
35 The value loop – a new framework for business thinking

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Introduction

The survival of our natural environment in its present form, and the existing type of human society within it, is not assured. One of the main direct causes of this environmental and cultural risk, or unsustainability, is the pattern and scale of the worldwide industrial economy. As the industrial economy approaches the same physical scale as the biosphere, a new organizing pattern for industry is urgently becoming needed, one in which a new form of physical organization will be matched and supported by a new organizing template for business activity. This chapter expands on the concept of the 'value loop' as a potential solution.

In the present mode of industrial production the pattern of physical flows is putting ever-increasing pressure on nature. Raw materials are extracted from the environment (the biosphere and the Earth's crust), processed to create products and economic value and the waste is eventually dumped back into the natural environment. The assumption is that industry can act like a suction tube, pulling materials from nature, using them briefly to create economic value and then pumping the residue back into nature as waste and pollution. This is workable if industry is small and nature is vast, but as industry continues to grow rapidly and approaches the same scale as nature itself, it quickly becomes a major problem. For one thing, if the flow of materials being sucked from nature begins to be as large as the stocks and flows in nature itself, then the supply of materials will not last for very long. For another, if the flow of pollution is too large in comparison to the waste-processing capacity of nature, nature is likely to be overwhelmed.

The driving force behind this flow of materials is business activity around the world. Business operates by creating products and services it can sell and most of these economic transactions involve an exchange or flow of material. In the case of products, the material forms the product itself, and services usually need energy – which itself involves a flow of materials – and often depend on some exchange or consumption of materials.

Business activity therefore forms a flow of transactions that parallel the flow of materials through the industrial economy. Primary industry is responsible for extracting resources from the environment, manufacturing industry turns it into products, which the retail industry then sells to consumers. This flow of transactions is known in business as the 'value chain' – a concept first articulated by Michael Porter in 1985 in the *Harvard Business Review* (Porter, 1985).¹

Each business is concerned about the viability of its place in the chain, and uses whatever materials and energy it needs to create value. Each one is concerned that it can earn marginally more money from the products and services it sells than the amount it must spend to buy the resources it needs. This is how businesses survive. Few if any businesses are concerned about the survival of the chain as a whole. Each one assumes that there will be another organization or activity upstream and downstream of its own operations that

will provide the resources it needs and deal with the ultimate fate of the materials it sells or discards. However, upstream and downstream of the whole chain there is nature and nature's survival in its current form cannot be assured if the flow through the chain grows too big.

The whole industrial economy is already very large compared with nature, and is growing very rapidly in terms of physical flows – it is doubling in size every 20 years or so. Very soon now we will need to redesign the whole thing if we want our present way of life to survive. The good news is that there is a way of doing this. The essence of the redesign will be to shift from operating industry as a straight-through chain of activities, to operating it as a circular flow. The ends of the chain can be linked together to form a loop, which could then be known as a 'value loop', in place of the existing 'value chain'.

In the value loop, businesses connect to each other and to their customers in circles of transactions with no breaks, and the materials they need flow between them continuously in a sustained cycle. Instead of being put under increasing pressure at each end of the chain, nature can now be kept largely independent of the loop.

Linear flow is unsustainable

As described, the existing industrial economy is based on a straight-through, or source to sink, flow of materials. For convenience, the straight-through flow will be referred to as 'linear' in this chapter. This linear flow cannot be sustained for two reasons: scale and rate of growth. If the scale of industry was small compared with nature – meaning the biosphere – then its activities could be sustained without undue difficulty. Particularly if it was not only small but also growing slowly, then the linear flow of materials could be sustained for a long period.

Industry is not small however. Even compared with the vast size of the global biosphere, the industrial economy is now very large. Several measures can be used to show this. One example is the production rate of toxic heavy metals. Another is the annual rate of consumption of biomass.

The toxic heavy metals are elements that occur naturally in the Earth's crust and include lead, copper and arsenic. Because of natural processes such as the weathering of rock, a certain quantity of these elements does enter the biosphere naturally each year and is safely absorbed. Human activity, principally mining, has greatly increased the rate at which these elements are released into the biosphere. Lead, for example, a nerve poison, is still used in a number of countries as an anti-knock additive in petrol (gasoline), which accounts for its high rate of release into the atmosphere. The global industrial flow of most of the toxic heavy metals is now significantly greater than the natural background flows. This means that for these elements, which are particularly important because they are poisonous, industry is now, quite literally, larger than nature.

A similar but better-known example is the release of carbon dioxide into the atmosphere from burning fossil fuels. There is a natural flow of carbon dioxide into the atmosphere from the respiration of living things, including plants, animals and humans. This natural flow is very large since respiration is a basic activity of most living things, and carbon is one of the major nutrient cycles in the biosphere – it is one of the so-called 'grand cycle' elements that include nitrogen and sulphur. Every year roughly 200 billion tonnes of carbon is cycled through the atmosphere naturally – released to it and absorbed from it by the biosphere.

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By the 1990s the burning of fossil fuel and deforestation were releasing about 30 billion tonnes of carbon dioxide, containing eight billion tonnes of carbon, into the atmosphere every year. The total anthropogenic or human-caused flow of carbon is equal to about a fifth of the natural background flow, and is increasing the total atmospheric 'reservoir' by some 4 billion tonnes a year (only half of the excess carbon is being successfully absorbed by the biosphere and ocean every year). The effect of this accumulation is directly measurable. The concentration of carbon dioxide in the atmosphere has increased from an estimated pre-industrial level of 280 parts per million (ppm) in 1750, to 315 ppm in 1958 and 381 ppm in 2005. So in the case of carbon dioxide, industry is still significantly smaller than nature, yet this flow has already reached a scale that is thought to be triggering changes in the world's climate.

Another 'greenhouse gas', methane, is released in far smaller amounts naturally than carbon dioxide but has a more potent influence on global temperature. The human-caused flow is about 375 megatonnes per year, whereas the natural flow is only about 160 megatonnes per year. So in the case of this gas, the human-caused flow is already 2.3 times larger than the natural flow (Houghton, 1997, p. 35).

The annual consumption rate of biomass provides another way of understanding the scale of the industrial economy. In 1986 a study was conducted at Stanford University to estimate how much of the total annual biological growth, or increase in biomass of the biosphere as a whole, was being consumed by the human economy. The research team calculated that in 1986, when the world's population was five billion, the human consumption of food and biomass resources had reached 40 per cent of the entire annual land-based product of photosynthesis (Vitousek et al., 1986). The world's population has now grown to over six billion people, and since the human consumption of biomass reflects this growth plus increasing wealth, the percentage would now be significantly more. So in terms of the basic productivity of the whole biosphere, the industrial economy is now in the order of half the size of nature and growing rapidly. This growing percentage requires very large-scale clearance of wild habitat for agriculture and forestry and it is unlikely that the natural ecosystem can tolerate usage rates much beyond 60 or 70 per cent.

A similar measure of relative size is provided by the 'world ecological footprint' that is calculated annually by WWF International. The ecological footprint compares human consumption of renewable natural resources with the ability of the biosphere to regenerate them. The WWF analysis compares the estimated area needed to provide for human consumption renewably with the size of the most biologically productive part of the Earth's surface. On this basis, human consumption of renewable natural resources grew by 80 per cent between 1961 and 1999, to a level 20 per cent above the Earth's biological capacity. About 11.4 billion hectares, just under a quarter of the Earth's surface, is the most biologically productive. This area corresponded to an average of 1.9 hectares per person in 1999, but the level of human consumption in 1999 would have required the renewable productivity of 13.7 billion hectares, or 2.3 hectares per person on average.

Human consumption therefore overshoot the biosphere's renewable productive capacity by 20 per cent. This over-consumption is being achieved by depleting the natural capital base – an example would be the one-time clearing of forest instead of renewably harvesting from an ongoing forest, which would require a larger area to produce the same amount of timber but the renewable yield could be maintained over time instead of being taken as a one-off harvest. In contrast, consumption or draw-down of the natural capital base

removes the source of further renewable production, making it dangerously unsustainable. So on the basis of WWF calculations, the human economy as a whole is already 20 per cent larger than nature can support on an ongoing basis. The WWF expresses this in numbers of planets, pointing out that we would now need more than 1.2 planets to sustain the current rate of human consumption (WWF, 2002).

These measures all tell the same basic story: that the size of the human economy is now close to or already is the same size as nature. This would be problematic enough if the size of the human economy was static, but it is not: it is growing rapidly.

The human economy is growing in size because the human population is growing in numbers and simultaneously becoming more affluent. The growth to today's population of over six billion was sudden, recent and historically unprecedented.

For thousands of years of pre-history, the human population remained at a few million people worldwide, growing on average at not more than 0.05 per cent a year and not rising above 100 million until after 1000 BC. The increase was not steady during this period – there were alternating surges and contractions – and there was no consistent exponential growth towards present levels as is often assumed. From AD 1 to 1750 the average growth rate was about 0.07 per cent a year. The historically recent and unprecedented change is that from 1750 to 1950 the average growth rate jumped to about 0.7 per cent a year, and between 1950 and 1960 it jumped again to an average of 1.88 per cent, reaching a peak rate of about 2.06 per cent around 1965. By the late 1990s it had fallen back to less than 1.5 per cent – but this is still 20 to 30 times higher than the pre-industrial baseline (Cohen, 1995).

In terms of absolute numbers the world population is still growing extremely fast, even though the underlying growth rate is now declining. More people were *added* to the world population in the 1990s than existed in the entire world in 1750. The world population has doubled during the lifetime of anyone now over 40 – a unique occurrence in human history – and if present rates of growth were maintained, the total population would double again within the next 40 to 50 years. If the growth rate continues to slow as it has since 1965, the population will still increase by about another three billion people before it stabilizes.

As rapid as this population increase is, the flow of materials through the industrial economy is growing twice as quickly. At its current rate of growth, materials consumption will double in 20 years, compared with the current doubling time of about 50 years for population. In broad terms this is because material affluence is rising twice as fast as the number of people. The consumption of materials in the United States has ballooned from 140 million metric tonnes a year in 1900 to 2.8 billion metric tonnes a year in 1990, up from about 1.6 tonnes a person to 10.6 tonnes a person. Environmental pollution has been rising in step with this, because in a straight-line-flow economy the flow of waste and pollution is proportional to industrial throughput. For example, the amount of carbon dioxide released into the atmosphere every year has doubled twice over since 1950, in line with the 20-year doubling time.

The Stanford University calculation described earlier, estimating the human consumption of annual biological growth, provides a way of thinking about what this rate of increase means for the biosphere. If we assume the take of biomass is increasing in line with the growth in the throughput of all materials, then the 40 per cent number calculated by the Stanford team in 1986 will have doubled by 2006. This means it would reach 80 per cent by 2006 and 100 per cent by 2013, which would mean no wild biosphere remaining.

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These numbers are only speculative approximations but they do show that the problem might reach crisis point in the very near future, not in many decades time.

Why does this problem seem to be rushing at us so suddenly? The growth of materials consumption is exponential, which means it doubles with every tick of the time interval that corresponds to its growth rate, in this case every 20 years. Like a rocket taking off, at first this appears very slow and then suddenly accelerates into an extremely fast increase. Exponential growth in a finite space – like the surface of a planet – is highly deceptive psychologically as it appears to be reassuringly slow at the outset but later accelerates suddenly to use up remaining space or resources with startling speed. This is particularly dangerous for political and other decision-making as it is notoriously difficult to take exponential change seriously until it is almost too late.

There is a French riddle for children, quoted by Donella Meadows in *Beyond the Limits*, that illustrates the problem exponential growth poses for decision-makers:

Suppose you own a pond on which a water lily is growing. The lily doubles in size each day. If the plant were allowed to grow unchecked, it would completely cover the pond in 30 days, choking off all other forms of life in the water. For a long time the lily plant seems small, so you decide not to worry about it until it covers half the pond. On what day will that be? (Meadows, 1992, p. 18)

The answer is surprising on first encounter: on the 29th day. On the 30th day the lily doubles for the last time, taking the pond from half-full to full. What is also worth noting is just how small the lily is for most of the month – as late as the 25th day it still covers only 1/32 of the pond, yet five days later the pond is full.

What might happen when human economic consumption reaches very high levels in terms of worldwide biological capacity? Are there likely to be any obvious warning signs if we are approaching danger point? The answer lies outside our experience because we have never pushed a whole planet to the limit before. As Professor Edward O. Wilson at Harvard University succinctly puts it: 'One planet, one experiment' (Wilson, 1992, p. 182). However, we do know what happens in the case of certain individual ecosystems.

Ecological systems are capable of absorbing very considerable amounts of stress over extended periods without showing apparent harm but while this is happening their capacity for resilience is gradually being depleted. The moment comes when a critical threshold is suddenly crossed, followed by very rapid and 'unexpected' breakdown in some aspect of the ecological system – a condition of acute unsustainability.

The recent history of Big Moose Lake in the Adirondack Mountains illustrates this kind of abrupt ecological breakdown (Stigliani and Salomons, 1993). From about 1880 onwards, huge amounts of sulphur were deposited as acid rain in the watershed of the lake, from coal burnt several hundred miles upwind in the Ohio River valley. The burden of sulphur climbed steeply until 1920, when it stabilized at around 3.5 million tonnes a year. Yet it was not for another 30 years after this that the acidity of the lake water showed any change. The acidity of the water had held steady for 200 years – as long as it had been measured – but between 1950 and 1980 it suddenly increased tenfold, from a pH of 5.5 to 4.5, killing all the fish in the lake.

The explanation for the delayed but sudden onset of this environmental breakdown turned out to be that the soils in the watershed of the lake had provided an enormous buffering capacity that was able to neutralize the acid rain for six decades. Finally when

the buffering capacity was exhausted, the acidity of the lake abruptly registered a change that had in fact been initiated 60 years earlier.

If ecosystems responded to stress by showing continuous gradual degradation we might be justified in hoping for a similar pattern of response at the global level that could at least provide some degree of warning. Unfortunately many ecosystems don't respond like that – they absorb significant environmental impacts with no sign of degradation and then suddenly collapse without warning. The uncomfortable question that confronts us is whether the global ecosystem will show similar behaviour and the implication is that there could be abrupt ecosystem breakdown at the planetary level.

This possibility is explored in the book *Beyond the Limits* (Meadows, 1992), the 1992 update and revision of the controversial *The Limits to Growth* (Meadows et al., 1972). It describes a series of runs on a computer model originally developed at the Massachusetts Institute of Technology (MIT) called 'World3', which show in broad terms how the global system might react in the years ahead, based on a variety of different assumptions about resources and responses. When the World3 computer model was run to reflect continuing 'business as usual' economic activity, the result was a general collapse early in the twenty-first century. This is acute unsustainability with a vengeance – the equivalent of a fatal heart attack. As the book says (Meadows, 1992, p. 130):

On a local scale, overshoot and collapse can be seen in the processes of desertification, mineral or groundwater depletion, poisoning of soils or forests by long-lived toxic wastes. Legions of failed civilizations, abandoned farms, busted boomtowns, and abandoned, toxic industrial lands testify to the 'reality' of this system behavior. On a global scale, overshoot and collapse could mean the breakdown of the great supporting cycles of nature that regulate climate, purify air and water, regenerate biomass, preserve biodiversity, and turn wastes into nutrients. Twenty years ago few people would have thought ecological collapse on that scale possible. Now it is the topic of scientific meetings and international negotiations.

Our worldwide situation today bears an uncanny resemblance to the situation in late medieval England, when the population had soared from roughly two million to around six million over a 200-year period, reaching the limits of environmental and social organization of the time, triggering livestock disease and famines. Then the climate changed, with the onset of the 'Little Ice Age', and the Black Death struck soon after. The 'Great Dying' of 1348/49 alone killed 40 per cent of the English population in a two-year period, and the plague returned again in the 1350s and the 1370s. By the end of the fourteenth century the English population had collapsed to only 2.5 million from its peak of six million in 1300. It took 450 years for the population to recover from the calamitous experience of the fourteenth century. Today's graph of rapid demographic growth over a 200-year period looks eerily similar to the graph of English population up to 1300, except that it reaches a level exactly three orders of magnitude higher, six billion instead of six million, and encompasses the whole globe (Heinzen, unpublished).²

Continued exponential growth of the global industrial economy based on a source-to-sink flow of materials is genuinely unsustainable and can only be maintained for another few years at best. All the evidence about the relative scale and rate of growth of the economy in fact points towards the very real risk of an abrupt environmental discontinuity in the near future. For this reason a new pattern of organization for the industrial system is now urgently needed.

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Cyclic flow is sustainable

The alternative to a linear flow of materials is a 'cyclic' flow, in which materials continuously flow in circular loops and are reprocessed for reuse each time they reach the end of a period of use. A circular flow of materials has two main advantages over a linear flow, particularly when the linear flow reaches large scale.

One is that it avoids exhausting a finite environmental stock of materials, since it draws on the stock only once, to fill the loop, and then keeps circulating and reusing the material. In this way it ensures an indefinite supply of materials for the industrial economy.

The other advantage is that a cyclic flow avoids the pressures a linear flow exerts on the environment. At the start of the chain, extraction of materials often causes damage, for example, habitat and species loss, collateral pollution and changes to geological structures and hydrology. Similarly, the release of waste at the end of the linear flow puts a heavy and growing burden on the environment's limited capacity to act as a sink and processor for waste and pollution. The circular flow, or loop, creates a supply of materials that is independent of nature once it has been created and so does not exert pressure on nature.

A cyclic flow thus assures sustainability in two senses: the sustainability of nature and the sustainability of a society able to use a high level of technology. The creation of a physical 'cyclic loop' of materials is therefore one of the key aspects of securing sustainability at the material or physical level.

The 'loop' is the overall form of the pattern seen at the scale of the whole system but at a finer level of detail the cyclic flow would form a complex network or web of interlocking flows. This is similar to the way the overall circulation of the blood is evident at the scale of the whole body but seen through a microscope at the level of the capillaries it looks like a meshwork of small flows in a variety of directions.

At the most basic level the materials in the loop are the full set of elements we wish to use for practical purposes, such as copper, iron and silicon. In the case of minerals, it is easy to see that once they have been mined and refined, the resulting purified elements can then continue to be reprocessed and reused without requiring more mining. For example, enough gold has probably already been mined to meet all human uses indefinitely if it were to be put into circulation instead of being stockpiled in banks. In the case of organic compounds and structural materials from biological sources, the picture is more complicated, since the reprocessing and remanufacturing part of the loop may actively depend on nature for the tasks such as biodegradation and agricultural production. The scale of this production and the degree to which it may compete with food production then becomes a determining issue.

In contemplating an evolutionary transition of our industrial economy from a linear to a cyclic flow of materials we are following in nature's footsteps. The biosphere itself operates as a cyclic system, endlessly circulating and transforming materials and managing to run almost entirely on solar energy. The evolution of this global cyclic pattern from its early non-cyclic origins – about 2.5 thousand million years ago when oxygen first began to accumulate in the atmosphere – mirrors the transition that our global industrial materials processing system now needs to make.

The British scientist James Lovelock was one of the first to recognize that the web of life on Earth creates a set of flows and feedback loops that resemble the physiology of a regular organism – an inter-relationship he termed Gaia (Lovelock, 1979), the name of the Ancient Greek goddess of the Earth. Lovelock pioneered the study of planetary

physiology, or geophysiology as he calls it. Geophysiology can be understood as including geological processes, climatic and hydrological cycles, and ecology, all of which are responsible for materials flow in the natural environment. The overall aim of creating a circular flow of materials for industry is to accommodate the global industrial system – or more generally the human use of advanced technology – within the physiology of the whole planet on an ongoing basis. Put another way, this means creating a global technological infrastructure able to harmonize with the unique bio-geo-chemical processes and cycles of this planet.

As we learn more about the intricately interlocked workings of geophysiology, the detailed implications for industry are becoming clearer. Our own bodies provide an analogy for what needs to be achieved. We have within us biochemical processes that not only serve our own life, but also enable the bio-geo-chemical processes of Gaia. In a very literal sense, we are a functional part of the planet. Industry needs to be structured the same way – to serve human needs as well as planetary needs. Industry must become a cooperative (or at the very least not a harmful) part of the planet, of the life of Gaia.

The cyclic loop: the physical design

From a practical point of view, the cyclic loop has two distinct aspects that need to be considered. One is the physical design of the loop itself. The other is the idea of a circular flow considered as the basis of creating value. It is important first to understand the main aspects of the physical design as this sets key parameters for value creation.

The first question of physical design relates to the choice of materials that the loop will contain. There are two reasons why a limited set of materials might be chosen – recycling volume and stability.

Recycling materials is more economic if there are large amounts of material available for reprocessing and one way to achieve this is to focus on a relatively small number of materials. At present this is simply not an objective for product engineers. For example, one study in Australia showed that the components of a typical domestic washing machine contained in the order of 200 different materials. Yet it would almost certainly be possible to design all the components of a fully functional washing machine using only a dozen or so different materials. This has not been done up to now because there has been no motivation for engineers to focus on reducing the materials count of manufactured products.

The choice of materials could also affect the stability or resilience of the industrial facility that makes use of them. At the scale of an industrial production zone, the cyclic flow would be likely to take the form of an 'industrial ecosystem'. Industrial ecosystems are complex food webs between companies and industries that optimize the use of materials and make use of byproducts that would otherwise become wastes. A complex of industrial producers applying these principles has been referred to as an 'eco-industrial park'.

If an eco-industrial park is optimized to reduce materials use and waste, what happens if or when one of its component processes becomes obsolete, perhaps because the market for that firm's product has declined? Does the whole industrial ecosystem then become unviable? Or can structures of interlock be designed that allow for change, such as cleaner future technology?

One way of addressing these recycling and stability concerns would be to select a suite of elements and materials that offers an adequate range of physical properties for design engineers to use, allows production processes to interlock and provides ease of

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reprocessing. This suite of materials would ideally also be bio-compatible and eco-compatible (in other words, in the chemical form used, not toxic to organisms or ecosystems) and abundant in nature. The objective would be a fairly small set of acceptable materials, with long-term geo-physiological compatibility that could be used to provide say 80 per cent or more of all production needs. A first step towards identifying these materials might be to start by considering the 16 or so elements that are the most abundant in the biosphere, as these constitute both the large-scale cycles in nature and comprise the living molecules such as enzymes that both process the flows and form the physical basis of life itself.

The next step might be to devise clusters of production processes that use some or all these materials and which can be interlocked ecosystem-style. Focusing production activity on a small number of 'basic materials' would enhance resilience, because if one firm in an eco-industrial cluster failed, it would be more likely that another that used the same materials could be found to take its place. The resulting industrial clusters or industrial ecosystems would then stand a reasonable chance of being stable over time. The Zero Emissions Research and Initiatives (ZERI) at the United Nations University in Japan has shown that focused industrial clusters of this sort that aim for zero waste can make very good business, social and environmental sense.

The second physical design question relates to the amount of material the loop would contain. Once the flow of materials in the cyclic loop is established, does the volume of materials flowing in the loop need to be maintained at a given level, or can it be allowed to vary or grow?

At present the demand for industrial goods is rising exponentially. If all materials flowed in a cyclic loop and demand continued to grow exponentially, additional new materials would need to be added to the loop continuously to meet the growing demand. Under these circumstances the demand for virgin materials would be equal to the margin by which current demand for new materials exceeded the return flow of recycled material from previous demand. Even if demand was not growing when a new loop was being created, the demand for virgin materials would continue during the period when the loop was being primed or filled with materials, before the materials in use began to return for reuse.

Being able to avoid the use of virgin non-renewable resources would mean either that demand has ceased to grow, or if not that the materials intensity of economic output – the physical mass consumed per dollar of economic value created – is decreasing fast enough to offset the growth. In principle either of these would allow the amount of material in a cyclic loop to remain stable over time.

The phenomenon of declining physical mass per unit of value created is referred to as dematerialization, sometimes dubbed 'doing more with less'. As it happens, this kind of decline in the materials and energy intensity of industrial production is an existing 'mega-trend' in industrially developed economies, and in fact constitutes one of the long-run drivers of fundamental economic growth. Both materials and energy use (measured as quantity per constant dollar of Gross National Product or GNP) have been falling since the 1970s (Larson et al., 1986). This is because the market for basic products has saturated in developed economies, while the weight and size of many other products has fallen. For instance, the progressive miniaturization of information technology allows more product features to be added as product bulk is reduced. However, in spite of the dematerialization trend, the absolute growth in demand is still outstripping the rate of dematerialization,

which is why the total amount of materials used in the global industrial economy is still growing rapidly.

Assuming that the global population increases by up to 50 per cent and also becomes more affluent during the time a global industrial cyclic loop is established (say during the next 20 to 40 years), then reducing or just holding steady the amount of material in the loop will require accelerated dematerialization. The rate of dematerialization would have to equal or exceed the absolute rate of growth in demand, which is the product of population times per capita consumption. If the rate of dematerialization exceeded the rate of demand growth, this would represent a complete decoupling of materials flow rates from economic growth rates, allowing goods to be provided equitably for a growing population from a fixed or even diminishing flow of materials in the cyclic loop.

To achieve this level of dematerialization will require not only deliberate efforts by design engineers to reduce the mass of materials in use but also significant technological advances. Fortunately emerging materials technologies such as nanotechnology – which is beginning to enable assembly of materials atom by atom – promise to accelerate the dematerialization phenomenon by vastly improving the performance-to-weight ratio of materials.

This means that continued exponential growth in demand could potentially be offset by a dramatic dematerialization of the useful products created, to the point where the volume of materials in the loop could at least be kept stable. Assuming that this could be done, would this stabilization then allow a cyclic loop flow of materials to provide all the physical materials the economy would require without harm to the environment?

The answer depends on several further factors. One is the level of leaks from the loop. The cyclic flow of materials, like anything flowing in a large-scale engineered system, would inevitably suffer from unintentional losses – the failure to fully recapture all the material for recycling – which would then require replacement virgin material. The level of these losses could be reduced either by progressively improving the completeness of recycling or by reducing the volume of material flowing in the loop.

Another class of 'leaks' arise from design, not accident. At present the way many materials are used results in them being 'dissipated' or dispersed into the environment as they are used, with no hope of recovery for recycling. This problem can be overcome by designing differently. For instance, as car brake pads wear down they leave behind a finely dispersed toxic powder. In electric or hybrid electric cars, such as the Toyota Prius, this can be avoided by generating electricity as a means of braking. By having the wheels turn the electric motors during braking, the energy of forward motion of the car is converted back into electricity that can be returned to the battery or captured by a rapid storage device such as an ultracapacitor. This process, known as regenerative braking, causes the car to slow down without involving heat-producing friction or the dissipation of brake pad material in the form of toxic dust.

In general, if a particular usage of a material results in dissipation, then as far as possible that use should be minimized by a different (least damaging) choice of materials or by a design reconfiguration. This however, implies a broad assumption that all dissipative uses are negative. There are some counter-instances where dissipation is positive. For example, if zinc is added to mineral-deficient soil this involves the dispersion of zinc into the biosphere, but in this case there is a beneficial outcome. However, even this may run the risk of overdosing the soil, in which case monitoring is required, and the dissipative use needs to

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be curtailed at the point when it starts to have negative environmental or health impacts. Similarly, there may not necessarily be a problem releasing carbon dioxide to the atmosphere if emissions are in balance with absorption elsewhere. This is after all what nature does: dispersion of carbon dioxide into the atmosphere is the biosphere's means of moving carbon from sources to sinks. So the general principle is not as simple as 'zero emissions' but instead that the cyclic flow of materials should be maximized and any non-cyclic dispersion of materials into the biosphere should be consistent with zero biospheric harm (which includes human health). An extreme example of violating this principle would be the use of depleted uranium in armour-penetrating munitions, as on impact the uranium burns to a fine radioactive powder that disperses into the environment.

Energy supply is another factor determining the level of materials that can flow in the loop. The energy requirement for keeping materials moving around the loop can be significantly less than for producing new materials. To recover copper from scrap takes as little as 15 per cent of the energy requirement for smelting copper from ore, and atmospheric emissions of carbon dioxide and sulphur dioxide are also substantially reduced. Even in a loop, materials do need to be transported and reprocessed to keep them useful as they move around the loop, and this requires energy. For a given process or activity, the amount of energy needed will depend on the volume of materials in the loop that need processing.

If the type of energy in use produces a dissipative mass flow (such as carbon dioxide from fossil fuels), then the materials flowing in the loop would need to be reduced over time to reduce the dissipative flow from the energy consumption. For example, if the energy is provided by fossil fuels that cause an unbalanced flow of carbon into the atmosphere, this flow could be reduced if the demand in the loop for materials processing was reduced. So the type of energy used in the future for processing materials as they flow around the loop will determine whether the volume of the cyclic flow needs to be progressively reduced over time. If future energy technology moves towards low-carbon, low-waste sources, and if leaks from the loop can be minimized, then in principle simply stabilizing the volume of materials flowing in the loop would protect the environment.

As it happens, energy technology has been evolving in this direction over time. Energy sources have been 'decarbonizing' – their carbon content has been falling – for more than 150 years. As countries successively industrialized they moved from high- to low-carbon fuel sources, starting with firewood, then going to coal, to oil and recently to the lowest carbon so far, natural gas (methane) (Ausubel, 1989, p. 83). A completely carbon-free energy supply could in principle be provided using pure hydrogen gas produced from renewable energy sources, if the technical and economic challenges can be met. In one possible scenario this could lead to the creation of a future 'hydrogen-electric economy'. This would involve hydrogen gas (the lightest element), used as a clean, low-mass carbon-free carrier and store of renewable energy. Fuel cells could convert the hydrogen into electricity at the point of use, meshing with the increasing use of electricity-based technologies for efficiency, precision and convenience in final energy use.

In fact, a hydrogen-electric economy would itself form part of the overall cyclic loop since the hydrogen would flow in a continuous loop through the technosphere and back via the biosphere. The hydrogen would be generated from water using clean electricity from a wind farm or solar plant, transported by pipeline or tanker to the point of energy use, and used to generate electricity by fuel cells that release almost pure water vapour into

the atmosphere as exhaust. From there the water (hydrogen plus oxygen) would move through the natural water cycle, returning to the wind farm or solar plant as rain or surface water.

A further point related to energy for materials processing needs to be noted. Energy is required for materials processing when it involves the application of heat or pressure for a physical transformation, as in the melting of metal scrap for recasting or the movement of materials from place to place. However, when the processing of materials involves a chemical change or reaction, as in the case of processing mineral ore into metal, the situation is usually more complicated. In this case the energy carrier is often not simply supplying energy but also some mass that takes part in the reaction. For example, if the ore is iron oxide and the energy carrier is carbon, the chemical energy potential of the carbon (known as exergy) drives a chemical reaction that produces pure iron with carbon dioxide as a waste product. In cases of primary processing of minerals like this where the fuel supplied takes part in a process reaction, the laws of thermodynamics indicate that some level of waste may be inevitable (Baumgärtner and de Swaan Arons, 2003). However, in dealing with a cyclic flow of say, iron, after the primary processing of ore has been completed, it should be possible to continue cycling the refined material by incorporating it into an energy and materials 'industrial ecosystem' that has no net waste.

A further factor influencing both the level of leaks and the amount of energy required to run the cyclic loop is the velocity of the materials flowing in the loop. If the velocity increases, this will increase the energy requirements for reprocessing as there will be more material moving through the loop in a given time. High velocity would mean rapid capital stock turnover and new generations of products rapidly replacing earlier products, and would be needed for accelerated product dematerialization and improvements in the energy efficiency of products and production equipment. At a time of rapid technological change and high rates of innovation, a high velocity of materials flow through the loop may therefore be desirable as a means of reducing overall energy consumption and materials intensity. This follows the principle that the velocity should only increase where technological development is rapid enough to offset the additional energy consumption for increased materials cycling and reprocessing.

At present, while population growth is still rapid, the marginal energy efficiency of new technology is improving, but absolute energy consumption is increasing. This is partly because total market growth is outstripping the marginal gains in efficiency, and partly because the large potential for efficiency improvement is not being fully deployed in new production and infrastructure. If the full potential for improvement that now exists were to be applied in all new product design the growth in absolute energy consumption could be slowed. Actually reducing absolute energy demand will become more feasible as the world population continues to decelerate. Similarly, absolute materials consumption continues to grow rapidly, but is likely to be reduced in the future by a combination of advancing materials technology, design-driven dematerialization and population deceleration.

This overview of the physical characteristics of the cyclic loop sets the stage for thinking about the way business will need to change. The emergence of the cyclic loop will require a new way of thinking about business models. The existing way of thinking, which involves creating a product concept that can be scaled up to achieve high levels of physical growth, will no longer be the key to success when materials flow in a loop and the volume of cyclic flow is continually falling.

The value loop: creating business models based on the cyclic loop

Business activity around the world is the force driving the existing linear flow of materials through the industrial economy. Each business creates economic value by transforming materials to create goods and services people will buy. The result is a linear progression of materials through the industrial economy. Primary industry extracts materials from the Earth's crust or from the biosphere, then sells them to manufacturing industry, which converts them into products, which are then sold by retailers to consumers, who later discard them. This post-consumer waste, along with the waste generated at each previous stage, generally flows back to the environment.

Businesses are therefore linked by a linear sequence of transactions that Michael Porter described as the 'value chain'. Each business in the chain must have a 'business model' that enables it to earn marginally more money from its offerings than the amount it spends to buy inputs. The inputs embody materials on which work has been done by the preceding business in the chain.

Each business uses whatever materials and energy it needs to create value. The only limit placed on this consumption is its ability to purchase these inputs in the market. If the ultimate sourcing and disposal of materials, at the start and end of the chain causes problems, these are not considered to be the responsibility of the businesses using the materials in the middle of the chain. These environmental or social impacts may result in costs that economists call 'externality costs' (external to market costs) that must often be paid by society as a whole, but in general they are not linked back to the way materials are priced throughout the value chain.

The amount of material that a business in the middle of the chain must buy or sell to create a specific type of economic value is in general continually being reduced by technological advances. In effect these technology-driven gains in productivity represent the whole history of industrial development since the 1750s. However, as has been described, they are not enough on their own to eliminate the pressure on nature at each end of the linear flow, since technological capability also gives rise to these flows in the first place.

If the flow of materials through the economy were to be reorganized into a loop, the corresponding flow of transactions in business would also form a loop. The important question for business is what difference this would make to business activity. The most obvious adaptive challenges would be for businesses at the start and end of the value chain.

Mining companies, for example, would no longer be able to view themselves as a one-way source point for materials in the industrial economy. Their role in the value loop would be still be to supply concentrated, purified materials in specified physical forms to manufacturers who will convert these materials into finished goods. Instead of sourcing the materials by digging holes in the ground, they would be 'mining' the scrap flows from urban areas. Future business viability of these 'urban miners' would depend on having well-located plants in or near urban areas, much as today's miners rely on having concessions in highly prospective mineral provinces. This logic already determines the location of steel mini-mills that process scrap steel from old automobiles, as with the 40 hectare Rooty Hill steel mini-mill in the western suburbs of Sydney designed by BHP to achieve very stringent requirements for environmental performance and noise reduction.

The linear flow of material along the value chain progresses from 'raw materials' to 'end products' such as consumer goods. Businesses generally add value by putting materials in

progressively more organized states, so increasing their usefulness. In physics, the idea of less or more ordered states of matter is referred to as an increase or decrease in entropy. If no work is done on materials, their condition will gradually deteriorate towards thermodynamic disorder, and this is said to be an increase in entropy (the term is used counter-intuitively). At each step in the value chain, energy is expended and work is done on materials, reducing their entropy as they move along the chain. At any point when it is not economically useful to reduce the entropy of materials any further, they become waste, either immediately or after a period of use.

One strategy for reducing the negative environmental impact of materials is to retain materials in a useful low entropy state as long as possible. Examples include extending the useful lifetime of products or finding ways to directly reuse components. This strategy has its limits, and if advancing technology is making new more efficient generations of products possible, extending the useful lifetime may simply prolong, say, high energy use. It can therefore be necessary for materials to fall back to less-ordered, higher entropy states before they can once more be reorganized into new low-entropy states. This is the 'return' path of the value loop. The 'forward' half of the loop corresponds to the value chain, in that it involves a reduction in entropy, while the return half must generate economic value from a transient increase in the entropy of materials.

A key challenge of the value loop is to create business models that can generate value as the entropy of materials increases, or even better, to design loops in which the entropy is kept low as the material moves through a sequence of transformations, each one having some intrinsic value. The generic activity involved on the return path is to collect waste material and return it to a point where it can be reprocessed into new 'raw' material. This can be thought of as a sequence of steps, from product take-back, to product demanufacture and materials deprocessing. Some materials may move directly from product demanufacture to reprocessing, or a material deprocessing step may be needed first, depending on the formulation of the material. The demanufactured or deprocessed material will have value to the reprocessor as an input, although it is likely to compete unfavourably with mined raw material unless externality costs are taken into account.

At present, rising externality costs are leading indirectly to increasing waste disposal fees and return path business models are possible based on charging a fee for product take-back that is competitive with waste collection fees. This in effect subsidizes the demanufacturing and deprocessing steps, allowing the new 'raw' material to be competitive in price with mined material. This type of business model depends on legislation that has a narrow focus on regulating waste disposal. If in the future there is legislation that more broadly enables the value loop as a whole, the opportunities can be expected to shift.

It is useful to consider what form this legislation might take. New and proposed legislation in the EU for product take-back indicates that policy-makers are beginning to think in terms of mandating end-of-life product take-back for consumer products, while simultaneously requiring a minimum percentage of recycled content in new products. The EU End of Life Vehicles Directive of 2000 requires that carmakers pay for the cost of taking back and recycling old cars, starting with cars sold in 2001. One of the aims of this directive is to raise the reuse or recycling of the metal content of vehicles to 85 per cent by 2015, while also banning the use of hazardous heavy metals. This is leading car manufacturers such as BMW and Volkswagen to redesign their products to make them easier to demanufacture, and to use materials that require less deprocessing. The carmakers are adopting

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a cyclic loop business model that focuses on a target for recycled content, and uses redesign of the product to keep down the costs of the return loop, making it economically viable for third-party reprocessors. The benchmark for this viability will not, however, be the comparison with waste disposal costs, but the lowest competitive bid for fulfilling the manufacturer's take-back responsibilities. The manufacturer has an incentive for keeping this cost low, hence the product redesign, and it can be expected that product manufacturers and third-party reprocessors will jointly develop innovative systems for doing this at steadily lower cost.

Another approach is to avoid having the product ever become waste. One way of doing this is to lease the product to its user rather than sell it. Possibly the best-known proponent of this cyclic loop business model is Interface Inc., based in Atlanta, Georgia. Interface manufactures carpets but sells the services carpets provide, for example, replacing carpet tiles when necessary as part of the service contract. In the company's words:

Client carpet needs can be met initially and rejuvenated periodically, prolonging the useful life of the carpet. Large initial capital expenditures may be reduced and replaced by predetermined monthly billings. Monthly billings are actually a 'lease' on the flooring systems and the services associated with them . . . Interface continues to own the means of delivery (i.e. carpet) for its useful life in the building, ensuring that as product is replaced, it is either used again or reclaimed and recycled, and that it never ends up in a landfill.

However, the company does note that full cost pricing is necessary if the used carpet is to be financially worth salvaging to replace virgin petrochemicals. They comment: 'When the price of oil reflects its true cost, we intend to be ready.'

Yet another possible business model would be to brand and manage each material itself throughout the cyclic loop. At present it is not possible to supply certain global metal requirements from recycling alone, so mining is still a valid starting point for a transition to cyclic flows. For instance, suppose a major new copper mine were being established in say, central Kalimantan (Indonesian Borneo) – a plausible location given that it is one of the few remaining largely unexplored mineral provinces in the world – with the intention of developing a world-class example of 'sustainable mining'. The metal from the new mine would be branded as 'cyclic copper' and linked to the mine and the story of its location, its exemplary environmental performance, and the inclusion of the local people in the social ownership strategy of the business. The cyclic copper would be used by manufacturers willing to include the cyclic copper as a branded product feature, and able to retrieve and return it at product take-back. This would work initially in markets with take-back legislation where, say, luxury carmakers could highlight their environmental performance by using branded cyclic copper in their cars. Given that the copper would be embodied in products for about 10–15 years, after this time substantial amounts of copper would begin to return to the cyclic copper company. Supposing the mine had an expected working life of 30 years, the rising flow of recycled copper would smoothly replace the declining output of the mine during the second half of its life. From this point forward, the cyclic copper company would be the ongoing steward of a sustained cyclic loop of copper with a total mass equal to the entire output of the mine over its lifetime, providing an indefinitely sustained livelihood to shareholders and local people at the minesite. This would contrast with conventional mining operations that often leave a legacy of environmental, social and economic problems when a mine is exhausted.

Already, producers of toxic metals are being forced to think in this way, though without the benefit of ownership or control of the material throughout its lifecycle. Lead is toxic, and the lead industry could face significant constraints on its future markets if it cannot convince regulators and communities that its products will be handled in the safest possible way. The industry has launched a 'Green Lead' initiative to address the difficulty facing one or a few companies acting alone in meeting all of their environmental objectives, or in producing a genuinely 'green' product, without the involvement and cooperation of all the other companies they interact with. This collective industry response is paving the way for the development of a set of interlocking cyclic loop business models.

The need for new cyclic loop business models also applies to energy producers. The biggest linear mass flow from industry into the biosphere today is carbon from the use of fossil fuels. Alternative business models that can create economic value from selling less energy are therefore important while fuel sources contain carbon and other pollutants.

One approach is for energy companies to carry the capital cost of investments that improve energy efficiency on the customer's side and then to share the value of resulting energy savings with the customer. This approach to offering energy efficiency services can be effective but ultimately has limitations, as it is in tension with the company's basic role as a seller of energy. The sharing of savings will only work as long as it can be related to a pre-existing high energy-use context and will only come at the cost of lower long-term energy sales. If energy efficiency technology advances rapidly, this approach would be counter-productive as it would shrink the remaining market opportunity for both energy sales and the money value of available savings. Another way of putting this is that 'negawatts' (saved watts) can only be delivered in a system that delivers watts, and that every negawatt sold reduces the remaining market for watts, even if demand is growing.

Overcoming this dilemma would require a different business model, one that moved from selling energy plus savings of energy, to one that sold energy end-use benefits rather than energy. An electric utility could sell lighting services rather than electricity, measuring the service provided, light, in its own intrinsic units, lumens. The utility would own the customer's lighting system and would have a clear incentive to install the most efficient lighting technology available at any given time, as this would require the least amount of energy, reducing the utility's operating costs.

This approach would create value over the long term by riding the accelerating trend towards more efficient energy end-use technology. The economic gains from this long-run technology trajectory will flow to the owners and operators of the technology assets. Charging for energy service performance supplied (lumens, air temperature and so on), and creating a margin by consistently investing in and operating the latest and most efficient technology for providing the service (light, heat and so on), would yield a sustained revenue flow while reducing emissions of carbon dioxide and pollutants. Although this model would contribute to cyclic loop objectives by reducing linear mass flows, a more radical approach would be needed to achieve a true cyclic loop business model for fossil fuel use.

A further type of business model is possible, based on merging technological and business innovation, and co-designing the material flow and the business logic. In the energy field, an American technology-based social enterprise called Eprida is offering a sustainable energy technology that creates hydrogen rich bio-fuels and a restorative high-carbon fertilizer from biomass alone, or a combination of coal and biomass, while removing net

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carbon dioxide from the atmosphere. The process involves making charcoal from biomass in a sealed vessel, producing heat, steam and hydrogen. The hydrogen can be used directly as a non-fossil energy source, or it can be used to make fuels such as GTL (gas to liquid) biodiesel. Charcoal on its own can be used as a soil enhancer, increasing soil fertility and returning the carbon from the biomass to the soil and increasing fertility. The charcoal provides a substrate for microorganisms and fungi, which bind organic carbon to minerals to enrich soil. In the Eprida process, the charcoal is also brought together with ammonia, carbon dioxide and water, forming a nitrogen-based fertilizer that binds inside the pores of the charcoal. In comparison, conventional nitrogen fertilizer releases one molecule of carbon dioxide for each molecule of ammonia made, and is not retained in the soil, typically washing away and causing algal blooms in waterways. The carbon dioxide for this fertilizer step can come from burning coal, reducing the carbon footprint of this still extensively-used fossil fuel. The charcoal, plus ammonia made from about 30 per cent of the hydrogen from burning the biomass, will together remove 60 per cent of the carbon dioxide from burning coal, plus all of the sulphur and nitrogen oxides that would otherwise cause acid rain. The process makes it possible to burn coal and biomass and produce a slow-release nitrogen fertilizer bound to charcoal. This returns almost all of the carbon from the biomass to the soil in a stable form, enriching the soil and sequestering the carbon for up to several hundred years, thanks to the cooperative action of soil fungi. In addition, when used alongside a coal-fired power plant, it can remove much of the carbon dioxide from the flue gas.

This innovative energy system forms a cyclic loop for carbon when used with biomass alone, and also simultaneously forms the basis for a viable energy business and fertilizer operation. It may well be that this kind of combined technology system and business model design will prove to be the most powerful kind of cyclic loop business model in the future, simultaneously meeting environmental and economic objectives without the need for supporting regulations. It is also a loop in which the entropy remains low as the material moves through a sequence of transformations, each one having some intrinsic value in the overall process.

Conclusion

The aim of this chapter is to offer a new template for business thinking to supersede the familiar concept of the value chain. The concept of the value loop corresponds to the transition that needs to take place in the flow of materials through the industrial economy if sustainability is to be achieved. Although the objective of 'closing the loop' is well established in the field of environmental technology, it is not well known in the business community, possibly because no correspondingly simple value-creation principle has been articulated. This chapter explains the environmental pressure resulting from the existing linear flow of materials and presents the rationale for a shift to a cyclic flow of materials. The examples of value-loop business models offered here are only early indications of the way the value loop can be applied but hopefully they do provide a sense of what can be achieved.

Ideally, the concepts of the cyclic loop and the value loop will provide a framework that can enable business innovators and entrepreneurs to create economic value at the same time as addressing significant global environmental issues. This kind of business activity is vital if we are to create a sustainable future economy.

Notes

1. In his original article, Michael Porter refers to the value flow within businesses as the 'value chain' and the flow between businesses as the 'value system' but this distinction was subsequently overlooked.
2. The land area of Great Britain is approximately 24 million hectares and the land area of the Earth is approximately 13 billion hectares.

References

- Ausubel, J.H. (1989), 'Regularities in Technological Development: An Environmental View', in Ausubel, J.H. and Sladovich, H.E. (eds), *Technology and Environment*, Washington, DC: National Academy Press, pp. 70–91.
- Baumgärtner, S. and de Swaan Arons, J. (2003), *Journal of Industrial Ecology*, 7(2), 113–23.
- Cohen, J.E. (1995), *How Many People Can the Earth Support?*, New York: W.W. Norton.
- Heinzen, B., *Feeling for Stones*, unpublished.
- Houghton, J. (1997), *Global Warming: the Complete Briefing*, Cambridge, UK: Cambridge University Press.
- Larson, E.D., Ross, M.H. and Williams, R.H. (1986), 'Beyond the Era of Materials', *Scientific American*, June, 24–31.
- Lovelock, J.E. (1979), *Gaia: A New Look at Life on Earth*, Oxford: Oxford University Press.
- Meadows, D.H. (1992), *Beyond the Limits*, Post Mills, Vermont: Chelsea Green Publishing.
- Meadows, D.H., Meadows, D.L., Randers, J. and Behrens III, W.W. (1972), *The Limits to Growth*, New York: Universe Books.
- Porter, M. (1985), *Competitive Advantage: Creating and Sustaining Superior Performance*, New York: Free Press, pp. 33–61.
- Stigliani, W. and Salomons, W. (1993), 'Our Fathers' Toxic Sins', *New Scientist*, 11 December, 38–42.
- Vitousek, P.M., Ehrlich, P.R., Ehrlich, A.H. and Matson, P.A. (1986), 'Human Appropriation of the Products of Photosynthesis', *BioScience*, 36(6), 368–73.
- Wilson, E.O. (1992), *The Diversity of Life*, Boston: Belknap, Harvard University Press.
- World Wide Fund for Nature (WWF) (2002), *Living Planet Report*, Cambridge: Banson.

