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Sustainability—The next chapter

R.J. Batterham*

Rio Tinto Limited, The Institution of Chemical Engineers, Melbourne 3001, Australia

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Abstract

In the last decade significant progress has been made in recognising and understanding the issues in sustainability. Much remains to be done because the science that underlies sustainability is still far from exact. Given the natural abilities of chemical engineers with systems analysis, balances and modelling, there is a key role for chemical engineering science to play in its development.

An integrated approach requires addressing cascading levels of sustainability objectives. The levels are global objectives, industry strategy, enterprise targets, specific targets and individual actions/measurement outcomes. We need to consider the reality of the cascade effect—is it possible for global objectives to cascade all the way down to individual actions and what will be the effect of each of the steps between?

Exploration of the existing metrics and sustainability systems in relation to these cascading levels reveals that there is no single approach that can address both global responsibilities and enterprise and company interests. It is time for a framework for sustainability to be developed that can be used across all scales of application.

Indicators that address all levels of sustainability goals will enable a paradigm shift, allowing us to move beyond individual problems and to offer options on the pathway to the ultimate solution. Without these indicators it is difficult to translate our broad goals into decision-making processes. Reliable indicators would also assist companies to resist the pressures that work against sustainability, for example, those from investors for short-term returns.

Chemical engineering has a history of embracing new disciplines and has a special role to play in the change process. An understanding at the micro and molecular levels and the integration of this knowledge into macro systems will be integral to the shift towards process engineering addressing the sustainability framework. Breakthroughs in greenhouse gas reduction, climate change prevention and process redesign will require a strong base of chemical engineering science. I see opportunities for chemical engineers to play a leadership role by collaborating with other industries in building critical mass and contributing to step change beyond best practice, by broadening the scope of the discipline and by restructuring chemical engineering education at an individual level.

Keywords: Sustainability

1. Hierarchy of sustainability

Many companies today appear to view reporting as a sustainability strategy in itself, rather than as a tool to measure progress towards sustainability targets. Whilst business enterprises have adopted sustainability goals, the actual development of sustainable systems is not as advanced (Batterham, 2004). This rate of advance is being held back by the lack of an overarching system of metrics.

Sustainable development is complex and needs to be addressed at different levels. An integrated framework for sustainability, with five hierarchical levels, is presented in this paper as a start to addressing this shortcoming with the emphasis on the means by which these objectives can be achieved.

The definition of sustainable development that I use here and the one many others use refers to the sustainability of the entire earth. The complex interactions between industry, society and ecosystems can only be meaningfully addressed by taking a systems view. Hierarchical methods are able to handle such systems in a rigorous manner.

In this paper I have attempted to express this as an integrated framework of sustainability, where the framework elements are the physical entities, or organizational units through which objectives and their supporting actions can be achieved.

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* Tel.: +61 3 9283 3183; fax: +61 3 9283 3419.
E-mail address: catherine.goodman@riotinto.com.

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This hierarchical perspective has its roots in systems theory, decision analysis, functional modelling and process systems engineering and brings together these disciplines and applies them to the design and operation of industrial processes. Indeed, evidence of hierarchy can be inferred from observing the way in which nature organizes itself for ecological sustainability.

The integrated framework of sustainability as presented here originates from reflecting upon the various existing metrics and systems which attempt to assess sustainable development performance and progress. Five levels were chosen as the minimum number required to create a connecting path between global and individual activities:

Level 1: Global objectives.
Level 2: Industry strategy.
Level 3: Enterprise targets.
Level 4: Specific projects.
Level 5: Individual actions/measured outcomes.

Global objectives (*Level I*): Some issues are inherently global. An example of this is greenhouse gases. Wherever these gases are produced or by whom, they affect the entire world. Whatever their impact actually is, it will be felt globally.

The Natural Step's (<www.naturalstep.org>) principles of sustainability illustrate a global approach. This approach says that in a truly sustainable world, nature will not impacted by increasing concentrations of substances extracted from the earth's crust; by substances produced by people or by degradation of the environment by physical means and yet, in that world, the needs of all people will be met (Gips, 2004).

Industry strategy (*Level II*): Issues affecting sustainable development at the industry level impact on all industry participants and so in at least some ways are pre-competitive. Because these issues are not specific to particular companies, there is willingness to collaborate to address the issues—if industry participants do not, the industry itself may not survive. Together, companies are finding ways of addressing complex sustainability issues.

A way industries can collaborate for sustainability is by creating roadmaps to inform the way forward for their industry. Recent examples are the Aluminium Industry Roadmap <www.oit.doe.gov/aluminium/pdfs/al_roadmap.pdf>, the Copper Roadmap <www.amira.com.au/documents/copperrm/public.htm>, facilitated by the Australian Mining Industry Research Association. The United States Department of Energy led the way in developing the roadmapping process and has conducted roadmaps of several energy related issues (<www.climatevision.gov/sectors/electricpower/pdfs/carbonsequestration_roadmap.pdf>;<www.netl.doe.gov/coal/fuels/refshelf/roadmap.html>; <www.netl.doe.gov/coal/CCPI/pubs/CCT-Roadmap.pdf>). The top priority issue identified in the Copper Roadmap process is an integrated sustainability model and calls for the more efficient use of water. Such roadmap outcomes are being used by various industries to guide both their strategic direction and their immediate development plans.

Enterprise targets (*III*): It is at the enterprise level that tangible ownership begins to empower sustainability strategies. Each enterprise has command of its own activities and can, if it so decides, modify its activities, change its direction, educate its workforce and design improved technology to achieve its sustainable development objectives.

Project level IV: Level IV describes particular projects to increase sustainability which are within the control of a specific enterprise. Whilst it may be possible to develop a new installation or retrofit an existing operation, it is rarely possible to refit an entire enterprise or industry. Specific projects are the small finite steps which can lead the way forward towards sustainability for the rest of the enterprise and even the rest of the industry.

Where several industries are located in a region, opportunities for regional synergies and industrial ecology arise. An example of one such initiative is the work of the Kwinana Industry Council in Western Australia. This project involves several industry participants across the areas of alumina refining, titania pigments, power generation, ferrous smelting, vanadium production, cement manufacture, port and civic authorities and construction (<www.kic.org.au>). This initiative has set the target of completely eliminating wastewater from industrial uses. This is an astonishing target yet it is credible, based on recent progress in industry research and development. Large waste streams such as red mud sand from alumina refining will be used in other processes. In this case, it will be used in construction.

The Kwinana Industrial Synergy is an example of a collection of interlinked projects (Level IV), each controlled by an enterprise (Level III) to achieve the goal of no industrial wastewater in that region.

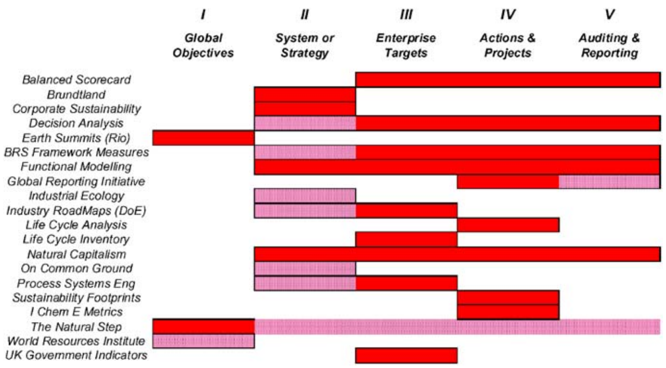
Individual actions/measured outcomes level V: Level V, individual actions and measured outcomes deals with the practical, tangible everyday activities that individuals can undertake, whether these be as individuals or within the enterprises they work in or engage with.

People can act as individuals or group together with others via the various levels of this integrated sustainability framework to effect change. Individual actions can be as simple as choosing to shop at the supermarket with a reusable cloth bag rather than accept plastic bags.

Some examples of measured outcomes are application of the global reporting initiative (GRI) (www.globalreporting.org/guidelines/2002.asp) set of metrics, or the Institution of Chemical Engineering set of metrics (Institution of Chemical Engineers, 2002) to a process. Such data, when collected in a disciplined well-formed way constitutes a valuable resource to use in generating options for tackling sustainability issues and changing behaviour.

There are risks associated with becoming too concentrated on one level of the sustainability hierarchy and losing sight of the big picture. Opportunities for collaboration over the various levels may be lost if the focus becomes too narrow. Focussing solely on sustainable management of individual projects means that opportunities to move towards system redesign are overlooked. Additionally, focussing on company objectives will miss out on what companies can do broadly for their industry sector eg. the Kwinana Industrial Synergy would not have occurred without big picture thinking.

Table 1
Some of the available systems and their level of application



	I Global Objectives	II System or Strategy	III Enterprise Targets	IV Actions & Projects	V Auditing & Reporting
Balanced Scorecard			🟥	🟥	🟥
Brundtland		🟥			
Corporate Sustainability		🟥			
Decision Analysis		▨	🟥	🟥	🟥
Earth Summits (Rio)	🟥				
BRS Framework Measures		▨	🟥	🟥	🟥
Functional Modelling		🟥	🟥	🟥	🟥
Global Reporting Initiative				🟥	▨
Industrial Ecology		▨			
Industry RoadMaps (DoE)		▨	🟥		
Life Cycle Analysis				🟥	
Life Cycle Inventory			🟥		
Natural Capitalism		🟥	🟥	🟥	🟥
On Common Ground		▨			
Process Systems Eng		▨	🟥		
Sustainability Footprints				🟥	
I Chem E Metrics				🟥	
The Natural Step	🟥	▨	▨	▨	▨
World Resources Institute	▨				
UK Government Indicators			🟥		

Many systems, indicators and performance measures have been developed to help understand and classify the interacting elements of sustainability and to assist with setting strategy and monitoring progress towards sustainability goals. Most have been developed for use in a particular level, for example the Institution of Chemical Engineers set of metrics, which targets Level IV. This is intentional and reflects current professional positioning. Some attempts have been made to extend these systems and metrics to the whole level or beyond the level.

I reflect on the questions: how capable are the existing metrics of covering every level of sustainability—singly or collectively? Does each system/metric meet the needs of the highest level to which it aspires? How do individual measures compare?

Table 1 lists the systems and metrics examined and the level(s) for which they were devised. Also shown, in paler fill, are the levels which they are capable of covering.

In examining each of these approaches, it is apparent that there is no one system which will result in comprehensive measurement and there is no common set of metrics.

A review of the systems and metrics available leads to the conclusion that no single system can cover all levels of sustainability. However, the existing systems are useful in their areas of applicability, as described below:

At the *Global level*, the natural step is soundly based for discussion and understanding. Lifecycle Inventory is a practical tool to assist in meeting global targets.

At the *Industry Level* (and cascading down to Individual Level) the BRS framework (Bureau of Rural Sciences, 2002) is extremely practical in delivering both useful metrics for the issue under discussion and for stakeholders committed to productive action.

Process systems engineering combines many of the disciplines of particular use in analysing complex systems. Its techniques are well developed and constitute a practical tool-kit to support the redesign of existing processes and the creation of innovative process solutions to sustainable development challenges. An important contribution for process systems engineering is in reducing the costs of breakthroughs to minimize barriers to project uptake at enterprise and industry levels.

The Institution of Chemical Engineers' metrics framework acts as a minimum checklist at the project level and if undertaken year-by-year provides a valuable resource of data which can be examined for trends which will indicate if the process is moving towards or away from its sustainable development targets.

2. Recommendations

TNS or similar for globally focused system

- discussion/understanding

BRS for industry level and beyond

- industry understanding and knowledge
- system and measures

PSE as practical tool kit

- use & development of tools to support extended systems
- reduce costs of breakthroughs

Lifecycle Inventory as practical tool for global targets

- time effectiveness

WRI/WBCSD for global measures

- analysis and process steps to reduce all of life impacts

IChemE as minimum checklist

- provide data.

3. Scorecard

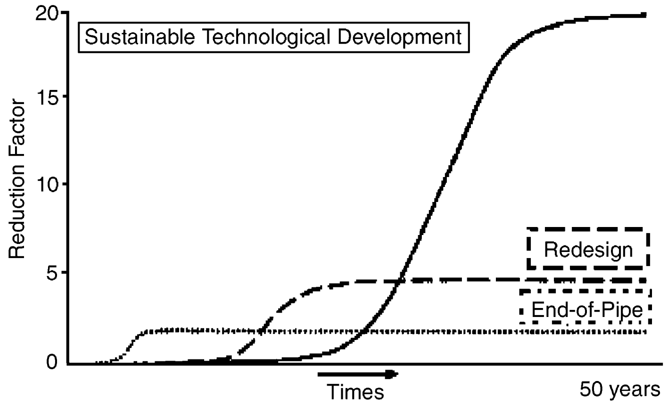
At a very fundamental level and reducing the complexity of frameworks already discussed, adopting sustainability scorecards is an option for organisations. A scorecard itemises the areas affected by a process such as economic, environmental, health and social and through comprehensive questions in each area it can be used to facilitate rigorous exploration of the costs and benefits of various options. Ultimately, a scorecard evaluates the sustainability of a process and enables the most appropriate one to be selected. Table 2 is an example of what a typical scorecard might contain.

4. Process engineering

The process industries are in a good position to take a leading role in system redesign to better address sustainability issues and chemical engineers must move beyond providing solutions to individual problems and offer options on the pathway to sustainability. Once-through systems designed for production only are often not sustainable and give no consideration for waste management. The process industries are now moving strongly forward from once-through systems to process redesign and then further again onto whole-of-life-cycle analysis (Fig. 1).

Table 2
A sustainability scorecard

Economic	Environmental	Societal
Direct	*Material consumption*	*Quality of life cycle*
Raw material costs	Products & Packing mass	Breadth of product or service availability
Labour costs	Useful product lifetime	
Capital costs	Hazardous materials used	Knowledge enchancement
Operating costs	Eco-efficiency	Employee satisfaction
Potential hidden	*Energy consumption*	*Peace of mind*
Recycling revenue	Life cycle energy	Perceived risk
Product disposition cost	Power in use operation	Community trust
Contingent	*Local impact*	*Illness & disease reduction*
Employee injury cost	Product recyclability	Illness avoided
Customer warranty cost	Run-off to surface water	Mortality reduced
Relationship	*Regional impacts*	*Safety improvement*
Customer retention	Smog creation	Lost-time injuries
Business interruption due to stakeholder interventions	Acid rain precursors	Reportable releases
	Biodiversity reduction	Number of incidents
Externalities	*Global impacts*	*Health & wellness*
Ecosystem productivity loss	Global warning emissions	Nutritional value provided
Resource depletion	Ozone depletion	Subsistence costs



Source : RJ batterham, Presidential IChem E address

Fig. 1. Schematic of the trade off between end of pipe solutions, process redesign and whole of life cycle changes.

Chemical engineering is well accustomed to embracing new challenges and has a special role to play in this change process. An understanding at the micro and molecular levels and the integration of this knowledge into macro systems will be integral to the shift towards process engineering addressing the sustainability framework.

Chemical engineers are trained to be reductionist, deductive, deterministic and are also capable of integration. They consider outcomes and implications—core enabling skills in working towards sustainable development, itself a strategic framework which builds on the traditional frameworks of mass and energy balances. Chemical engineers can take relevant information, incorporate it with best practice to achieve a process and product that takes into account life-cycle analysis and satisfies the needs of the community and try to find a preferred pathway through uncertainty.

Traditional chemical engineering addressed issues such as materials technology, modelling systems (Level IV) and process measures and analysis (Level V). The new sustainable chemical engineering needs to engage in issues such as greenhouse gas reduction (Level I), waste heat prevention and extended systems and partnerships at the enterprise level (Level III).

Making this transition, as a discipline, requires its members individually to make changes in how they practise chemical engineering. For example, sustainable development needs to be taken on by chemical engineers as a managerial responsibility so that they can show leadership within their professional institutions and at an industry level. Individual engineers, at all levels in enterprises, need to expand their comfort zone and increase their familiarity with sustainability concepts and most importantly how to implement the actions they require. They need to foster integrated approaches as well as continue to use the traditional tools and synthesis of unit operations. They have a contribution to make to step-changes beyond best practice by using new tools, especially for extended systems. The increasing availability of modelling such as computational fluid dynamics enables faster, less risky and cheaper analysis of problems. The scope of the discipline needs to broaden from a technically-oriented thrust to broader involvement in roadmapping and workshops that cross the enterprise boundary.

All of this requires the way chemical engineering is taught to change to keep up with society's demands of the profession. Such restructure is at the individual level (Level V).

The way our universities teach chemical engineering needs to change globally in response to this global need. Whilst some universities have taken action to improve their courses significantly (<www.eng.ox.ac.uk/chemeng/sustdev.htm>) in most cases sustainable development is still an add-on rather than a core unit. The Chemical Engineering Institutions are taking a key role in supporting this change.

Chemical engineering course improvements have been summarized (<www.io.tudelft.nl/research/dfs/education/educationset/html>) as:

- building attitude—embracing sustainability concepts and co-operating with others,
- building skills—taking an integrated approach, being action-oriented, systematic and communicative,
- building knowledge of technology, culture and structure.

Sustainable development can only be accomplished if approached in a multi-disciplinary way since environmental issues encompass so many disciplines. Ultimately, chemical engineers will provide options over problem-solving. Chemical engineers will need to participate in society in more creative ways and to reflect this in the innovations they develop.

5. HIsmelt—an example

An example of the type of innovation required to make significant breakthroughs towards more sustainable industry is HIsmelt (Davis Mark et al., 2003). Direct smelting has long been aspired to in the steel industry, but has been veryslow in coming out of the developmental stage due to the difficulties associated with harnessing complex fluid dynamics. More recently, the incentive has intensified due to increased environmental pressure on the processes associated with traditional blast furnace ironmaking.

HIsmelt uses iron ore and coal fines directly by injecting them into a molten bath at high velocity. Smelting gases (mainly CO_2) are released from the bath and burned in the topspace by hot oxygen-enriched air. A fountain of metal and slag erupts from the bath and, as droplets and splashes traverse through the topspace, they carry heat back to the bath to sustain the process (Fig. 2). This ‘heat pump’ is the heart of the HIsmelt process.

A major enabling step in the development of the process was understanding the fluid dynamics involved together with the associated heat and mass transfer processes (Fig. 3). Recent improvements in computing capabilities and large systems modelling has provided the means to make the necessary technology breakthroughs. HIsmelt is an example of a breakthrough of a significance that is rarely seen today.

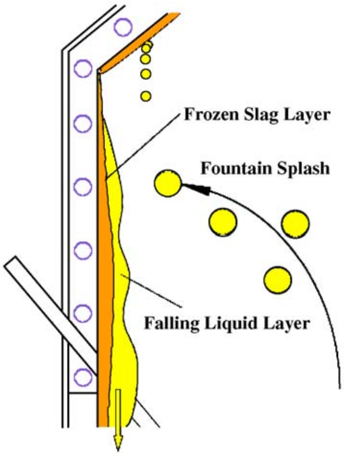


Fig. 2. Barrel wall conditions.

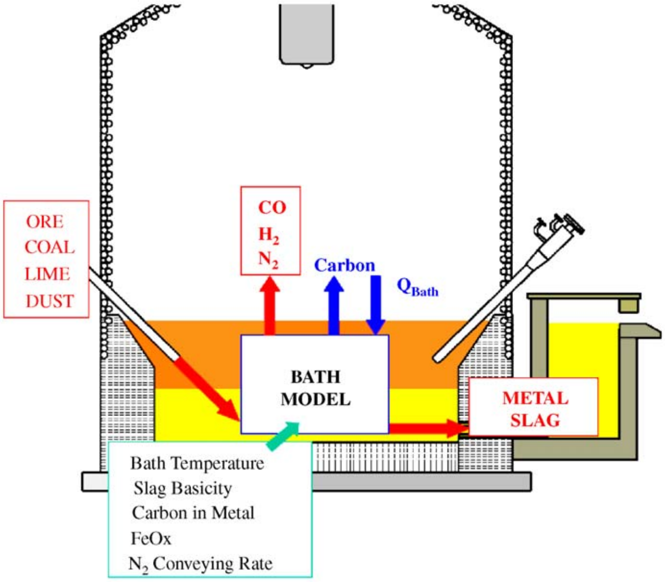


Fig. 3. Calculation of bath performance.

The flow models developed are regarded within the HIsmelt business as major risk-management tools with considerable predictive power in terms of scale-up and process optimisation. It has helped de-mystify the behaviour of the system to the point where full commercial implementation is now possible and a 0.8 Mt/a plant in Western Australia will be commissioned in 2005.

6. Conclusion

Much remains to be done in the areas of sustainability and sustainable development because the underlying science is still far from exact. Given the natural abilities of chemical engineers with systems analysis, balances and modelling, there is a key role for chemical engineering and chemical engineering science.

A review of the existing metrics and systems has shown a lack of effective integrated indicators which span all levels of sustainability. Reliable indicators would assist companies to resist the pressure that work against sustainability, for example, those from investors for short-term returns. The integrated framework of sustainability provides a useful way to begin to integrate the existing work on sustainability metrics and indicators.

At the global level, The natural step and lifecycle inventories are applicable and for industry level through to individual level, the Bureau of Rural Science’s evaluation framework is extremely useful. Process systems engineering provides a valuable toolkit at the project and individual levels to enable breakthroughs and reduce costs. The institution of chemical engineers set of metrics is important at the project and individual level and provides a readily implementable checklist of metrics.

Acknowledgements

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