



NAMINDO EDITION

Principles and Practice of Design for Sustainability

Twelve principles of green design, with case studies

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01

The idea

Design for sustainability is everyone's job

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Systems design for sustainability

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Design of sustainable systems is a multidisciplinary field involving fundamental sciences, business, law, arts and engineering.

The fields that feed it

Green chemistry

Green engineering

Environmental design

Sustainability

Industrial ecology

Natural capitalism

The role of system design and engineering



Remediate and conserve capital

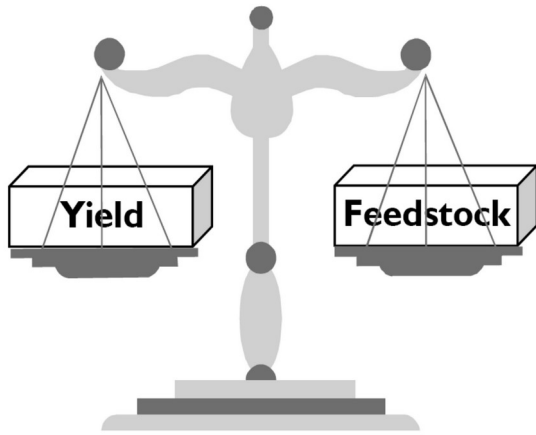
- Natural capital: air, water and soil
- Human capital
- Manufactured capital
- Financial capital
- Community capital



Design, develop and implement

- Industrial processes
- Educational processes
- Business processes
- Research designs
- Classroom and laboratory

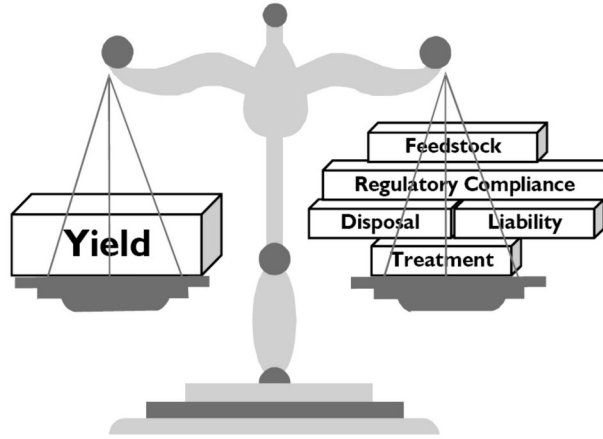
Balance in design: from economics to cradle to cradle



PAST

Only economics

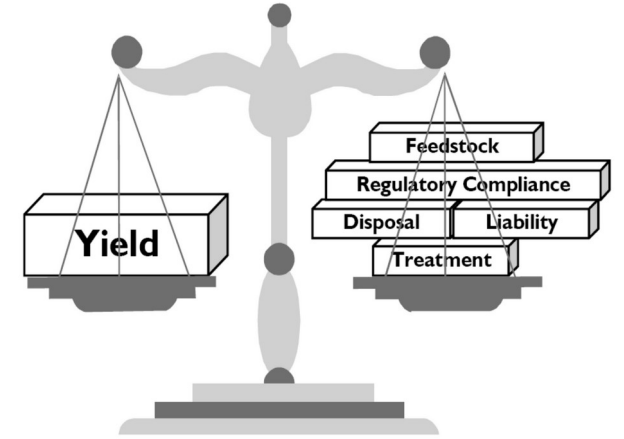
Yield is weighed against feedstock.
Nothing else counts.



PRESENT

Life cycle: cradle to grave

Feedstock now sits with regulatory compliance, disposal, liability and treatment.



FUTURE

Life cycle: cradle to cradle

Add end-of-life use, lifetime ecology, environment and total resource footprints, and afterlife renewal and regeneration.

Green engineering defined

- 1 Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.
- 2 Conserve and improve natural ecosystems while protecting human health and well-being.
- 3 Use life-cycle thinking in all engineering activities.
- 4 Make all material and energy inputs and outputs as inherently safe and benign as possible.
- 5 Minimise depletion of natural resources.
- 6 Strive to prevent waste.
- 7 Develop and apply engineering solutions with care for local geography, aspirations and cultures.
- 8 Go beyond current or dominant technologies: improve, innovate and invent to achieve sustainability.
- 9 Actively engage communities and stakeholders in developing engineering solutions.

02

Twelve principles

Each principle, with a case study from building and the home

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The twelve principles at a glance

1

**Inherent rather than
circumstantial**

2

**Prevention rather than
treatment**

3

Design for separation

4

Maximise efficiency

5

**Output-pulled rather than
input-pushed**

6

Conserve complexity

7

**Durability rather than
immortality**

8

Meet need, not excess

9

Minimise material diversity

10

**Integrate material and
energy flows**

11

**Design for commercial
afterlife**

12

**Renewable rather than
depleting**

Inherent rather than circumstantial

1

PRINCIPLE

“

Designers should evaluate the inherent nature of the selected material and energy inputs to ensure that they are as benign as possible as a first step toward a sustainable product, process or system.

Design inherent to location



North-facing windows

Full double glazing on the north side to take the winter sun.



Insulation to the south

Extra insulation on the south-facing walls.



East-to-west ventilation

Cross ventilation along the east-west axis.

1

Principle 1

**Inherent rather than
circumstantial**

Prevention rather than treatment

2

PRINCIPLE

“

It is better to prevent waste than to treat or clean up waste after it is formed.

- Large sums go on waste treatment, disposal and remediation. In the past these were often left out of plant cost. Full cost accounting (life-cycle analysis) brings them in.
- Treatment usually needs extra unit operations.
- The industrial mindset is changing.

Non-toxic finishes, inherent colours



Coloured glazed roof tiles

The colour is in the tile, so the roof needs no paint.



Natural brick walls

Wall surfaces left as natural brick.



Natural oiled wood

Wall surfaces finished in natural oiled timber.



Principle 2

**Prevention rather than
treatment**

Design for separation

3

PRINCIPLE

“

Many traditional methods for separation require large amounts of hazardous solvents, whereas others consume large quantities of energy as heat or pressure. Appropriate upfront designs permit the self-separation of products using intrinsic physical and chemical properties.

Décor woodwork with wooden nails



Hardwood pegs as nails

A special drill sets hardwood inserts as joiner nails.



100% recyclable

With no metal in it, the woodwork becomes fully recyclable.



Principle 3

Design for separation

Maximise efficiency

4

PRINCIPLE

“

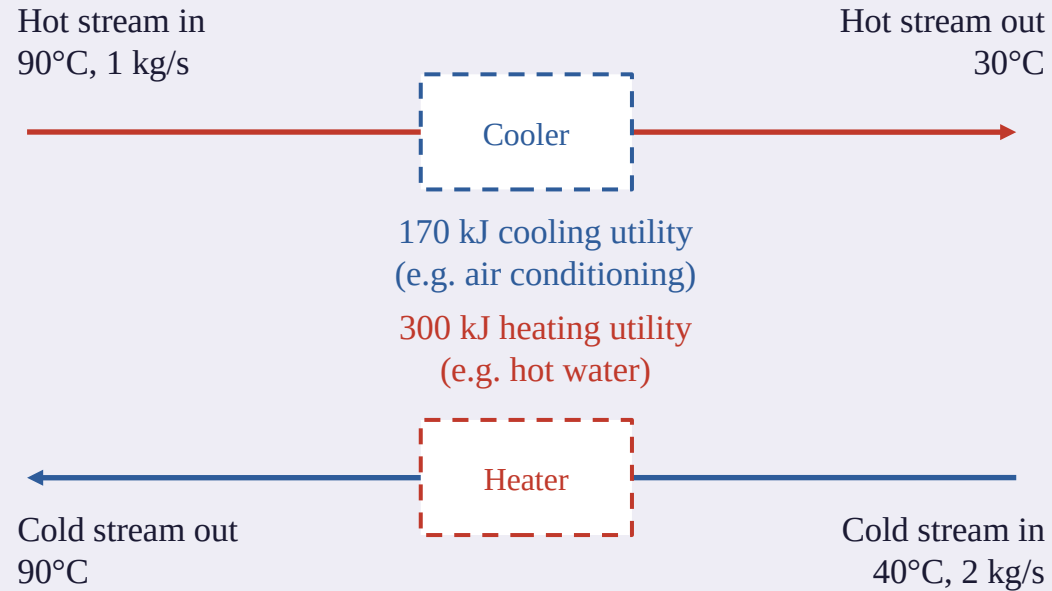
Products, processes and systems should be designed to maximise mass, energy, space and time efficiency.

- Mass and energy efficiency is standard engineering optimisation.
- Related to principle 8: no overcapacity.
- Related to principle 10: mass and energy integration.

Heat and cooling integration

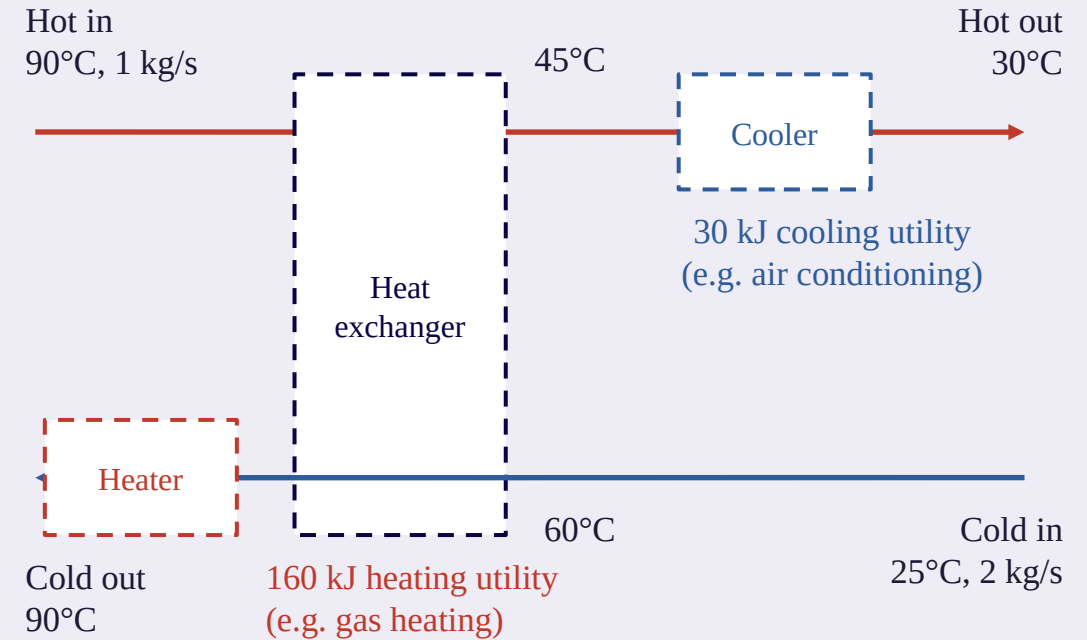
Without integration

Each stream gets its own utility



With integration

The hot stream warms the cold stream first



Example after Allen and Shonnard (A&S), 2002. Figures as given in the original talk.

Output-pulled rather than input-pushed

5

PRINCIPLE

“

Approaching design through Le Chatelier's principle minimises the amount of resources consumed to transform inputs into desired outputs.

Economical to build and economical to run



Low cost to build

Keep the building cost low, so homes are built because people need them.



Low energy to live in

The house should use little energy while we live in it.



Practical, not a status symbol

An eco-house should not be a fad or bragging rights. It should be useful.



Principle 5

**Output-pulled rather than
input-pushed**

Conserve complexity

6

PRINCIPLE

“

Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse or beneficial disposition.

- More focused on products than processes.
- Less complicated products are easier to recycle.
- If a product must be complex, design it to be reused.

Simple, quick construction



15 kinds of fastener

A prefabricated timber house used 15 types of fastener: needless complexity.



Cut to 5

Reduced to 5 types of nails, bolts and screws.



Easier at end of life

The house is easier to take apart and recycle.



Principle 6

Conserve complexity

Durability rather than immortality



“

Design products with a targeted lifetime to avoid immortality of undesirable materials in the environment. Balance this with products durable enough to withstand anticipated operating conditions.

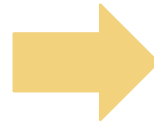
Refrigerant CFCs: stable was the problem



Why CFCs were chosen



- Non-flammable
- Non-toxic
- Inexpensive
- Effective
- Stable



What went wrong

- Long-lived, so they migrate to the upper atmosphere.
- There, UV light breaks them apart, which depletes the ozone layer.

Meet need, not excess

8

PRINCIPLE

“

Design for unnecessary capacity or capability, such as “one size fits all” solutions, should be considered a design flaw.

- Do not over-design. Keep contingency factors low.
- Extra size means wasted material and energy.

The modular house



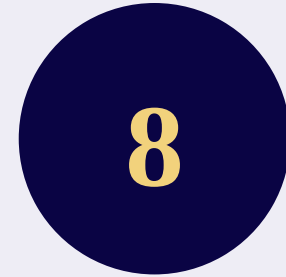
Start with four bedrooms

Master, children and guest.



Shrink to two later

Take two bedrooms down when the nest is empty.



Principle 8

Meet need, not excess

Minimise material diversity

9

PRINCIPLE

“

Options for final disposition are increased through upfront designs that minimise material diversity yet accomplish the needed functions.

Use wood or composites



Wood

Wood can be used in many ways.



Recyclable plastic composites

They can serve as flooring, structural members and walls.

9

Principle 9

Minimise material diversity

Integrate material and energy flows

10

PRINCIPLE

“

Design of products, processes and systems must include integration and interconnectivity with available energy and materials flows.

- Make use of what is already available.
- Heat integration: see case study 4.

Make ash bricks on site



Coal power in the Latrobe Valley

In the Latrobe Valley of Victoria, a lot of coal is burnt to make power.



Ash is a waste

The ash left over is waste, and hard to use.



Cold-set bricks

A study found a way to mix the ash with very little cement and mould cold-setting bricks.



Quiet walls

The bricks suit construction and make excellent noise-absorbing walls.



Principle 10

Integrate material and energy flows

Design for commercial afterlife

11

PRINCIPLE

“

To reduce waste, components that remain functional and valuable can be recovered for reuse or reconfiguration.

Plastic lumber and reuse



Take equipment apart

Disassemble equipment so its components can be reused.



Plastic lumber

Make “plastic lumber” from used polymer packaging: reuse at the molecular level.



MDF from wood chaff

Use wood chaff to make MDF boards.



Principle 11

Design for commercial afterlife

Renewable rather than depleting

12

PRINCIPLE

“

Material and energy inputs should be renewable rather than depleting.

- Do not deplete natural resources.
- Keep resources there for future generations.
- Energy: solar, wind, hydroelectric, geothermal, biomass and hydrogen (fuel cells).

Plantation timber houses



Old factories into homes

Convert old factories to housing.



Plantation timber

Build houses from plantation timber.



Principle 12

Renewable rather than depleting

03

A worked example: carpet tiles

All twelve principles applied to one redesigned product

Redesigned carpet tiles

2.6 billion kg

of carpet went to US landfills each year,
as cited in the original talk.



**2003 Green Chemistry Challenge
winner**

- Redesigned for recycling.
- Pile of nylon 6 or nylon 6,6.
- PVC plastisol backing replaced with branched LDPE.
- Both the nylon and the backing can be taken apart and recycled.

The twelve principles, applied: 1 to 6

1 Inherently non-hazardous

Coal fly ash replaces virgin calcium carbonate filler. Mostly branched LDPE replaces PVC and phthalate plasticiser; the metallocene catalyst is key. A less toxic flame retardant, not Sb_2O_3 .

2 Prevent waste

Recycle everything: the nylon pile and the LDPE backing.

3 Minimise mass and energy use

Low-energy mechanical separation and size reduction for recycling. Nylon goes for depolymerisation (Honeywell).

4 Efficiency

Extrusion coating uses less energy than radiant gas fusing, and avoids VOCs. New tiles are 40% lighter, which helps shipping. Telescoping boxes.

5 Output-pulled, not input-pushed

On replacement, the customer gets an assured return on the afterlife material.

6 Embedded complexity is an investment

One material cannot meet the performance needs. Separating and recycling is the next best thing.

The twelve principles, applied: 7 to 12

7 Durability, not immortality

The materials are long-lived, but they have a recycling afterlife. Can they be recycled forever? No.

8 No unnecessary capacity

It is a replacement market, so demand is easy to predict.

9 Minimise material diversity

Performance criteria limit this. The same backing serves several products.

10 Mass and energy integration

Plant cooling water runs in a closed loop. Recycling the polymers closes the loop.

11 Design for commercial afterlife

Recycling takes care of the afterlife.

12 Renewable rather than depleting

The materials and energy used are not renewable, but the company has invested in a wind farm.

References

- 1 **Allen and Rosselot**, *Pollution Prevention for Chemical Processes*, 1997, John Wiley & Sons
- 2 **Allen and Shonnard**, *Green Engineering*, 2002, Prentice-Hall
- 3 **Seader and Henley**, *Separation Process Principles*, 1998, John Wiley & Sons
- 4 **Segars et al.**, *Environmental Science & Technology*, 2003, 37, 5269

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Thank you

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