IChemE Institution of Chemical Engineers

Education Subject Group Webinar

CHEMICAL ENGINEERING IN AN UNSUSTAINABLE WORLD: OBLIGATIONS AND OPPORTUNITIES

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Human society faces an uncertain future!

We are exceeding the capacity of the planet to provide many of the resources we use and to accommodate our emissions, while many of the planet's inhabitants cannot meet even their most basic needs.

RAE, 2005

"I don't think the American public has gripped in its gut what could happen. We're looking at a scenario where there's no more agriculture in California. I don't actually see how they can keep their cities going"

Chu, 2009

Human society faces an uncertain future!

"The consumption driven modern way-of-life continues unabated in all fronts, everywhere."

Pereira, 2009

"perfect storm" of "increased demand for energy, increased demand for food, increased demand for water ..and climate change."

Beddington, 2009

There is 'a significant risk that many of the trends will accelerate'

Copenhagen, 2009

The problem with ongoing unsustainability

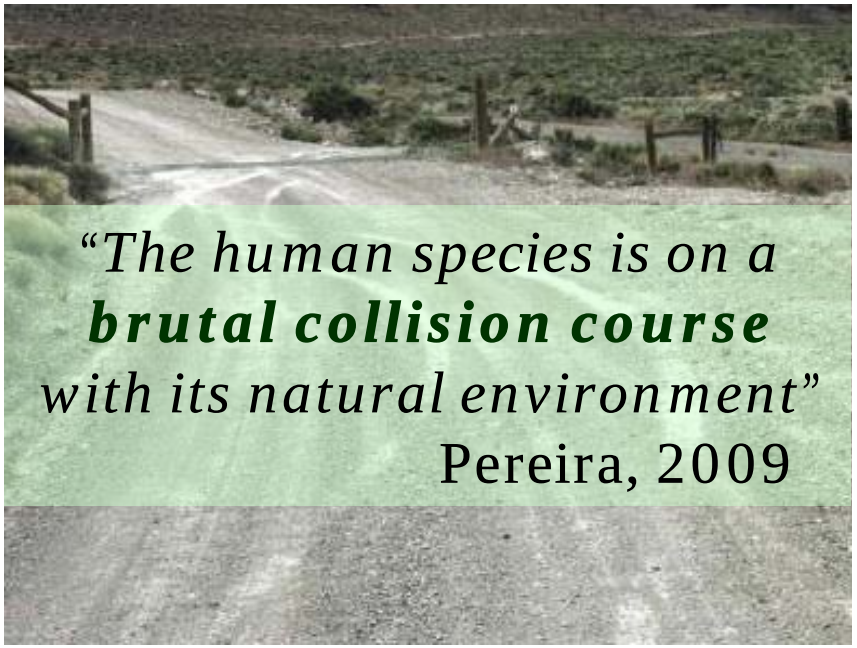
severe weather events

water shortages

drought

food shortages

famine



accelerating climate change

sea level rise

flooding

habitat extinction

species extinction

is that, like vehicle with ongoing lack of control, it is destined to eventually crash! ...unless a brake is applied in timely fashion.

The **dominant social paradigm** dictates that we organise society in a way which envisages our natural environment as something that is to be **exploited** for our own isolated (short to medium term) ends.

Dewberry and de Barros, 2009

A longstanding and historical paradigm…

"All the animals on land and all the birds of heaven, they are placed in your hands. Be fruitful then and multiply, teem over the earth and subdue it*!"*

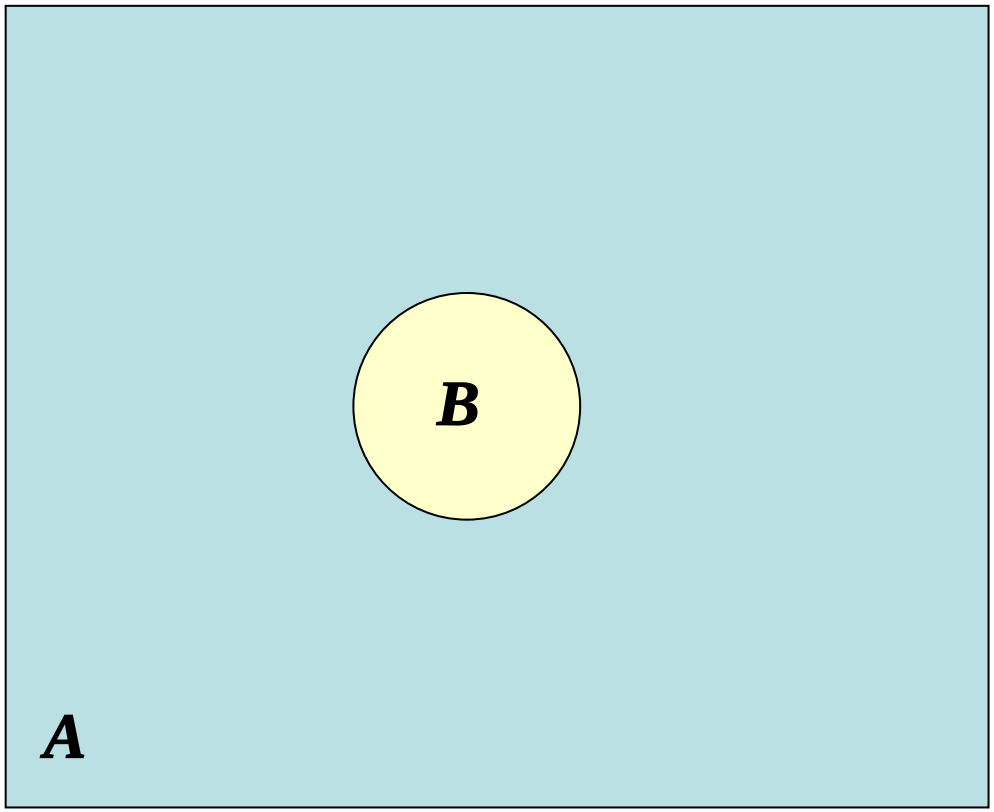
Genesis, 9, 1-2,7

"It is possible to reach a kind of knowledge which will be of the utmost use to men ..and thereby make ourselves the lords and possessors of nature."

René Descartes, 1638

Definition of Engineering: "The art of directing the great sources of power in nature for the use and convenience of man."

Thomas Tredgold, 1828



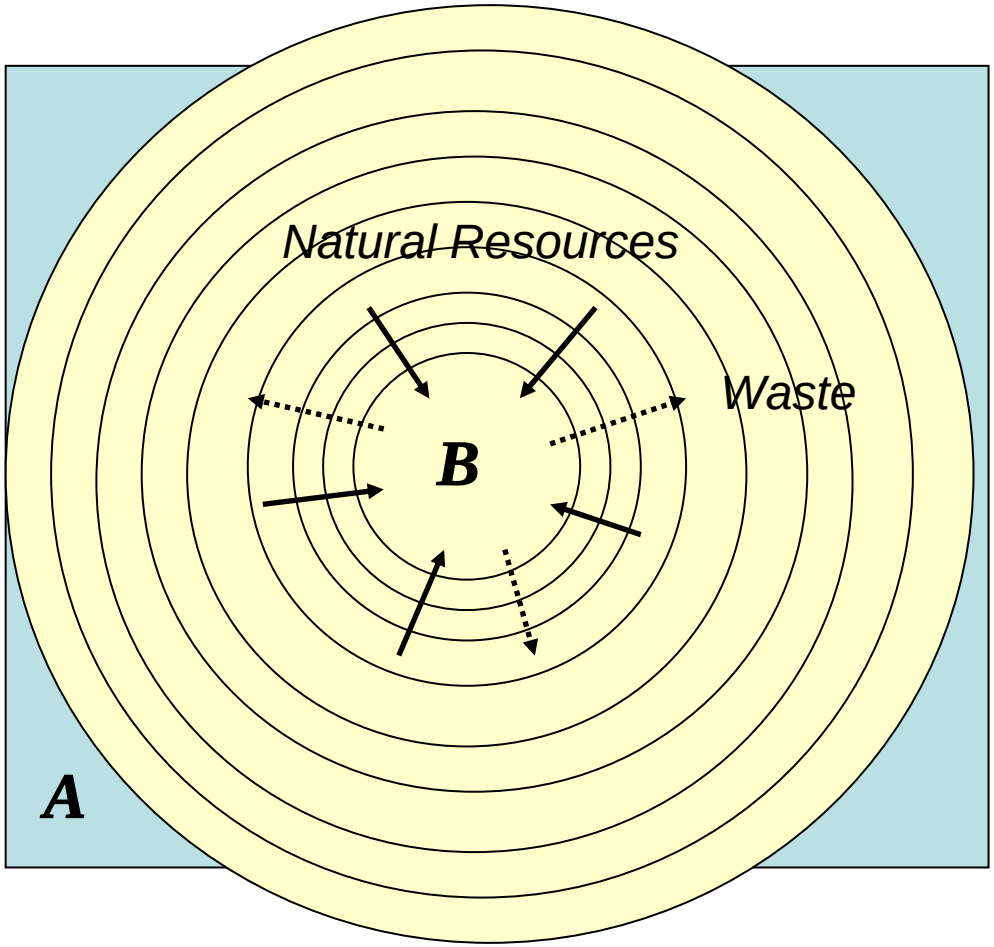
Which is which?

The economy

&

The environment?

..what next??



A) The environment

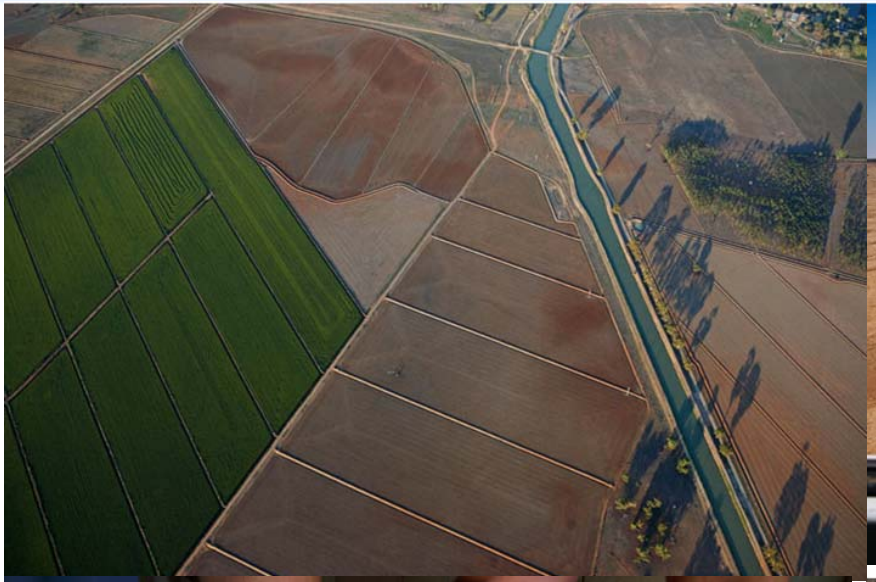
B) The economy

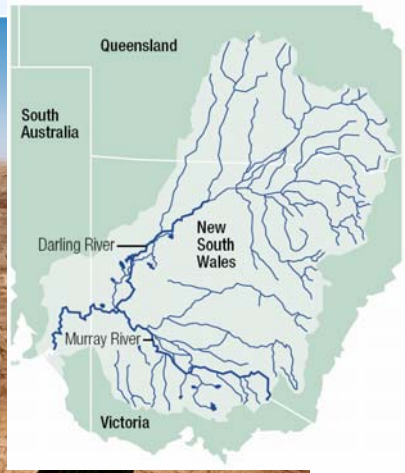
Material and energy transfer between economy & environment

Easter Island

17th Century construction & population boom

..18th Century collapse of society & population; 10,000 → 750 (est.) & long term subsistence living

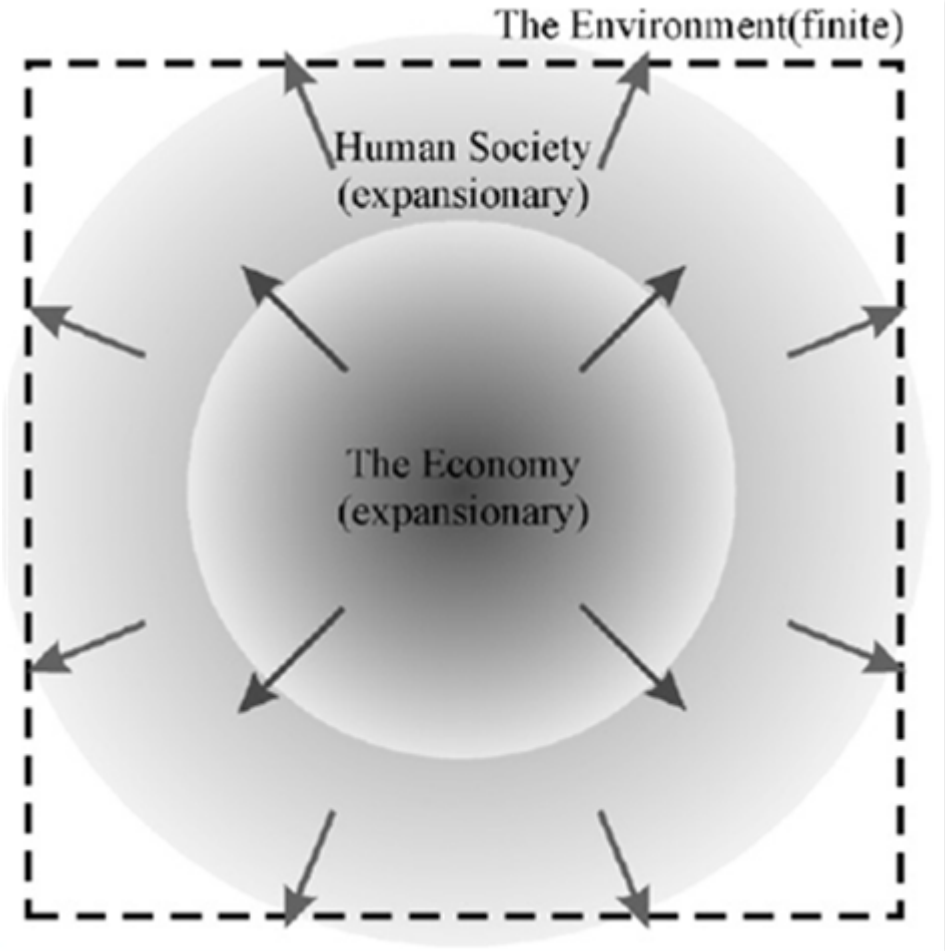




National Geographic, 2009

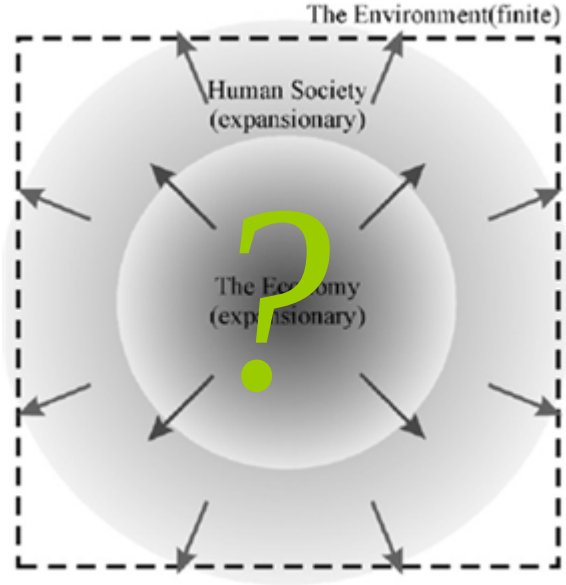
THE 'THREE SPHERES MODEL':

ECONOMY ⊂ SOCIETY ⊂ THE ENVIRONMENT



"Our collective cultural memory of the usefulness and usability of natural and manmade resources is ***independent*** *of any sense of* ***limits.****"*

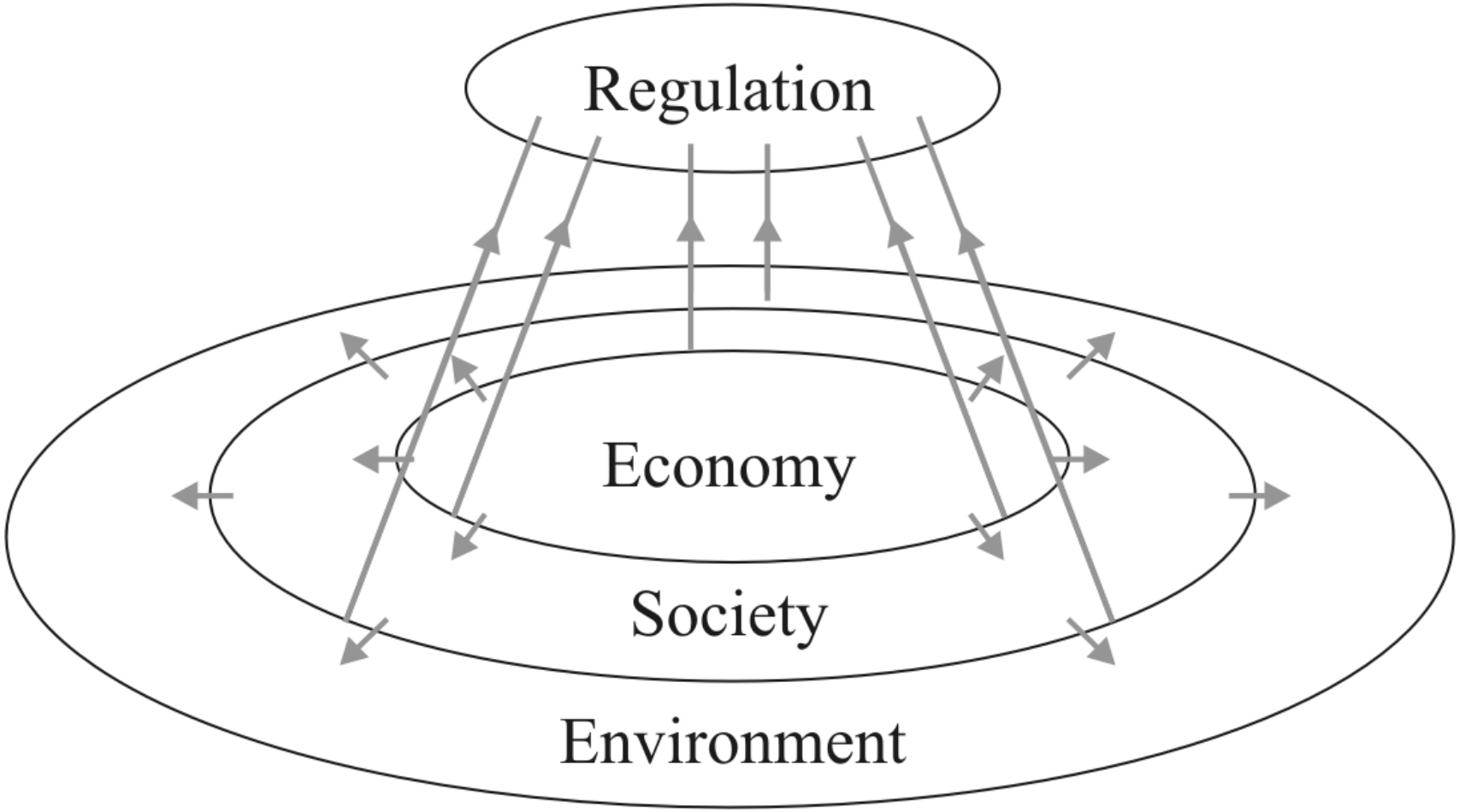
(Dewberry and de Barros, 2009)



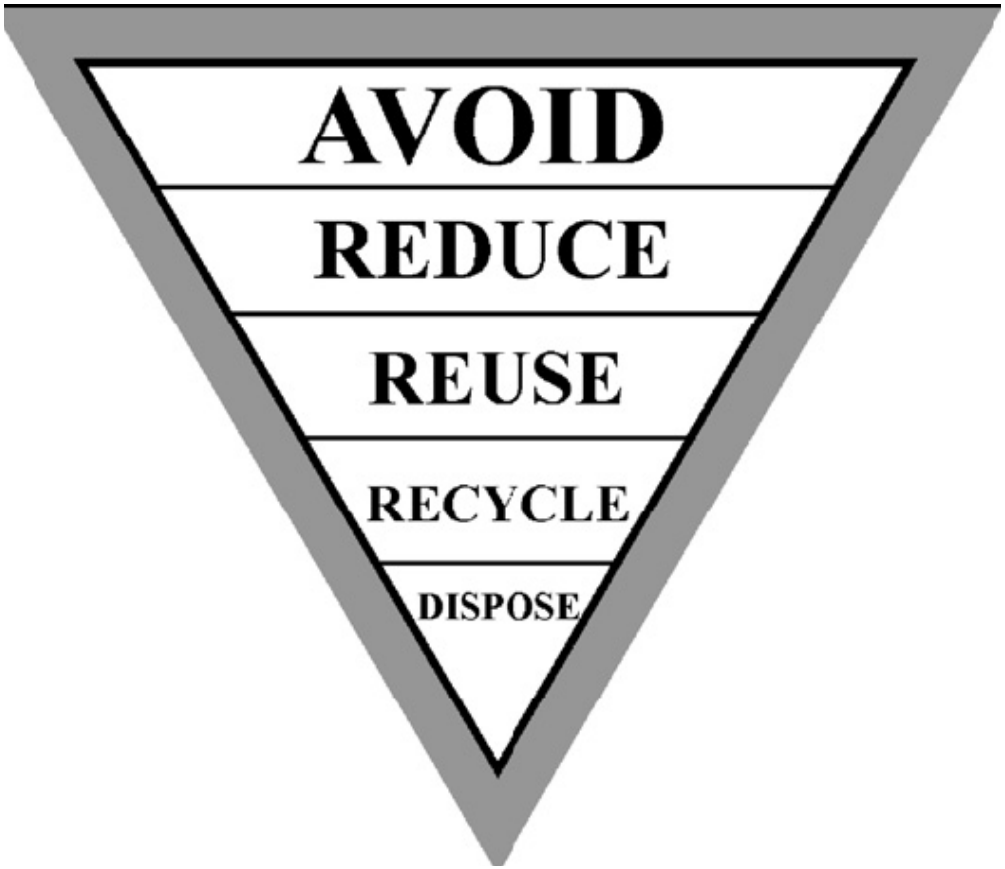
A **bottom line** conceptualisation may be appropriate, which recognises that "**absolute limits** of these trade-offs are dictated by the need to maintain a functioning life-support system."

(Fischer et al., 2007)

A FOURTH SPHERE: APPROPRIATE REGULATION



THE WASTE PYRAMID



Parallels with current global economic recession:

Economist (5/31/2003, Vol. 367, Issue 8326)
Special Section: A survey of property

"The rapid house-price inflation in many countries over the past few years is clearly ***unsustainable.*** *Alan Greenspan dismisses the idea of a national housing bubble that could harm the whole economy if it bursts. ..He needs to exercise his imagination."*

"Given the fragile state of many economies, the bursting of a housing bubble could easily drag them into ***recession*** *..Sooner or later it will* ***burst****"*

Economic

2003:	Growing Property Bubble
pre 2007:	Soft Landing?
2007:	'Sub-prime' correction
2008:	'Credit crunch'
2009:	Global financial crisis
post 2010:	?

Brown (2003): growing environmentally related bubble economy fueled by unsustainable global society

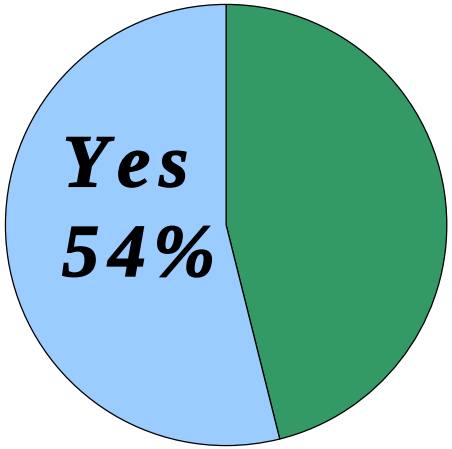
"global economy might be at some kind of tipping point" BIS, 2008

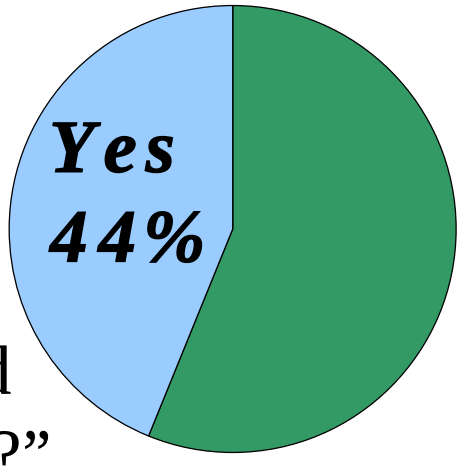
Can we engineer a *soft landing* via the creation of a sustainable society??

Chemical Engineering Perceptions

"Do you think global warming is related to cyclical sunspot activity and not CO_2 pollution?"

The Chemical Engineer, May 2007





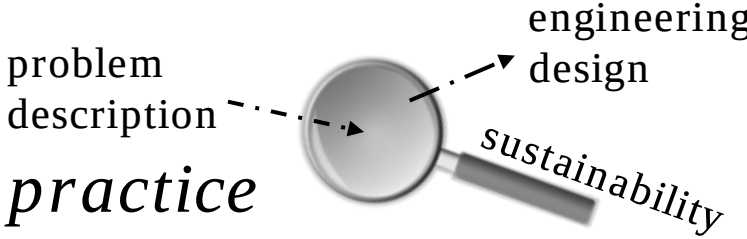
"The UN paints a stark picture of future world water shortages – is this just scaremongering?"

The Chemical Engineer, May 2009

A new (Chemical) Engineering Paradigm

From **'design with constraints'**

ABET, 2007: "*an ability to design a system, component, or process to meet desired needs within realistic* **constraints** *such as economic, environmental, social, political, ethical, health and safety, manufacturability, and* ***sustainability***."



..to being the **context** *of engineering practice*

1997 Joint Conference on Engineering Education and Training for Sustainable Development, Paris:

Sustainability should be "**integrated into engineering education**, *at all levels from foundation courses to ongoing projects and research*"

Professional engineering institutions need to "*adopt accreditation policies that require the* **integration of sustainability** *in engineering teaching*".

Sustainability & the Professional Institutions

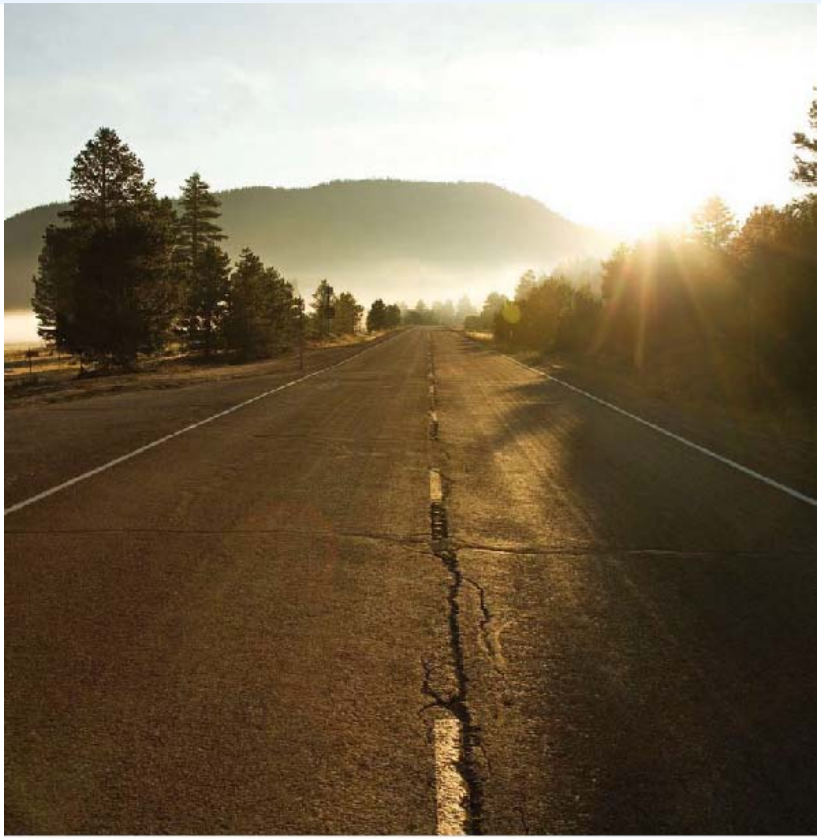

THE MELBOURNE COMMUNIQUÉ

2009: **ECUK**
(Six Sustainability Principles)

3. Do **more** than **just comply** with legislation and codes
5. Seek **multiple views** to solve sustainability challenges

2001: **Melbourne Communiqué**

2007: **Engineers Australia Sustainability Charter**:
"sustainable development should be at the **heart of mainstream policy** *and administration in all areas of human endeavour".*
.."requires a **fundamental change** *in the way that* **resources** *are used and in the way that* **social decisions** *are made".*



The IChemE Roadmap (2007) identifies six key themes for Chemical Engineering in the 21st Century:

1. Sustainability and Sustainable Chemical Technology
2. Health, Safety, Environment and Public Perception of Risk
3. Energy
4. Food and Drink
5. Water
6. Bioprocess and Biosystems Engineering

A new engineering paradigm to be fit for purpose for the 21st Century!

From 'lords and possessors of nature' to 'being part and parcel' of it.

From sustainability being a constraint on professional practice to being its very context.

From narrow role as 'value neutral' 'guns for hire' who are facilitators of techno-economic development, to a wider role envisaging the broader societal and ecological context, working in multi-disciplinary teams, and seeking to promote change 'to make the world a better place'. (Bucciarelli, 2008)

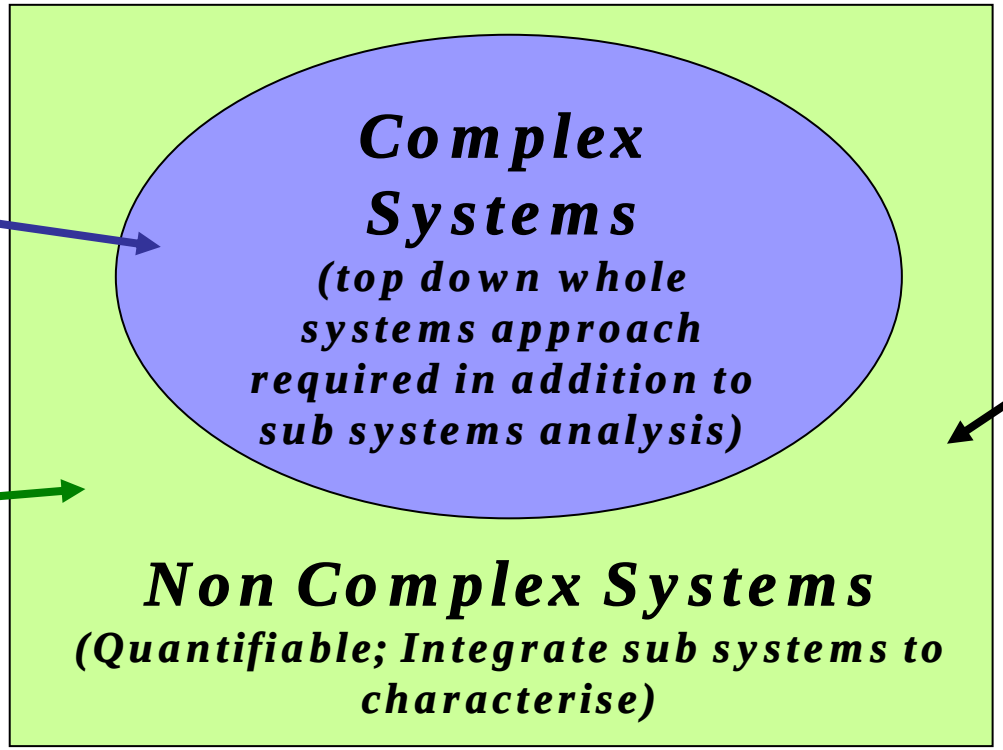
Recognise complex and wicked (Rittel and Webber, 1973) problems and learn to deal with them as such where appropriate, rather than through a reductionist approach.

Embrace role of the New Engineer/the New Model Engineer/engage in post normal science. (Beder, 1998; Clift, 2006; Functowicz and Ravetz, 1993)

Implications for Chemical Engineers: Characterising & Solving Complex Problems

Understand, Describe, Resolve, Govern

Know, Quantify, Predict, Solve, Control, Manage



Engineers are most comfortable in this domain

Engineers often seek to characterise problems which involve Complex Systems as Non Complex ones in order to elicit ***Quantifiable*** *solutions*

Embedding sustainability in Chemical Engineering programmes

Dedicated sustainability modules

Useful in enabling engineers understand the **language of sustainability**; its concepts, the role of the political, natural and social sciences and the engineer's relationship to them (Allenby et al., 2007; Kelly, 2008).

Dedicated modules and streams also provide a **focus** for sustainability on a given programme and explicitly demonstrate a clear **commitment** towards incorporating sustainability to accreditation bodies and potential recruits by educators.

Embedding sustainability in Chemical Engineering programmes

Dedicated modules and elective streams ***alone*** are **not sufficient** to demonstrate how sustainability should be the ***context*** through which 21st Century chemical engineering must be practiced.

Extra **modules** simply **bolted on** to an existing curriculum, without the concept being rooted throughout the programme provide a ***"less than satisfactory approach to the education of engineers"*** (Rahimifard and Clegg, 2008).

Also likely to be perceived (particularly by sceptical/disengaged academics) as yet another addition to an already overburdened programme.

Thus programmes need to **inherently & consistently demonstrate the need for sustainable practice** (Perdan et al., 2000; Azapagic et al., 2005).

Embedding sustainability in Chemical Engineering programmes

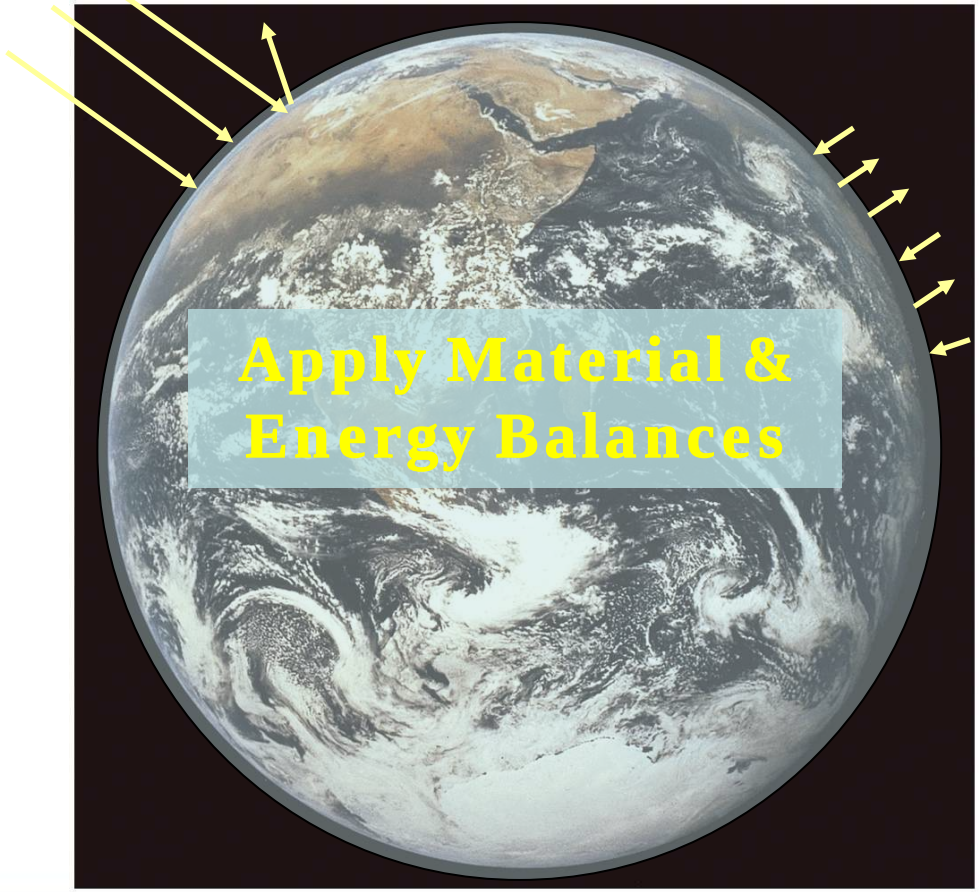
"*References to sustainable development are for the most part still at* ***too high a level****.*" (Desha et al., 2009).

Concrete examples, case studies and specific implementation intentions which relate to practice have shown to be more effective at **generating behavioural change** than generalised abstractions and principles (Arbuthnott, 2009).

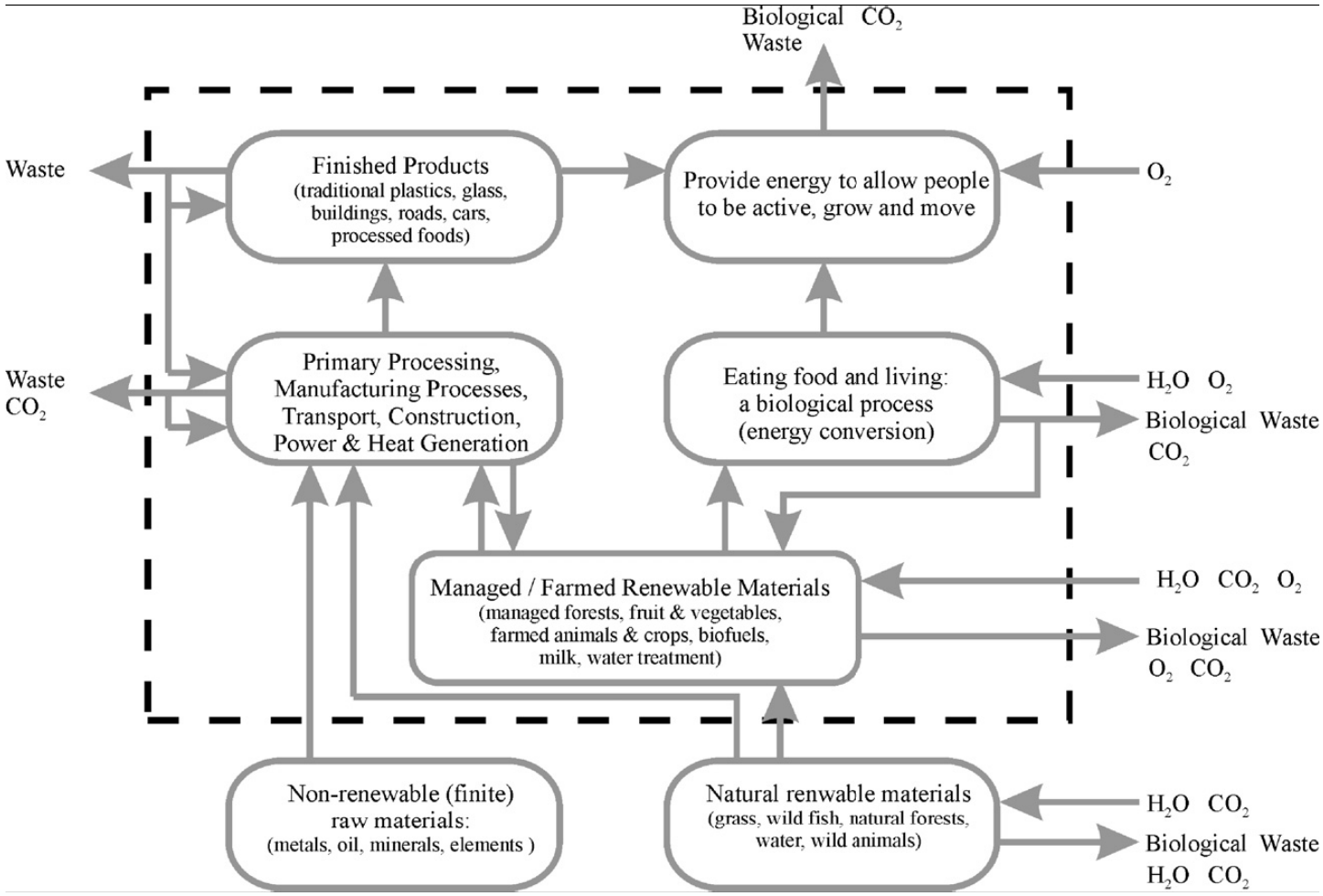
A number of the fundamental tenets or **"threshold concepts"** (Meyer and Land, 2003) relating to chemical engineering are ideally suited in helping realise a sustainability informed paradigm.

Material and Energy Balances

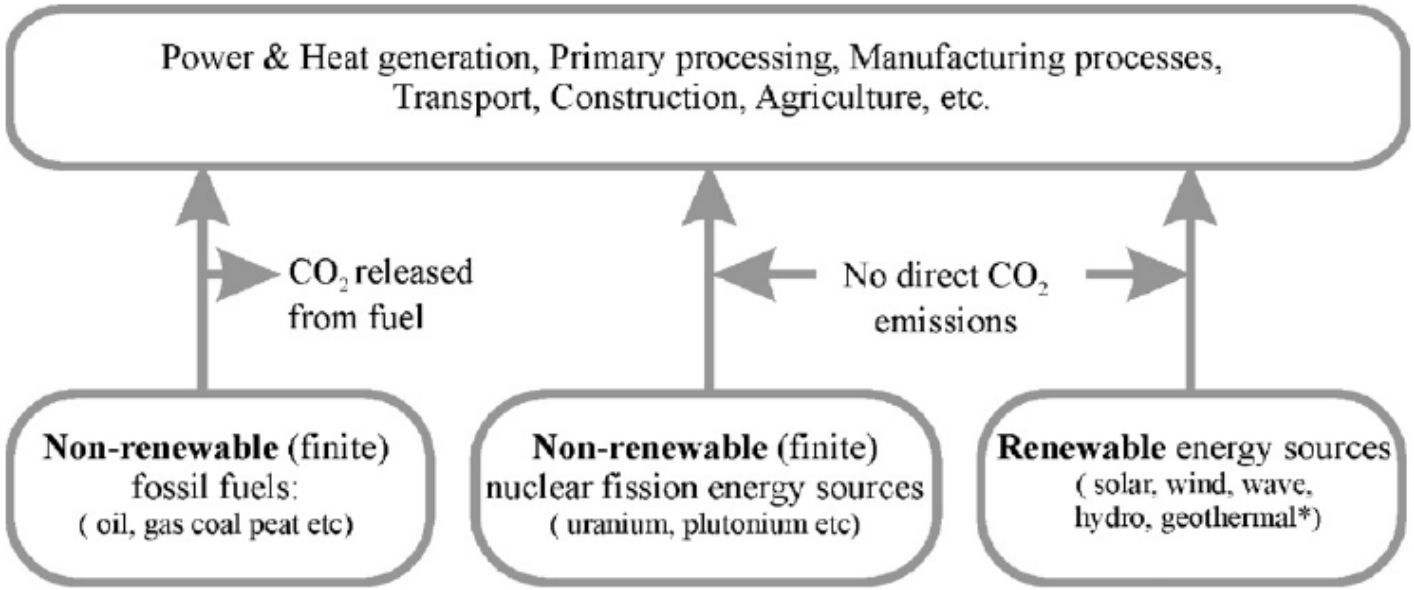
"*Human sustainability is possible only when it follows natural laws of mass and energy balance*" (Pereira, 2009)



Global Scale Material Balance



Global Scale Energy Balance



* not strictly renewable, but huge capacity exists

Entropy and the Second Law of thermodynamics

'The entropy of the universe increases with any spontaneous process'

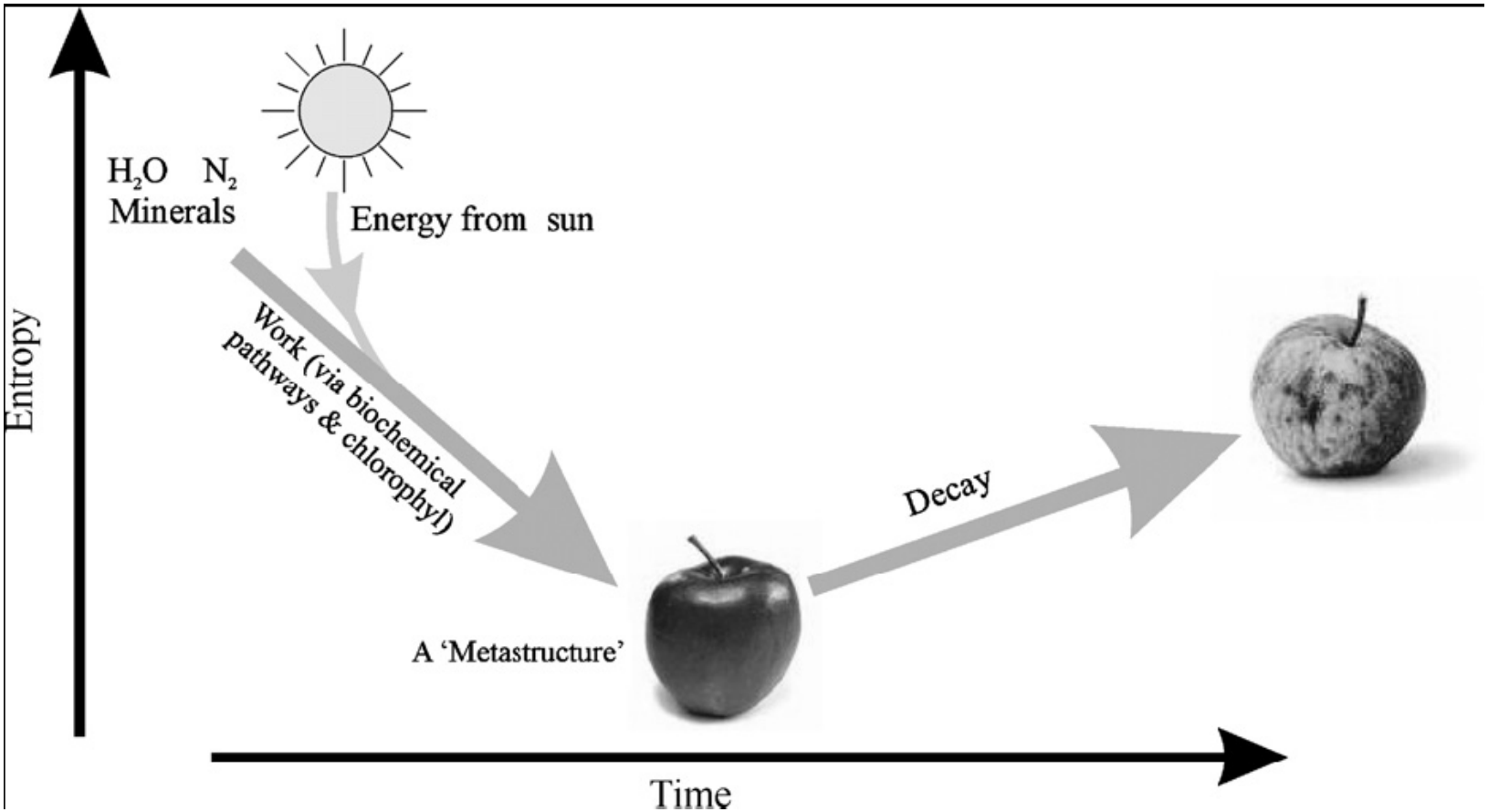
time

Concentrated Energy → 2nd Law → Diffuse Energy

2nd Law → Useful Work?

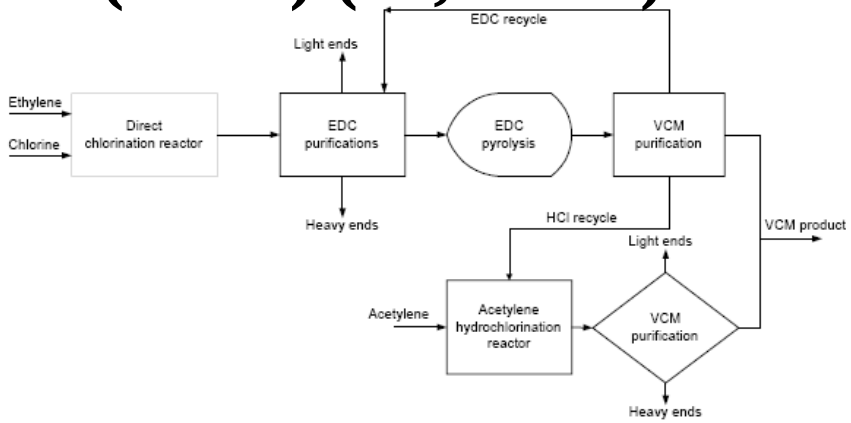
Increased Entropy

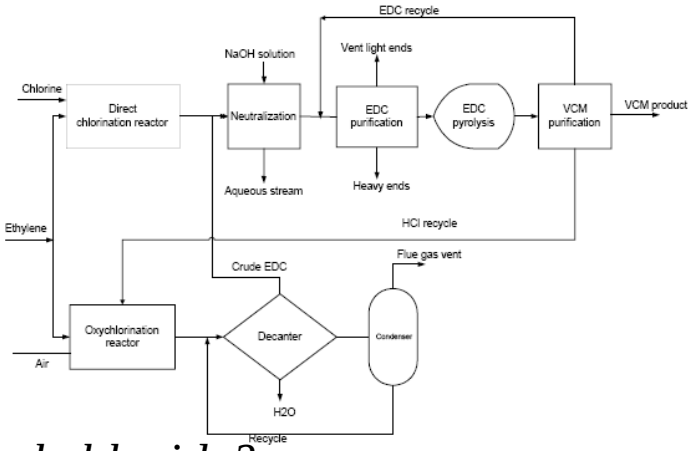
Entropy and the Second Law of thermodynamics



Process and product design

Design Project; Alternative processes to produce Vinyl Chloride (VCM) (Bi, 2005)





Question asked: *Design a process to produce vinyl chloride?*

Questions that could/should be asked: *What do we do with vinyl chloride?*

Does this entity really need to be produced?

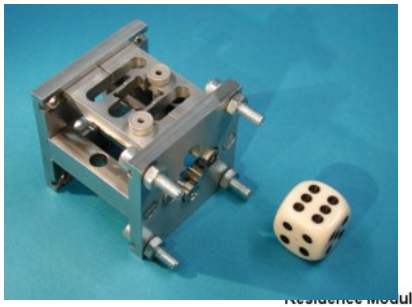
Are there other (less unsustainable) materials that could be produced instead? PLA?

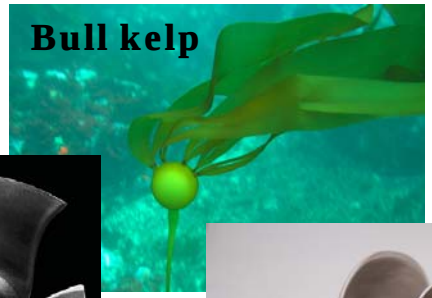
How feasible is it to produce plastics from renewable materials as opposed to oil?

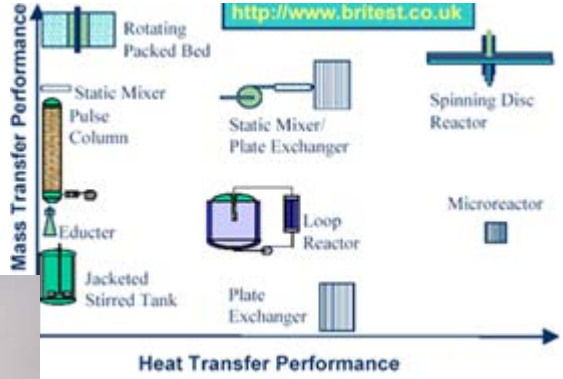
What are the technical and economic barriers to this?

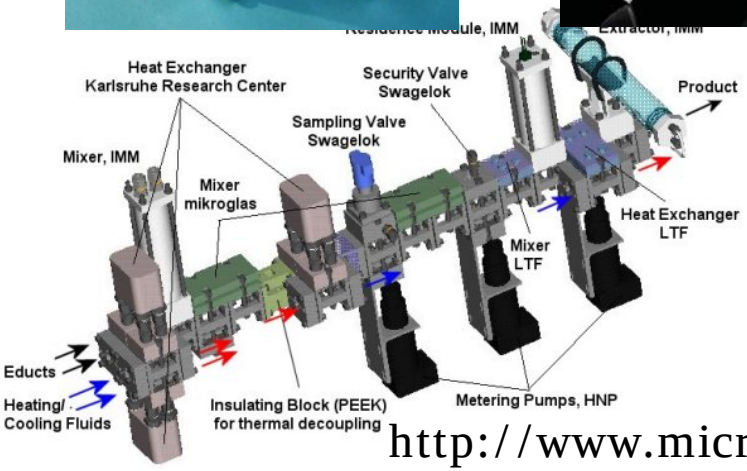
Process and product design

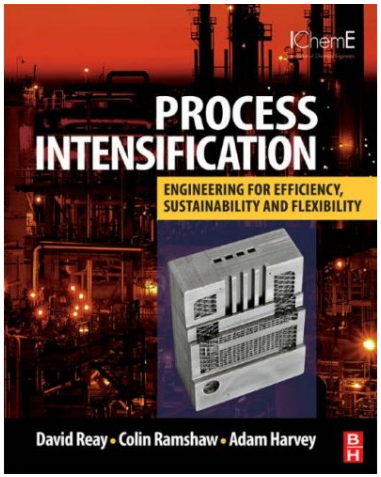
Innovative technologies: microprocesses, biomimicry, PI











http://www.microchemtec.de/

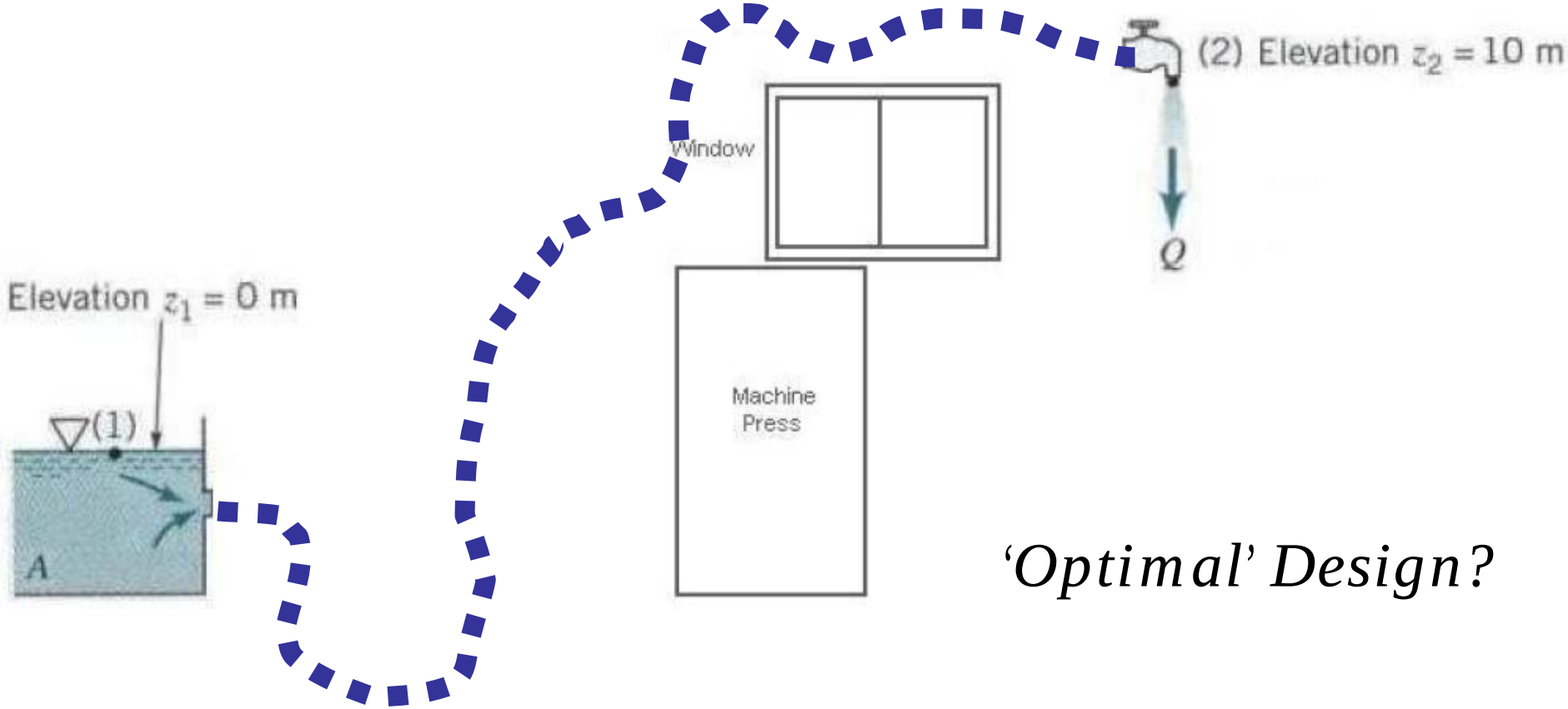
Engineering Ethics

Traditional teaching approach:
Case studies which are artificial, oversimplified, formulaic, well defined, individualistic problems, and which tend to overestimate the influence of individuals within an organisational structure and therefore often neglect **"the social complexities of engineering practice"** *(Bucciarelli, 2008)*

This minimalist approach doesn't appeal to students' better instincts to *"to **do good'** to better the environment, conserve energy"* (Bucciarelli, 2008)

A greater focus on the issues of sustainability in the ethics class, along with appropriate (complex, wicked) case studies would provide opportunities for deeper reflection of the **roles and responsibilities** of chemical engineers than the current 'object world' approach.

Fluid Mechanics; Process Flow Design

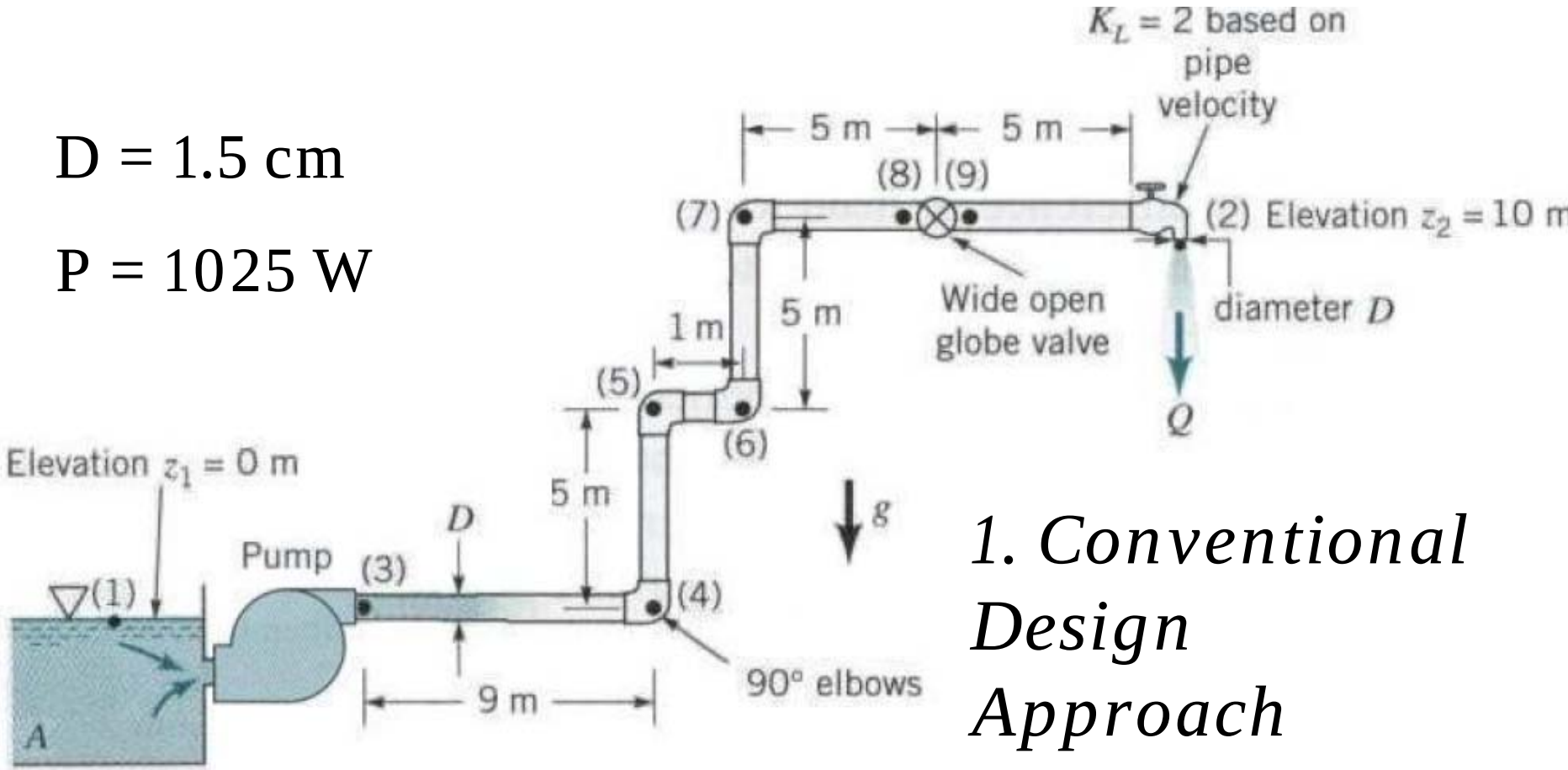


'Optimal' Design?

Fluid Mechanics; Process Flow Design

D = 1.5 cm

P = 1025 W



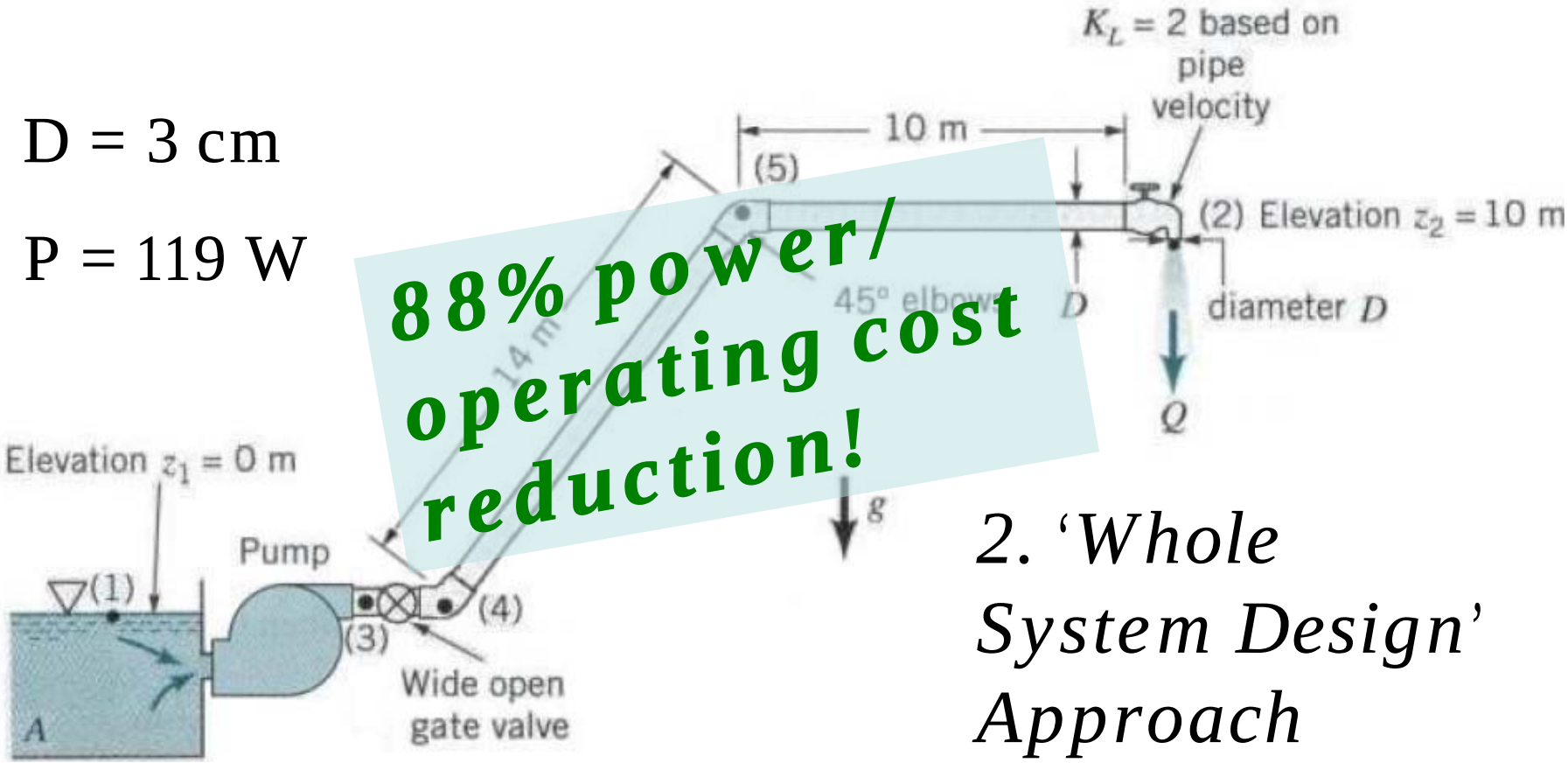
1. Conventional Design Approach

Source: Stasinopoulos et al., 2009

Fluid Mechanics; Process Flow Design

D = 3 cm

P = 119 W



88% power/ operating cost reduction!

2. 'Whole System Design' Approach

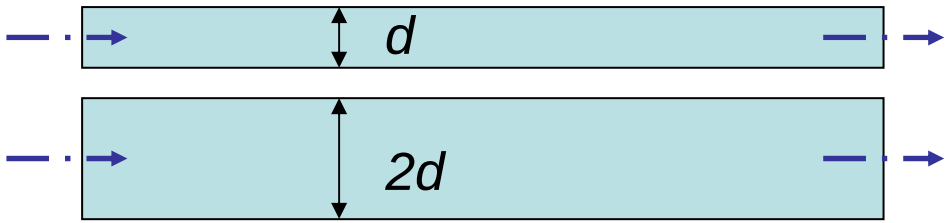
Source: Stasinopoulos et al., 2009

PE3001 APPL. THERMOD. & FLUID MECHANICS

SPRING EXAMINATION 2010

Q 1. Water must be pumped through a long straight horizontal pipe with negligible secondary losses at a specified flowrate. This can be done via either of two smooth pipes; the only difference between the two is that the second pipe has a diameter twice as great as the first. A quick calculation shows that flow through one of the pipes would be just about laminar with a Reynolds number of 2000, while flow through the other pipe would produce turbulent flow.

Which pipe would you choose? Show why. In answering the above, show in quantitative terms, the operating difference between the two regimes.



Pipe 1 (flowrate: q)

Pipe 2 (flowrate: q)

PE3001 SAMPLE SOLUTION

PE3001 Spr. 2010 Q.1 Sol^n

Pipe 1 — L, $2D_1$ — $Q_1 = Q$ (Turbulent) — $Q = Q_1 = Q_2$

Head losses are 40 times greater in Pipe 1 so choose Pipe 2.

(i.e. $\Delta P_1 = 40\,\Delta P_2$)

Primary losses only, $h_{L1} = \dfrac{4 f_1 L V_1^2}{2 g D_1} = \dfrac{4(.01) L V_1^2}{2(9.81) D_1} = \dfrac{.00204\, L V_1^2}{D_1}$

$$h_{L2} = \frac{4(.008) L \left(\frac{V_1}{4}\right)^2}{2(9.81)(2D_1)} = \frac{.000051\, L V_1^2}{D_1}$$

$$\frac{h_{L1}}{h_{L2}} = \frac{.00204}{.000051} = 40$$

Head losses are 40 times greater in Pipe 1 so choose Pipe 2.
(i.e. $\Delta P_1 = 40\,\Delta P_2$)

Attracting new (Chemical) Engineers

The Current Situation

UK Chemical Engineering **recruitment surge** (IChemE, 2008)

Against a **general decline** in proportion of students undertaking engineering programmes over the past number of decades in many developed countries (RAE, 2007; NSB, 2008)

Increase in number and popularity of sustainable energy, sustainability related options/programmes (Byrne, 2006; Jennings, 2009)

IChemE Roadmap and associated ethos instrumental as a powerful marketing tool??

Attracting new (Chemical) Engineers

"Making a difference to the world": number 2 aspiration of Engineering students at Imperial College London: (#1 females) (Alpay et al., 2008)

Two factors with greatest potential to engage people with engineering:

Potential to **effect large scale positive change** to the world

Expression of **social responsibility** – (RAE and ETB, 2007)

Embracing sustainability likely to result in increased **levels and quality** of **enrolments** to chemical engineering programmes (Clift, 2006)
...and thereafter higher levels of **student motivation** throughout their programme (Alpay et al., 2008)

Failure to modify programmes in a timely manner could **negatively affect recruitment** and ultimately present **accreditation difficulties**

(Desha et al., 2009)

Conclusions

Sustainability will be the ***context*** of chemical engineering practice through the 21st Century and beyond.

Professional Institutions and engineering **educators** have vital roles to play – in integrating policies into accreditation guidelines and developing curricula.

Curriculum renewal and a recalibration of chemical engineering self-perception will help;
- equip engineers with the skills to work with others in **leading societal transformation**.
- enhance public profile and capacity to **attract potential new recruits.**

Chemical engineers have a duty to use their knowledge and skills to **influence positive change** in facing up to the very substantial challenges of the 21st Century.

Educating Engineers for a Changing World

Leading transformation from an unsustainable global society

SYMPOSIUM TOPICS

- Educating the new engineer; new vision, new opportunities
- Embedding sustainability throughout the engineering curriculum
- Entrepreneurship and innovation in engineering education
- Engineering ethics; roles, responsibilities and sustainability
- Engineering for basic needs and the developing world
- Teaching sustainability
- Applying educational technology / IT to enhance learning
- Pedagogical approaches & assessment methods for achieving learning outcomes
- Industry perspectives on engineering education
- The Bologna process and engineering education
- Other engineering education topics, including discipline specific topics

3rd INTERNATIONAL SYMPOSIUM FOR ENGINEERING EDUCATION

University College Cork, Ireland

The twenty first century and beyond will present human society with a set of unprecedented challenges emanating from the unsustainable nature of the current societal model.

Clearly society must find a transformative model to a sustainable future, and fast. Engineers, with their technical know-how and systems approach to problem solving, are well placed to lead this necessarily interdisciplinary and collaborative endeavour. However, engineering education must provide twenty first century engineers with the necessary tools to undertake the massive challenges ahead.

This Symposium will reflect on key topical issues relating to engineering education. It will appeal to anyone with an interest in the education of engineers, presenting a dialogue conducive to signposting potential future directions and pathways.

We look forward to welcoming you to Cork for a stimulating, thought provoking and transformative ISEE Symposium in 2010!

www.ucc.ie/isee2010

http://www.ucc.ie/isee2010

Keynotes: Mullins, Shallcross, Desha, Wood

IChemE Institution of Chemical Engineers

Education Subject Group Webinar

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