Case Studies In TRIZ:
Renewable Energy Systems

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Abstract

The paper describes two case studies involving the application of TRIZ to renewable and sustainable energy systems. The work described in the paper builds on a substantial foundation of work in the environmental innovation arena supported by the European Government through the SUPPORT initiative. In this programme, a modified version of the TRIZ toolkit has been formulated specifically for users working in and around the area of sustainable technologies; delivering both education materials and bespoke problem solving tools.

TRIZ And Sustainability – An Overview

Since the mid 1980s, the load imposed by mankind on the environment has increasingly exceeded the capacity of the planet. In 2003, the discrepancy between load and capacity amounted to over 20% (Reference 1). While projections for the future vary wildly amongst the various environmental, governmental and commercial lobbies, a broad average suggests that we would need two Earth's in order to sustain the material demands we place on resources by around 2040. A stark contradiction is emerging, and it is one that does not allow a 'do-nothing' option. At the heart of the 'do-something' alternative is innovation. If we cannot keep on doing what we are doing to the planet, but we still want to maintain the lifestyle that the West in particular has become accustomed to, then clearly something has to change.

The TRIZ Ideal Final Result (IFR) concept points us to a future in which we get all of the benefits that we desire, without any of the cost or harm. 'Harm' in this equation encompasses all of those negatives – whether economic, environmental or social – that lie at the heart of the definition of 'sustainable'. The IFR is there to act as an end goal, but it is also there to define a direction of success: successful solutions, according to the concept, will deliver more benefits, less cost and less harm than the solutions they supersede. The implication of this direction is that, sooner or later, harm will reduce and we will live more sustainably. This is the good news. The bad news, on the other hand, is that given the choice between more benefits, less cost or less harm, the vast majority of consumers will put the 'less harm' option in a very definite third place. And why would they do otherwise? The consumer never asked for the harm in the first place, so why should they be expected to compromise their benefits and cost in order to have less of it? This phenomenon again leads us to the idea of contradictions and specifically the need to eliminate contradictions. The sustainability-focused innovator ought therefore to seek to reduce or eliminate the harm without compromising the benefits and costs.

This paper examines a pair of case studies, each of which has that idea of ‘sustainability without compromise’ as its focus. While neither can as yet claim to deliver ‘zero harm’, they can lay claim to challenging the status quo. More importantly, both cases are intended to serve the more important purpose of highlighting breakthrough-generating tools and strategies capable of being utilised in any kind of sustainable innovation situation. The paper follows on from a cluster of earlier papers focused on the sustainability topic (Reference 2, 3, 4) and from a recently completed EU-funded programme to assemble a TRIZ-based toolkit specifically at academics, consultants and engineers working in and around the sustainability arena. A final section of the paper provides more details of that programme. In the meantime, we move on to look at the first of the two case studies.

Wind Turbine Design

The first case study involves an evolutionary examination of wind turbine technology. The start point for the study was a small-scale, 50W turbine design that had been commercially available for some years. The first activity when considering how the design might be enhanced was to identify possible untapped resources in the present system. As is often the case, a significant part of this resource hunt used the Evolution Potential concept (Reference 5). Before getting into the details of the evolution potential of the 50W machine, it is worth spending a few moments to explore the Evolution Potential tool in the context of wind-turbines at large.

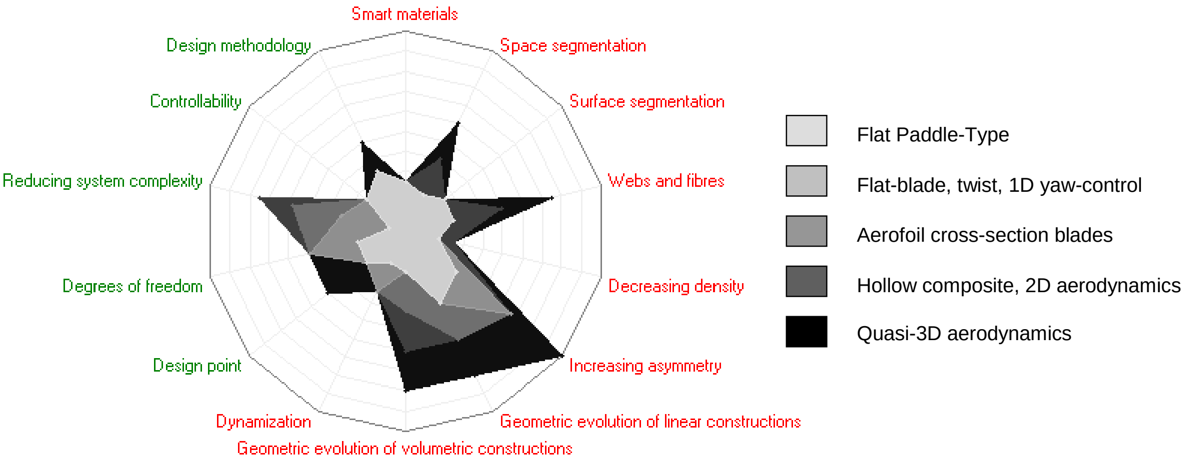
Reference 6 presented a useful review of the history of the evolution of wind turbines. As shown in Figure 1, that history spans a period from the late 19th Century to the present day. The reference paper describes how the performance of wind turbines, in terms of kW of useful power output per tonne of system weight has advanced from 0.25 to something over 9 by the end of the 20th Century.

Figure 1: Various Stages In The Evolution Of Large-Scale Wind Turbines

1888 1918 1956 1990

Over the course of the evolution of the design of wind turbines, the figure shows a number of significant design advances. The discontinuous trend jumps mapped in the Evolution Potential tool describe such jumps in generic terms. Figure 2 thus presents a summary of some of the major advances that have been observed. As per convention, each one of the spokes on the radar plot represents a discontinuous trend line, and the shaded regions represent the stage along each of the trends that the wind turbine had reached at different points in its evolution. The figure has been drawn for the blades of the turbines; other plots could have been constructed for other aspects of the overall design of the overall system, but since the aerodynamics play such a significant role in terms of overall W/tonne performance, this is where we will focus this analysis.

Figure 2: Evolution Potential Analysis of Wind Turbine Aerodynamics



The untapped potential identified in the figure emerges thanks to evolutionary advances that have occurred in other industries, but which have not yet found their way into the wind turbine aerodynamics sector. Each unused trend jump along each of the trends thus represents the opportunity to advance the capability of wind-turbines, taking advantage of the evolution directions that other industries have shown to be successful. The general rule of the trends is that ‘somewhere there is an advantage in moving to the more advanced trend stages. Without wishing to jeopardise any future intellectual property opportunities, Table 1 highlights a number of ideas that emerge when the untapped evolution potential is applied to the design of current turbine blades in general and the blades of our 50W machine case study in particular.

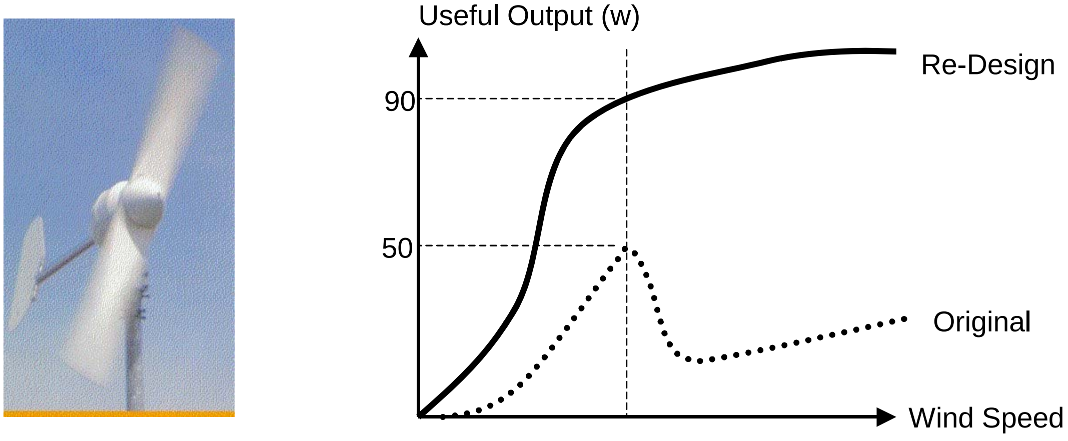
Table 1: Evolutionary Opportunities For Wind-Turbine Aerodynamics

Trend	Suggested Direction	Benefit
Smart Materials	Auxetic materials Shape-Memory Polymer	Improved impact resistance Self-feathering in high wind
Space Segmentation	Expanded foam plastic (Injection moulded) Free-floating elements	Improved strength/weight (Reduced material cost) Self-balancing properties
Surface Segmentation	Leading edge riblets Lotus Effect surface	Noise reduction Self-cleaning

	Dimples/protrusions	Improved efficiency
Webs And Fibres	Micro-fibre-composite Fibre aligned with loads	Strength/weight Improved stiffness in high wind
Increasing Asymmetry	End-bend rotor tips Blade twist	Improved vortex shedding Improved starting in low wind
Geometric (Linear)	Swept blades (‘sword fan’) Leaned/curved blades	Reduced tip speed/noise Improved gust stability/strength
Geometric (Volume)	Fully-3D aerodynamics	Improved efficiency/starting
Dynamization	Flexible/semi-flexible rotors Jointed tips Variable yaw control	Controlled feathering in high wind Improved controllability Improved off-design efficiency

Several of these ideas were subsequently incorporated alongside others not presented into the 50W machine blade design. While none of the ideas has yet been fully tested, CFD calculations predict a substantial improvement in performance without any compromise in terms of either the complexity or overall cost of the machine. Figure 3 presents the expected change in performance of the device – an almost 100% increase in overall output, with a considerable improvement in stability at different wind-speeds. While noise is notoriously difficult to predict, it is also anticipated that the innovations introduced into the design will also have a significant beneficial impact on the noise signature of the machine; this is important since one of the major complaints by wind-turbine opponents is the social harm caused by noise. The expected manufacture cost of the new blades looks set to be the same or lower than the current design, and so we expect to see a significant increase in the overall ideality of the system; more of the benefits *and* less of the harm.

Figure 3: Before And (Predicted) After Performance Of The 50kW Turbine



The discontinuous evolution jumps suggested by the Evolution Potential concept have now been encapsulated into a patent application. We are anticipating transfer of the idea to a production manufacture operation in the coming months.

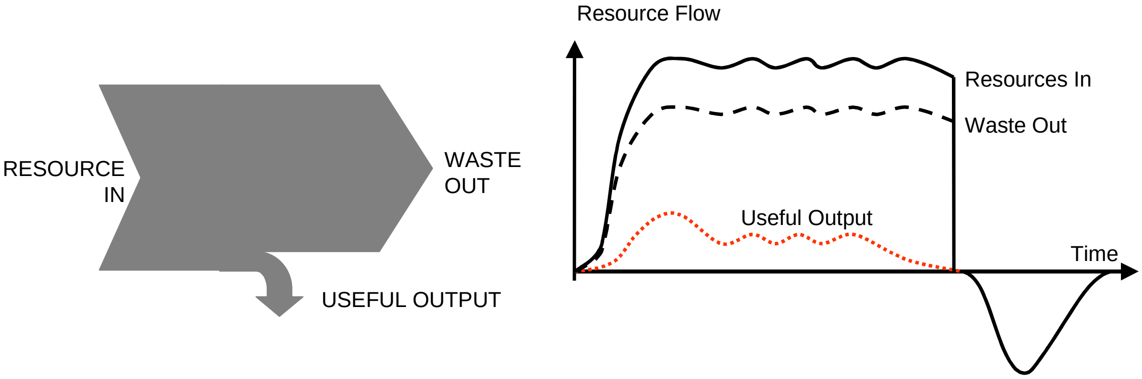
Odour Control

The second case study examines odour control processes within water treatment systems. In this case study, we first take a high level perspective of the problems of economically treating water and dealing with some of the adverse side effects caused during conventional treatment processes. We use this case study as a means of examining how function modelling and knowledge databases can help to generate win-win design solutions that are both sustainable and economically attractive.

The start point for the case study involves consideration of input-output diagrams. These diagrams are designed as a means of modelling processes from a sustainability perspective. As illustrated in Figure 4, any process – whether it be a man-made system or one found in the natural environment – may be thought of in terms of the flow of resources. Any process exists to deliver useful output. In the case of man-made systems this 'output' is the thing that generates the revenue that permits an organisation to generate revenue and hence survive. In a natural system, on the other hand, 'output' is essentially related to reproduction and, in turn, therefore, also survival. In either case, the creation of the useful output requires the inward flow of useful resources, which are transformed during the process into the useful output and, inevitably, waste.

As indicated by the diagram, the ratio of useful product to waste for any given process is often heavily biased in the direction of waste. In natural systems, the high level of 'waste' from one process (organism) is permissible because the waste produced by one life form invariably becomes the useful resource of another. In this way, over the course of billions of years of evolution, a complex network of balanced inputs and outputs has emerged. We might thus imagine millions and millions of natural systems each with their own input-output process map, each in turn linking with one another to form an intricate balancing act of inputs and outputs. The amazing self-organizing complexity of this network becomes even more apparent when we consider the right hand half of Figure 4 and the idea that each input-output diagram is a mere snapshot of an ever shifting equation in which inputs and outputs are constantly varying in order to accommodate the shifts taking place in other systems.

Figure 4: Input-Output Diagram Structure And Variation As A Function Of Time



In man-made systems this amazing flux-ridden balancing act is – alas – rarely present. The imbalance is particularly apparent in almost any commercially driven system. This imbalance occurs because the raison d'etre of the commercial enterprise is to maximise its useful output at the minimum cost. Commercial organisations have a largely unspoken but inevitable drive to externalise as much of the 'waste out' parts of the process as possible. By 'externalise' we mean that an organisation seeks – either implicitly or explicitly – to pass on the responsibility (and thus cost) of waste to someone else (Reference 7). Very often this 'someone else' turns out to be the environment. In the past, it was possible to simply dump waste into the environment because, even though it represented a change to the natural order of things, nature was able to compensate quickly enough that eventually balance would be restored. Latterly, of course, there are so many humans producing so much waste, that nature is finding it more and more difficult to keep up with us, and thus balancing the input-output accounts becomes more and more difficult to do. The imbalance is particularly apparent in our use of fossil fuels. The externalizing' of waste in this case comes in the form of CO_2. Nature has very little opportunity to restore the imbalance caused when we take carbon out of the ground and float it up into the outer atmosphere.

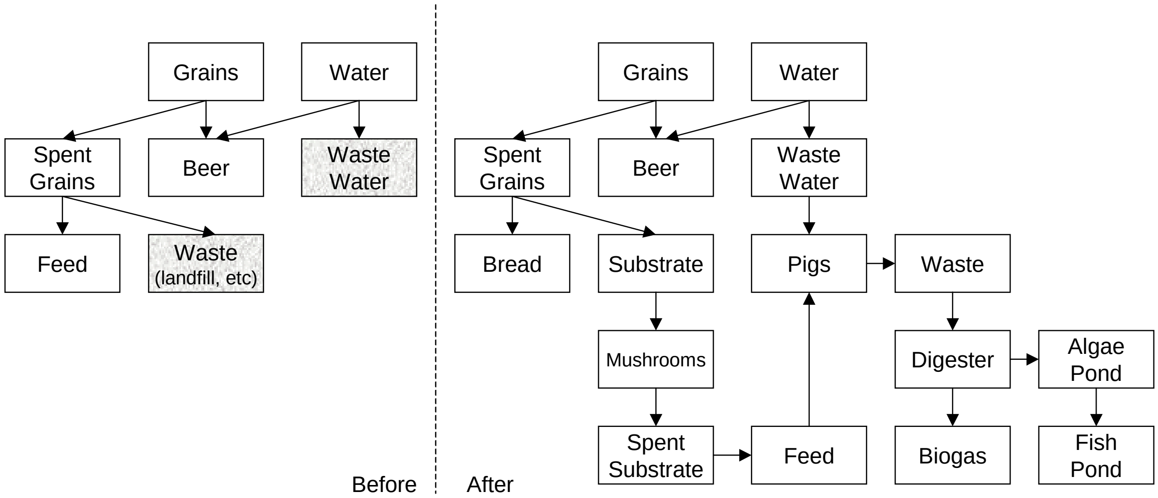
The ratio of useful output to waste in many industrial processes is quite shocking; we cut down forests and turn less than 25% of the materials into useful output. A typical brewery will extract less than 8% of the nutrients from barley or rice for fermentation and the other 92% goes to waste. Palm oil is a mere 4% of the biomass of a palm tree. Coffee beans are 3.7% of the coffee plant (Reference 8).

In many ways, sewage treatment plants are one of the better examples of the input-output equation given that they take a waste as input and manage to transform a considerable proportion into useful resources like fertiliser. One of the tiny 'wastes' from a sewage treatment plant is odour. That is 'tiny' in the sense of physical quantity. A few molecules of malodorous material blowing in the wrong wind, however, can very quickly turn into a barrage of complaints from the neighbours. Angry phone calls tend to count for more than a few grams of foul smelling gases in the corporate world, and so the utility companies will often go to extraordinary lengths to manage the odour problem. It is during the execution of these lengths that the input-output balance is likely to go badly astray. Odour treatment plants will typically consist of one or more of carbon filters, organic material filters, or wet scrubbers. Treatment plants are expensive to install and incur significant running and maintenance costs in the form of energy to run extraction fans, manpower, chemicals for scrubbers and replacement of filter materials. In addition, chimneys and exhaust flues tend to have to be installed at considerable cost. The input-output equation for odour treatment plants thus highlights a stark – as in several orders of magnitude – imbalance between input and useful output.

It is this imbalance that forms the focus of this second case study. The case started by considering the desire to achieve the function 'eliminate odour'. There are various TRIZ-oriented knowledge and effects databases around, but none specific enough to possess such a category, and hence it was necessary to build one in situ. Fortunately, this task becomes ever more easy to accomplish thanks to modern knowledge search tools. A wide-ranging search of the patent database and other deep-web sources then quickly revealed several additional means of achieving the desired function. Having a long list of candidate ways of doing a job, however, is often some considerable distance away from knowing which one best fits the specifics of the application at hand. This distance lies at the heart of the difference between ‘knowledge’ and ‘wisdom’. The problem of determining which out of a list of possible solutions is the ‘right’ one is further complicated by the fact that a solution that may not look viable in its current form, may well become the best solution in a modified form. Entries in a function database, in other words, may well just be the start that subsequently will require a series of modifications, combinations and other innovative steps to create a solution that meets the demands of sustainability. Adding a ‘sustainability’ criterion to the job of assessing whether a particular solution is good or not frequently leads to the need to construct a complex jigsaw of input-output models. The jigsaw is a useful analogy here since the sustainability aim is to produce a complete picture in which all of the pieces – inputs and outputs – fit precisely together with no gaps and no pieces left over.

Assembly of such jigsaw puzzles is a task often performed by the Zero Emissions Research And Initiatives (ZERI) organization – Reference 9. Figure 5, for example shows how a typically wasteful brewing process was transformed into a near 100% sustainable network of balanced inputs and outputs – a system in which waste from one process became useful input to another.

Figure 5: Traditional and Sustainable Brewing Process Models

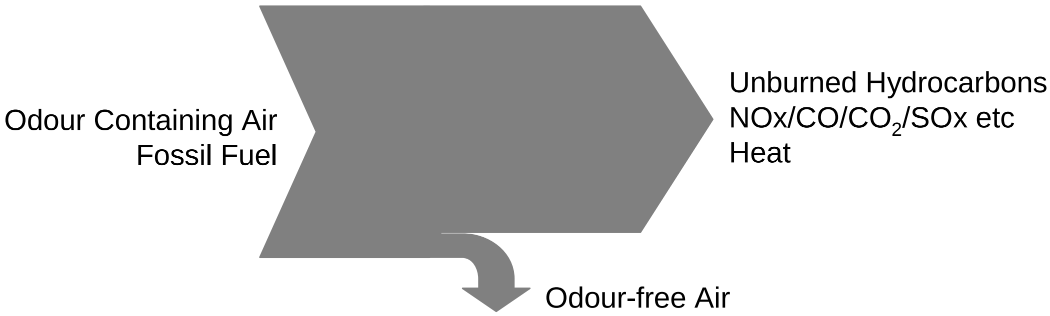


As a brief aside, it is worth noting that at the present time, the knowledge that allowed ZERI to re-design the brewery input-output network (e.g. knowing which algae can photosynthesise the nutrient solution output from the digester) has not been codified in a way that allows it to be readily picked up by others. While advanced data-mining tools can allow in situ creation of such databases, not many people as yet have ready access to them. The widespread availability of this kind of sustainability-focused, functionally-classified effects database would be a great service that the TRIZ community could help to create.

Meanwhile, back to the odour control problem; amongst the list of possible ways of removing odour was ‘combustion’: Pass organic material through a combustion process and it is highly likely that the odour-containing elements will be converted into something that does not possess any odour. The odour treatment industry has tended to favour active filters and scrubbers to combustion processes because their input-output equations are more favourable. Or rather, they are more favourable when considered in isolation. A filter on its own tends to look like a better solution to any kind of combustion process. But, taking the ZERI balanced-equation idea on board, we might ask how the equation would shift if the combustion process could be combined with other things? That was indeed the question we sat down to examine; was it possible to treat the odour while simultaneously balancing the input-output equation.

Figure 6 illustrates a simplified view of the various inputs and outputs present in a combustion process configured to remove the odour-containing matter in a gas. This input-output model shows a very high proportion of ‘waste’ outputs. Looked at as an isolated system – which is what the industry has thus far tended to do – it is little wonder that it is seen as an unattractive option.

Figure 6: Simplified Input-Output Diagram For An Odour Treatment Combustion Process

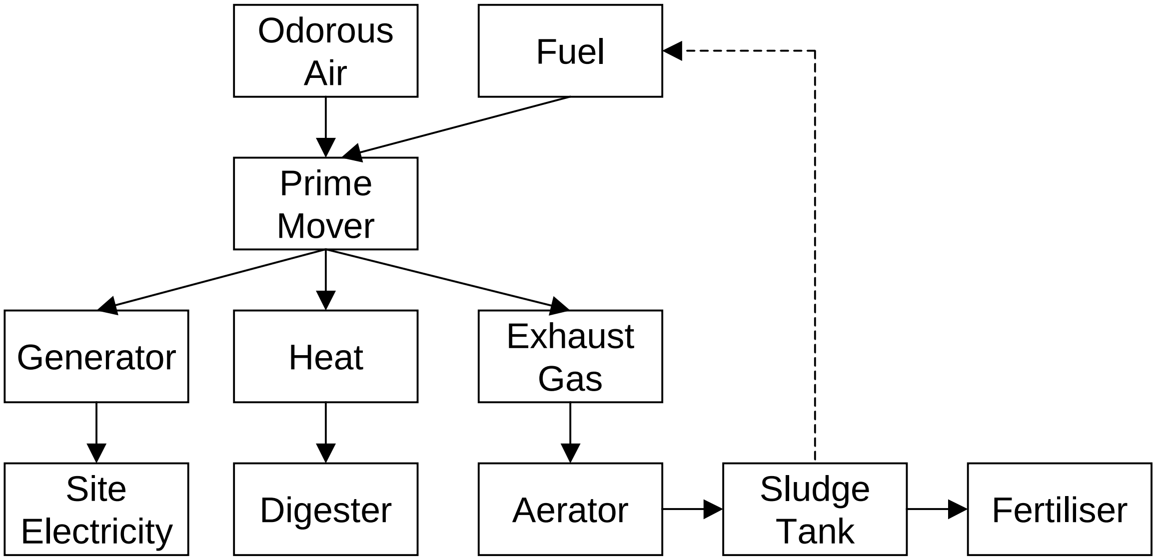


How, though, does that picture change if we find some way of transforming the ‘waste’ outputs into something useful? The combustion process input-output diagram thus becomes the first piece in a jigsaw. The other pieces start to appear as we identify ways and means of making positive use of the waste heat and the exhaust gas. The point of this discussion is more to describe a generic process rather than a specific solution and so we will not labour the specifics of the solutions derived for this particular odour control case. Nevertheless, when we had finished the overall input-output model looked something like the picture shown in Figure 7.

Thus we see that the waste heat generated by the combustion process offers an excellent complement to the existing sewage digester, offering the possibility of accelerating the digestion process by a factor of four or more and thus saving a considerable amount of time and money in both short and long term (where the improved efficiency of the plant obviates the need for additional plants as population demand grows). Similarly, rather than simply pumping the exhaust gases output from the combustion process to atmosphere, they can be used to aerate the sludge tanks and simultaneously clean up the majority of the emissions. The aeration offers the potential to massively accelerate the settling time, while simultaneously eliminating the need to run expensive stirrers and spray equipment. Another efficiency gain that emerges ‘free’ of charge.

By taking the combustion process a step further, it also becomes possible to drive a prime mover. Add a prime mover and you create the ability to generate either mechanical or electrical energy, which in turn can be used to power the plant; thus reducing the demand on the external grid system.

Figure 7: Network Diagram For An Integrated Sewage Treatment Plant



As shown in the dotted line, go yet another step further and some of the biomass output from the sewage treatment can be used as the fuel for the combustion process. By the time we reach this step, we are almost at the point where the input-output equation for the sewage treatment plant is totally balanced. With a little more careful thought, there is no reason why the equation should not only balance, but could produce a net gain. After all, the 'waste' that enters the plant is just one big river of resource.

As with the previous wind turbine example, the solutions generated during this case study are now the subject of a wide-ranging patent application. We are presently in discussion with a number of institutions to pull together a technology demonstrator programme.

SUPPORT Programme

The SUPPORT programme is an education programme incorporating the tools and techniques described in the two case studies presented here. The project was funded by the EU Leonardo da Vinci initiative. The 24-month programme was tasked with producing education materials presenting these and other TRIZ tools in a context appropriate to those wishing to create more sustainable designs. Successfully completing in January 2005, the programme has created and validated seven teaching modules:

1) sustainability context and need for innovation
2) sustainability measures and initial situation definition tools
3) situation definition tools – function analysis, Ideal Final Result, resources, etc
4) solution generation tools – contradictions
5) solution generation tools – trends of evolution and Evolution Potential
6) sustainability-oriented solution evaluation tools
7) project management strategies for sustainable innovation

The programme output now consists of a teaching book, electronic presentation materials and CD-Rom videos containing demonstrations of the materials in action. Reference 10 provides additional details and information on how to acquire the materials. Meanwhile, the programme has recently been extended to a number of other EU countries and in late 2005 we expect to have the materials translated and circulated into over a dozen European countries.

Summary And Conclusions

The wind-turbine evolution case study provides an example of how advances along the TRIZ discontinuous-evolution technology trends assist in the process of eliminating benefit versus cost or harm compromises and contradictions. The case shows how, with a few simple trend jumps, the efficiency of the machine was almost doubled and the noise signature reduced considerably, without any adverse impact on either cost or other harm factors. The TRIZ trends make the advances of other industries systematically available to others. In our experience of constructing many thousands of the radar plots, very few systems have used up more than half (measured in terms of area of the plot) of their available potential. Thus, any equivalent Evolution Potential analysis of other technical (or business for that matter – Reference 12) system will be highly likely to identify similar opportunities in other fields.

The odour control case study provides a demonstration of the process input-output map and the use of function databases and resource manipulation as means of generating more sustainable solutions. Most industrial processes seek to maximise output and minimise costs. This is the prevailing logic of corporate management. Balanced equations, however, can be seen to make sound economic as well as environmental sense. If an industry is presently sending 90+% of its input resources to landfill or the atmosphere as waste and one of the companies finds a way of turning some or all of that waste into useful revenue, do you think they gain a commercial advantage over their competitors? The logic is irrefutable; turning your waste into someone else's useful input is good for your business – not only do you not have to pay to dispose of your waste, you get to turn it into revenue.

Sustainability comes through recognition of the need to balance the input-output accounts. Historically, organisations have tended to minimise their costs by externalisation of the waste that they produce. In natural systems the waste of one process becomes the useful resource of another. In true TRIZ 'even the bad stuff is good stuff' fashion, the waste of one industry can become the useful input of another. TRIZ has a key role to play in facilitating the transition of such wastes into useful resources. Extension of the current function database concept will be a useful first step. As the odour control case study here has shown, that first step often needs to be followed by a second and a third, and maybe a fourth. Quite likely is the fact that the waste from one process cannot be *directly* input as a resource to the next process. Rather it needs to be modified in some way, by combination or segmentation or some other transformation. Very few breakthroughs are achieved by direct application of an existing idea. This is a cruel psychological inertia phenomenon – often experienced as the 'yes, but' moment. Yes we could use combustion to treat odour, but it is too expensive. We make one step and reach an apparent dead end. So we give up. The whole odour treatment industry has done precisely that. Apparent dead-ends, however, are not necessarily the same as real ones. ‘Yes, but its too expensive’ is not an end point, it is a start as far as TRIZ is concerned. This small step of viewing all of the ‘but’s as someone else’s potentially valuable resource is a giant leap towards a more sustainable future for all of us.

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