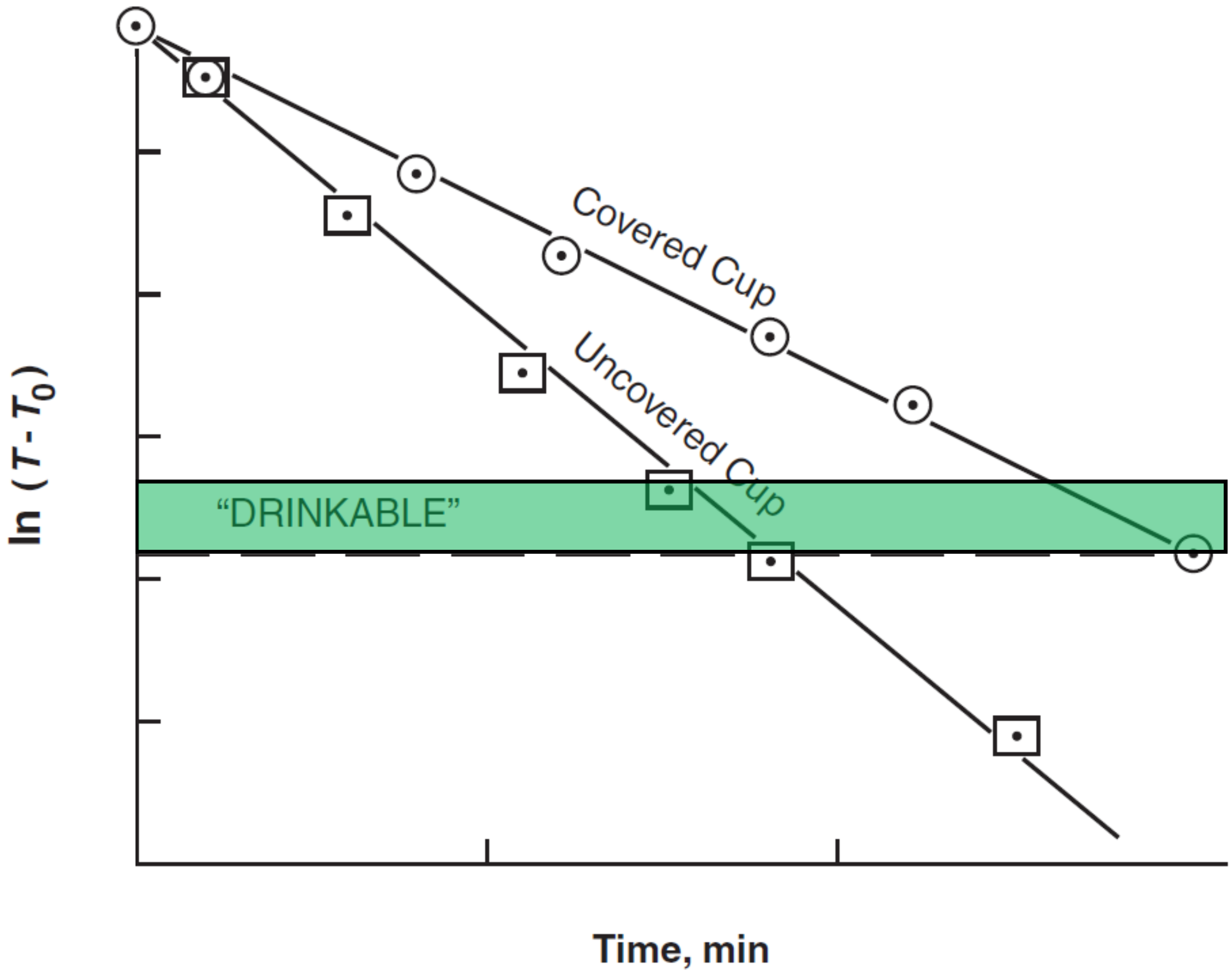
1. A cup with improved insulation
2. A cup with its own heating system (thermostat)
3. A cup with a thermal reservoir which melts at around 51°C

Using kinetic arguments, which ideas merit further development?

Selecting the top idea – example 2

Example: A cup of coffee at the perfect temperature

A simple experiment generates this data:



Selecting the top idea – example 2

Example: A cup of coffee at the perfect temperature

The unsteady state energy balance (assuming the coffee is always at a uniform temperature) gives:

$$\frac{d}{dt}\left(V\rho c_p T\right) = UA_s\left(T_0 - T\right)$$

Integrating this equation (assuming $V\rho c_p$ are constant) :

$$\ln\frac{T(t) - T_0}{T_i - T_0} = -\frac{UA_s}{V\rho c_p}t \quad \Rightarrow \quad \frac{T(t) - T_0}{T_i - T_0} = e^{-t/\tau} \qquad \tau = \frac{V\rho c_p}{UA_s}$$

Uncovered cup: $U = 57\ W/m^2K$ $\quad \tau = 24\ min$

Covered cup: $U = 19\ W/m^2K$ $\quad \tau = 72\ min$

So covering cup seems to work well (idea #1)

Selecting the top idea – example 2

Example: A cup of coffee at the perfect temperature

Lets evaluate heated uncovered cup when cup starts to heat when the temperature of coffee drops to around 51 °C.

$$Q = UA_s(T_0 - T) = 57 \times 0.02(51 - 20) = 35\ W$$

One “C cell” battery provides about 1-2 W, so, it will not work with batteries. We will need wired connection for this.

Selecting the top idea – example 2

Example: A cup of coffee at the perfect temperature

Lets evaluate thermal reservoir idea where the reservoir melts at temperature around 51 °C.

What substance could be used?

Hydrocarbon wax (e.g., pentacosane, $C_{25}H_{52}$)

T_m = 53°C, ΔH_{fus} = 220 kJ/kg

Alternatively, we can also use Bee's wax

T_m = 59°C, ΔH_{fus} = 180 kJ/kg

How much reservoir would we need?

$$m\Delta H_{fus} = UA_s(T_0 - T)t$$

For 20 min of temperature stabilization in a covered cup:

$$m = \frac{UA_s(T_0 - T)}{\Delta H_{fus}} t$$

$$= \frac{17\text{x}\,0.02\,(53 - 20)}{220000}\text{x}1200$$

$$m = 0.06\ \text{kg}$$

Selecting the top idea – example 3

Example: Water purification for the traveler: People travelling into wilderness areas require drinking water. Often, water sources like streams and ponds are contaminated by viruses and bacteria.

Product specification:

We need at least 2-3 liters of water per day (even for light activity)

Lower limit of purification flow rate: 1.4 mL min^{-1}

Fast acting (all water is prepared in 30 min): 67 mL min^{-1}

Other specifications:

- Has a capacity of 2000 L (before failure)
- Removes 99.9% of bacteria and protozoa,
- Costs less than $100,
- Has an operating range of 0–40 °C and 0.3 to 1 atm,
- Improves odor/flavor

Evaluating a promising idea : *Fontus*

FONTUS

HOME PRODUCTS ABOUT CONTACT IMPRESS

IF YOU'RE AN ADVENTURER, YOU KNOW THE ANXIETY THAT COMES WITH RUNNING OUT OF WATER IN THE MIDDLE OF A TOUR – THE LAST THING YOU WANT IS DEHYDRATION WHEN YOU'RE MILES AWAY FROM HOME.

FONTUS WILL SET YOUR MIND AT EASE!

we make water out of light and air.

Forget about worrying to find the next gas station or river to fill up your water bottle.
Just enjoy the road and let

your adventures come true.

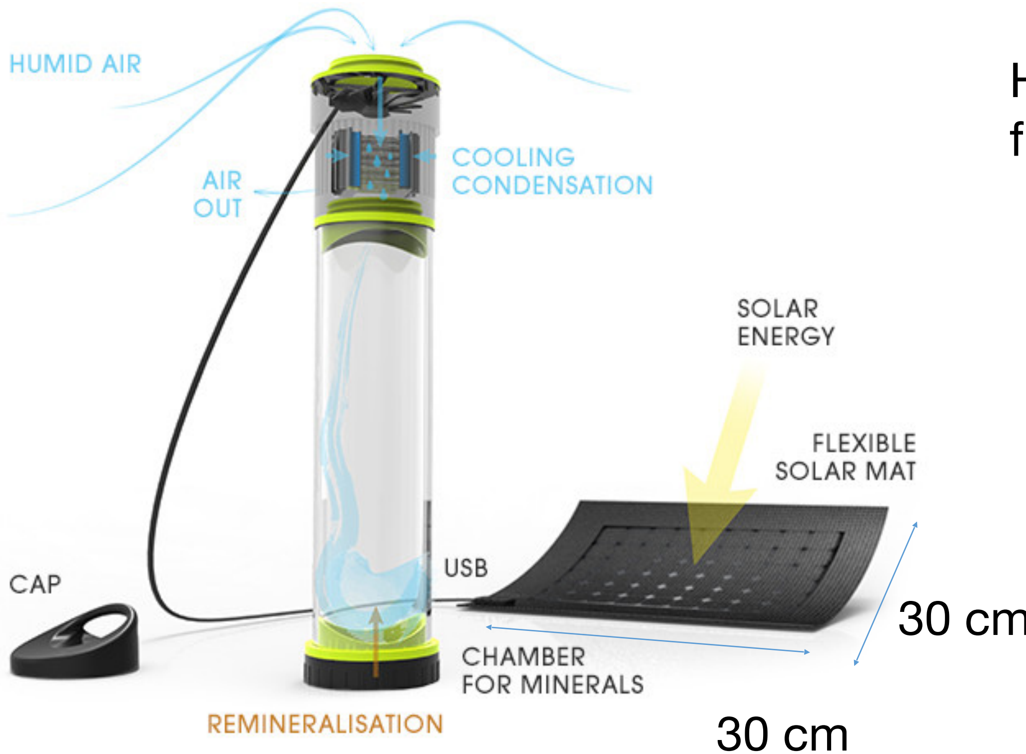
The Fontus bottles are a water bottle family that are capable of filling themselves up.

they literally never run dry!

These devices were designed to capture the moisture contained in the air, condense it and store it as safe drinking water.

Could this product satisfy this specification:
Lower limit of purification flow rate: 1.4 mL min^{-1}

Is Fontus reasonable for our specifications?



How much energy is available from the solar panel?

$0.09\ m^2$ (area, 30 cm x 30 cm)

Solar energy (max), $1000\ W\ m^{-2}$

Solar conversion efficiency, 20%

$0.09*0.20*1000 = 18\ W = 18\ J/s$

Enthalpy of condensation = – Enthalpy of vaporization

At 18 °C ΔH^{vap} for water is 2460 kJ/kg = 2460 kJ per liter of liquid water

Thus even if the condenser operated at 100% efficiency:

$0.018\ kJ/s\ /(2460\ kJ/L\ H_2O) = 7.31 \times 10^{-6}\ L\ H_2O\ /\ s = 0.44\ mL\ H_2O/minute$

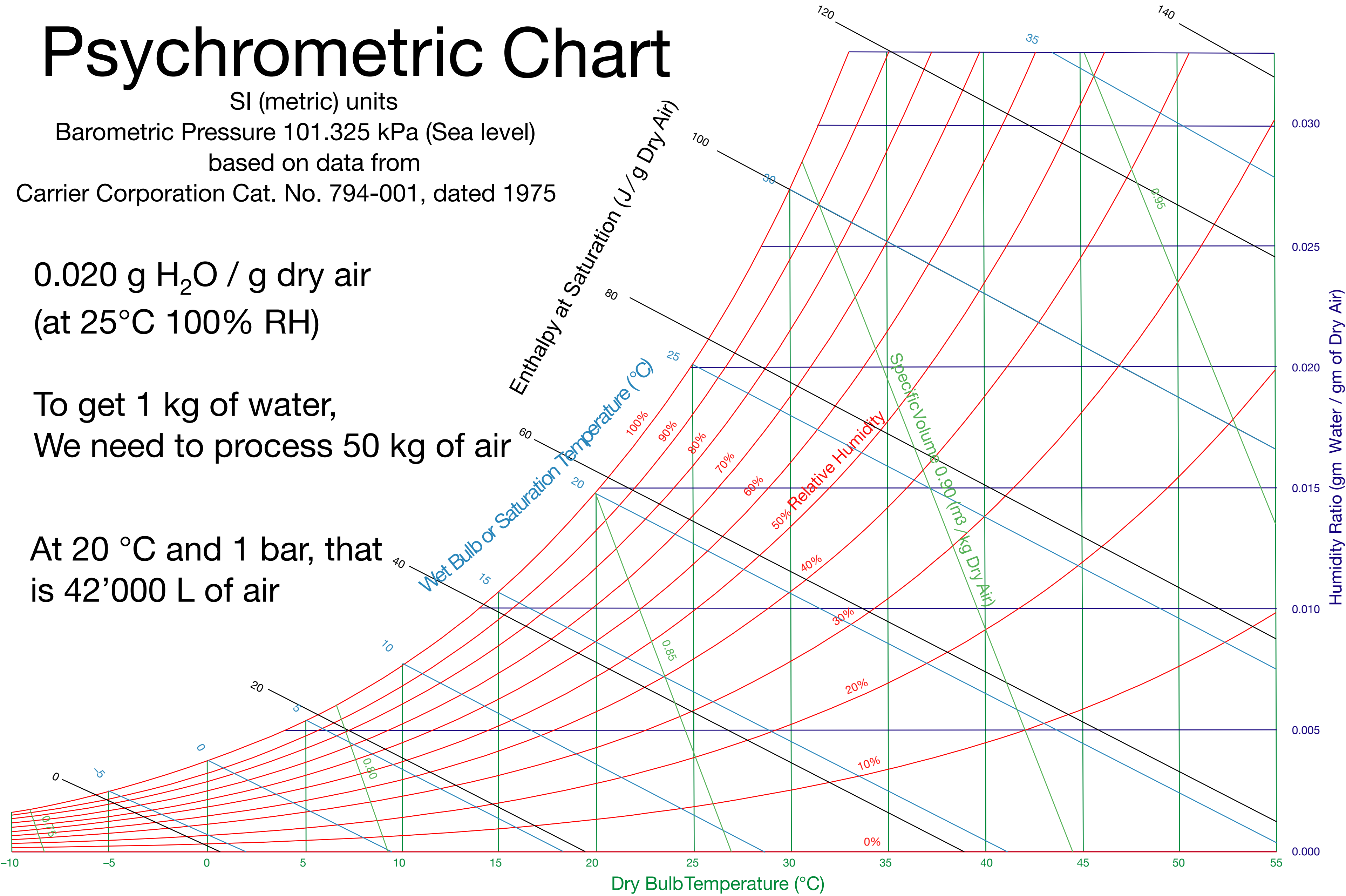
Psychrometric Chart

SI (metric) units
Barometric Pressure 101.325 kPa (Sea level)
based on data from
Carrier Corporation Cat. No. 794-001, dated 1975

0.020 g H_2O / g dry air
(at 25°C 100% RH)

To get 1 kg of water,
We need to process 50 kg of air

At 20 °C and 1 bar, that
is 42’000 L of air



Selecting the top idea – Subjective criteria

In several cases, subjective decision making will be necessary

- Sometimes, we need to compare "apples with oranges," i.e. make decisions between objectives but different criteria. For example, balancing cost against performance (new exhaust catalyst which will improve air quality but which will also be expensive).
- We may have to evaluate genuinely subjective issues – what do people like, how much do they care, etc.

When to make subjective judgments:

- Categories of criteria for making a selection matrix can be subjective.
- Beyond above, because comparing vague subjective choices is challenging, we will postpone them as long as we can.
- Finally, we can decide based on our core customers (e.g., aspirational users vs. need-based users).

How to make subjective judgments:

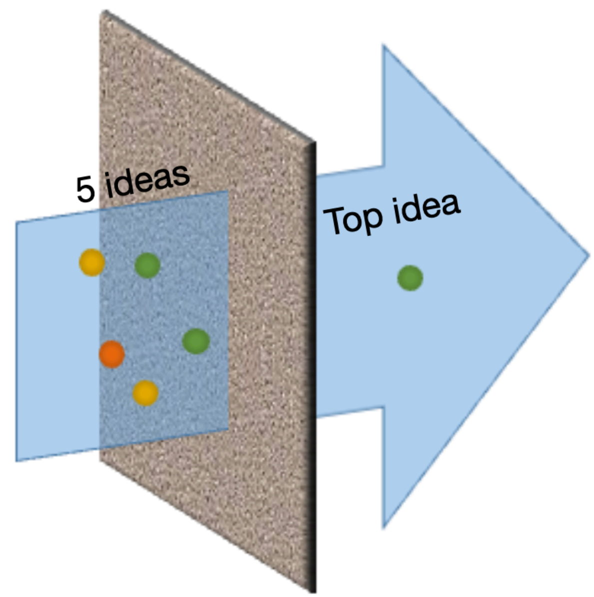
- Use independent criteria (e.g., ski being light and strong).
- Avoid repetition of criteria (or overlap) to prevent imbalances in scores.
- Use a complete list of criteria as much as possible.

Selecting the top idea – compare again!

Perform the **selection matrix technique again** using the detailed thermodynamic and kinetic calculations and the refined subjective criteria and also considering the **RISKS – (next lecture)**

Why we use selection matrices: Although selection matrices are far from perfect, there are several advantages in using this systematic approach

(1) The selection stage is the point of no return. Costs escalate rapidly once the best one or two ideas are chosen, as an extensive program of testing, prototyping, and market research becomes necessary. Simultaneously, this will be the point of fierce management review, so we must be able to justify our choice to those outside the core team. The decision matrix forces you to stop and consider seriously each stage of your decision making process . It also ensures that you thoroughly document your deliberations.



(2) The need to weight and score each idea forces the core team both to efficiently pool its resources and to search for external input. The need for justification of criteria, sensitivity tests, etc. will make the consulting of experts and customers inevitable. The use of numerical scoring tends to make it harder for a single personality to dominate the core team's deliberations.

(3) The selection stage is the last point at which we can sensibly combine aspects of different ideas to produce an improved product. The separate scoring of the different criteria ensures that the strengths and weaknesses of each idea will be very obvious and opportunities for enhancements by combination should stand out. Good but imperfect ideas may be combined into improved models.

Review of a simple 4-step process for product design

1. Needs : Identify what needs the product should satisfy

2. Ideas : What different products could satisfy these needs?

3. Selection : Which ideas are most promising?

- Use a selection matrix technique to compare products
- Use a details from chemical thermodynamics
- Assess the risks involved with each approach (next time)

4. Manufacture : How can we make the product? What are its final specifications?

Exercise problem: Cigarette butts

Tobacco does not only have a negative impact on the health of individuals consuming it but also threatens the health of the environment. More than 750,000 metric tons of cigarette butts are estimated to make their way into the environment every year. Cigarette and e-cigarette waste pollute water, air, and soil with residual nicotine, toxic chemicals, and heavy metals. Additionally, cigarette filters, commonly made out of cellulose acetate, take more than 10 years to decompose, meaning cigarette butts will stay around as unsightly litter for a long time.

Imagine you are part of a team including members of the local government and product development engineers from an environmental organization and your team is asked to develop a solution to this problem. During this process, you have already gathered many ideas in the first brainstorming step. With this many ideas suggested, 30 of which are listed in the table below, it is now your task to sort and categorize these ideas.

1.	Biodegradable (natural or synthetic) cigarettes that degrade faster than normal cigarettes
2.	Make cigarettes that do not contain toxic substances
3.	Cigarettes that can be eaten by birds
4.	Build a special car with a brush in the front bumper to clean the cigarettes
5.	Have a deposit system for cigarette butts
6.	Destroy the cigarettes with radiation
7.	Cigarettes that make a sound when thrown on the ground (social pressure)
8.	Make a license for cigarette smokers which proves that they know how to dispose of them
9.	Cigarettes that are edible after smoking
10.	Reward people that collect a lot of cigarette butts and return them
11.	Create cigarettes that are slowly decomposed by air
12.	Cigarette buds that degrade with UV light
13.	Have cigarette trash cans everywhere
14.	Only sell filter-free pipes and tobacco
15.	Make cigarettes really disgusting so no one buys them
16.	Make cleaning cigarette butts in the public a civil service task
17.	Expensive fines for those who do not dispose of the cigarette butts correctly
18.	Mandatory license to buy/smoke cigarettes
19.	Create shops that would pay to bring back finished cigarettes
20.	Have tracking chips in every cigarette butt to make it possible to find them
21.	Add a reminder on the packaging to not throw cigarettes into nature
22.	Use robots to clean the cigarette butts
23.	Flammable cigarettes that could be burnt easily once they are thrown on the streets
24.	Develop bacteria that are present everywhere and can decompose cigarettes
25.	Employ people whose only job is cleaning away cigarettes
26.	Reusable cigarettes
27.	Ban cigarettes
28.	Increase the price of cigarettes (e.g. by high taxes)
29.	Prison sentence for throwing away cigarettes
30.	Make cigarettes without filters

Exercise solution: Cigarette butts

General Comment: These are suggested example answers to the exercises. There are other ways to think about and tackle the different problems and there is always space for discussion on how different aspects are weighted or sorted.

Note: The criteria used for grouping are not important here. What is important is that the ideas can be grouped into different categories. Using sub-categories can be helpful.

I. Modify cigarettes
   - A. Improved disposal
     - i. Faster decomposition (1, 11, 12)
     - ii. Edible cigarettes (3, 9)
     - iii. Flammable cigarettes (23)
   - B. Reduce toxicity (2)
   - C. Eliminate filters (14, 30)
   - D. Make cigarettes less popular by changing taste (15)
   - E. Reusable cigarettes (26)

II. Improved cleaning
   - A. Specialized cleaning equipment (4, 22)
   - B. Accelerated decomposition (6, 24)
   - C. Government-funded cleaning (25)
   - D. Trackable cigarette waste (20)

III. Policy and social methods
   - A. Policy regulations (5, 13, 27)
   - B. Health education (8, 18, 21)
   - C. Social pressure (7)
   - D. Penalties for negative behavior (16, 17, 29)
   - E. Rewards for positive behavior (10, 19)

Exercise problem: Decaffeination of Coffee Beans

After fossil crude oil, coffee is the second-most traded commodity in the world. The rise of the general popularity of coffee started in the early 20th century when coffee consumption first surged as the industry's technology advanced and the availability of the products increased. A second wave of increase in popularity came in the 70s, when, through popular coffee brands and franchises, coffee started to be seen more as an experience than just as a commodity.

In the early 2000s, which marked the beginning of today's specialty coffee culture, an even greater interest in complex, lighter roast coffees, single-origin coffee beans, and general techniques of coffee preparation in general. With the increase in popularity of coffee not just for its caffeine content, but also just as a potentially delicious beverage, there is also an increase in the popularity of decaffeinated coffee.

Imagine you are hired by a specialty coffee roastery that wants to expand its product portfolio to include craft decaffeinated coffee. They are interested in finding the most promising method for decaffeination of their artisan coffee beans, mainly having a customer base in mind that is interested in the highest quality, locally-roasted coffees. For this, you are considering four methods for coffee decaffeination listed below.

(1)	Ethyl acetate method
(2)	Swiss water method
(3)	Supercritical CO_2 method
(4)	Methylene chloride method

In order to assess which method would be the best for producing decaffeinated coffee for a small local company, your team decided to use the matrix selection technique to assess these ideas. **Propose the criteria and weighting factors (<u>with justification for the criteria and weighting</u>) for the matrix. Then perform the matrix analysis (justification for the scoring is <u>not required</u>). Finally, based on your matrix analysis, give a conclusion about which method is the most promising.**

Exercise solution: Cigarette butts

General Comment: These are suggested example answers to the exercises. There are other ways to think about and tackle the different problems and there is always space for discussion on how different aspects are weighted or sorted.

Note: The criteria used for grouping are not important here. What is important is that the ideas can be grouped into different categories. Using sub-categories can be helpful.

I. Modify cigarettes
   A. Improved disposal
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