Survival is the driver for adaptation

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SURVIVAL IS THE DRIVER FOR ADAPTATION

SAFETY ENGINEERING CHANGED THE FUTURE, SECURITY ENGINEERING PREVENTED DISASTERS, AND TRANSITION ENGINEERING NAVIGATES THE PATHWAY TO THE CLIMATE-SAFE FUTURE

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ABSTRACT

Engineering has enabled the current western socio-economic paradigm that growth in wealth and material consumption can continue through innovation and technology development. However, the anticipation that green growth can solve the problems caused by fossil fuel utilization has not come to fruition. The Paris Accord in 2015 clarified the “climate failure limit” of cumulative fossil carbon extraction, but something has been missing; emissions have grown every year since 2015. The impacts of global warming already locked in as atmospheric CO$_2$ concentration reaches 420 ppm have put the survival of millions of people, plants, animals and ecosystems at risk. Consider a simple idea describing the time, space and relationship scales of survival. The proposed survival continuum concept represents a new way to think about sustainability that has clear implications for influencing engineering projects in all fields. The argument for survival as the driver for adaptation is developed sequentially, building on theory, definition, examples and history. The key idea is that sustainability cannot be achieved, but unsustainable systems can be changed. This work is called Transition Engineering, a new engineering discipline furthering development of the ethos at the heart of the field of safety engineering to longer time scale, broader space scale, and more complex relationship scale. The implication is that the past 100-year development of safety engineering can
be leveraged to fast-track the inclusion of sustainability risk management throughout the entire engineering profession. The conclusion is that a new, interdisciplinary discipline, Transition Engineering, is emerging as the way our society will achieve sustainability-safety through rapid reduction in fossil fuel production and use, and reduction in detrimental social and environmental impacts of industrialization.

INTRODUCTION

Technology enterprise is the ability of public and private human and financial capital to create, develop and deploy new technologies. After World War II the technology enterprise was directed to addressing the scientific and technological challenges defined by the Cold War, the space race, medical advancements, and the objectives of economic growth through innovation and generation of consumer demand for new products. By the 1970’s the large investments in engineering research and education had grown the technology enterprise to such an extent that unintended consequences of air and water pollution, resource depletion and waste management called into question limits to growth (Meadows, 1972). The Brundtland Commission (Bruntland, 1987) on sustainable development examined the range of environmental and social problems of industrial development and put forward directives:

“Sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs. We do not pretend that the process is easy or straightforward. Painful choices have to be made. Thus, in the final analysis, sustainable development must rest on political will.”

Clearly, the past 35 years of political will has not been up to the challenge of steering sustainable development. What has been missing? The United Nations has further developed the imperatives outlined in Our Common Future into the seventeen Sustainable Development Goals (UN, 2015). ‘Meeting our needs’ is rather subjective, and ‘considering the needs of future generations’ is not practically quantifiable, measurable or enforceable. One of the main problems is that neoliberal economics does not have a model for differentiation between essential, necessary and optional
activities and uses of resources. The market and the price are the rationale for production and consumption of goods. There are no mechanisms for including judgement about the essentiality of products or services for wellbeing, or for equitable access to essential goods and activities. There are ideas of including the costs of externalities in the price of goods as a way to reduce demand, but implementation has been limited. The international agreements acknowledging the severity of the problems created by seventy years of “business-as-usual” (BAU) have not noticeably affected the core attributes of engineering education or engineering professional practice that are at the core of the technology enterprise.

There are schools of thought about how societies either achieve sustainability, or they collapse. Anthropologist Joseph Tainter’s explanation of collapse of complex societies holds that socio-political complexity eventually fails to provide increased benefits compared to costs (Tainter, 1988). Jared Diamond proposed that societies either choose to collapse or they manage their resource and relationship situations through adapting shared cultural values in order to find some sustainable state (Diamond, 2005). The failure of complex engineered systems that most people depend on for all of their basic needs would represent a fundamental failure of the technology enterprise. Tainter and Diamond have not commented on the possibility of a development internal to the technology enterprise that changes the existing systems to correct for the modes of failure and achieve benefits within ecological limits.

Accounting approaches for sustainability have been proposed to include environment and society costs in the framework of conventional economics. Ecological Economics proposes ways to address the failings of growth-oriented classical economics by explaining how the world works and developing mechanisms and policies to make it work better (Daily, 2004). Sustainable growth as envisioned by Hawken Lovins and Lovins involves recognizing the four types of capital and increasing wealth while reducing resource use via increased efficiency, productivity, new technology and profits (Hawken, 1999). In recent years, corporations have Environment, Social and Governance (ESG) accounting and reporting, but has the practice changed the future, or is it greenwashing that perpetuates the business as usual (BAU) (Lashitew, 2021). In 1987 when the UN Commission on Environment and Development (UN 1987) sought to outline the need for strong economic growth that is socially and environmentally sustainable, the appeal to action was aimed at citizens, organizations, educators and scientists. Although nearly all of the environmental threats
identified were the result of engineered systems, the engineering profession was not mentioned. It is hard to set up requirements for engineering projects that involve the moral issues of our own needs weighed against needs of others who have no legal representation or economic participation. It is even harder for engineers to participate in socio-political decisions about collapse or complexity, let alone adopting new, non-standard economic accounting methods.

Limited evidence can be found that the philosophical, anthropological or economic arguments regarding sustainability have had a great impact on engineering education or the professional discipline. Commissioned reports and books on sustainability issues like peak oil (Hirsch, 2005) and global warming (Flannery, 2005) hardly give mention to engineering as either a source of problems or solutions. Even in research, engineering academics incorporating sustainability into education and research are rare (Christie et al., 2015).

The Natural Step (TNS) has emerged as a project-based approach to sustainability. TNS focuses on education of people in organizations about the system conditions of sustainability. The first question in a TNS project is ‘Does your organization have a definition of sustainability?’ (Nattrass and Altomare, 1999). This points to the crux of the problem for engineering. The first rule of engineering is ‘define the problem’. It is not a great surprise that the engineering professions have spent the past twenty years going about business as usual, including working on ‘green’ technologies that are perpetually ten years away from technical and economic viability. In a few engineering fields, notably air pollution, green chemistry and waste management, the goal to reduce environmental and health impacts of industrial pollution has seen great progress. On the whole, however, the engineering disciplines like petroleum engineering and mechanical engineering that are involved in fossil fuel production and conversion, need some flash point or break-through ‘unified theory of sustainability’ that fits with the principles and practices already established. In engineering we apply the things we know to be true from science, for example the Laws of Thermodynamics, in order to design to meet requirements or analyze performance against objectives. If society could define sustainability for us, then we would include it in the requirements.

Consider that a simple idea can circumvent the predicament of waiting for a ‘definition of sustainability’ and disrupt BAU engineering of industrial systems and products in order to address the risks of un-sustainability. Consider the scenario where all engineering professions will take up
Transition Engineering, in much the same way they have Safety and Hazards Engineering over the past century. Transition Engineering is emerging to achieve rapid adaptation of existing systems to reduce un-sustainability risks by combining existing change project engineering capabilities with the lessons learned from Safety Engineering. Transition Engineering has discipline-specific practices but impact across all disciplines.

The key to achieving the breakthrough disruption of BAU is an insight: safety, security and sustainability are all part of the same type of engineering work, changing systems that fail. This work is done to satisfy the moral responsibility to society, not the politics or economics. Figure 1 illustrates the idea of continuity of safety, security and sustainability as different dimensions of survival. Safety Engineering tracks accidents, near misses and hazards, and carries out change projects to avoid future failures. Through research and development, safety product design and operating standards workplaces, public spaces and products have become infinitely safer 100 years ago. The implications of this insight are that, just like safety, engineering in all disciplines will deliver the transitional research and adaptive changes that allow us, future generations and other species to survive our industrial success. An examination of the 100 years of Safety Engineering will demonstrate how survival depends on engineering first, then is enforced by policy and regulation, and finally economic benefits are understood. The current debates around sustainability of energy systems, water and climate focus on policy and economics and have not delivered progress in reducing un-sustainability risks. The conclusion of the argument is that currently practicing engineers taking up the projects of Transition will be the key to survival through adaptation.

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<td>Safety</td>
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<td>Time</td>
<td>Daily – Annual</td>
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<tr>
<td>Space</td>
<td>Immediate – Local</td>
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<td>Relationships</td>
<td>Individuals - Families</td>
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Fig. 1 The continuity of survival has dimensions across time, location and relationship scales. Survival depends on first engineering, then is enforced by policy and regulation, and finally economic benefits are understood.
INSIGHT: TRANSITION ENGINEERING IS THE WORK OF SUSTAINABILITY SAFETY

There is no doubt that engineered infrastructure, production and energy systems, chemicals and products are the primary source of risks to ourselves and future generations. Policies, behavior and economics do not produce dangerous atmospheric levels of CO$_2$ – burning fossil fuel does. The insight presented in this paper came as a flash of inspiration to the author after a thirty-year pursuit of sustainability via green technology R&D. The moment of inspiration is worth mention for the sheer frustration and impossibility of the situation. A round table meeting in 2007 of some forty top academics had completed a hard day of work and had concluded that the one thing needed before progress could be made was a definition of sustainability. The insight from this moment was that ‘No, you don’t!’ You don’t have to define sustainability; it is a self-defining term like safety or security.

Statement of the Law of Survival

Individual people, animals or plants, populations, social organizations, and species either survive or they don’t.

Corollary to the Law of Survival

Adaptation is the mechanism by which survival is achieved in response to change in habitat, circumstance, or resource availability.

This ‘Law of Survival’ is presented as a starting point for the Survival Spectrum theory which puts sustainability into the engineering workflow in a similar manner to safety and security. We must start the theory development with an agreed point of truth. The theory expresses the non-negotiable nature of survival. Survival is another self-defining term. Indeed it is only achieved if its negative is not realized. Simply stated – you either survive or you don’t. There is no conceivable debate about this law as there might be about the possible mechanisms of failure, such as climate change or peak oil. Survival is not a human construct like economics or politics. Survival does not have any particular means of success. Indeed, survival has as many manifestations as there have ever been individuals or species or organizations or civilizations or situations. The determination of survival
depends on the identification of a particular individual, organization or civilization, their characteristics and an appropriate time scale. A system boundary must be set to define the individual, organization or civilization before applying the Law of Survival.

The Corollary might present a bit of controversy on how adaptations come about, whether through natural selection, divine will or conscious choice, but the fact that species and groups do adapt to fit their habitat should not be contentious. The next step in the argument is a full definition of what adaptation means. The following definition is adapted from a dictionary, so will be taken as given (Encarta, 2009).

**ad·ap·ta·tion**

1. the process or state of changing to fit new circumstances or conditions, or the resulting change

2. something that has been modified for a purpose

3. the development of physical and behavioral characteristics that allow organisms to survive and reproduce in their habitats

4. the diminishing response to a sustained stimulus

The first three definitions of adaptation are accurate descriptions of Transition Engineering if taken in the sense of purposeful changes in the built environment, infrastructure, technology, products, systems etc. The fourth definition is interesting because it is clearly also possible for humans to adapt to situations that are bad and getting worse. An example is the time spent in rush hour stop-and-go traffic by people in modern cities. It seems undesirable to sit in a car going nowhere, yet people adapt to doing it. In fact, technology also has adapted in this case, as one of the primary design objectives of a hybrid vehicle is to stop the engine while still operating the comfort and entertainment systems for occupied vehicles, thus reduce idling pollution during gridlock.

Change of behaviors or characteristics is how we survive when our systems are not sustainable. The Classic Maya civilization of Mexico and Guatemala is often taken as an example of a civilization that was not sustainable, collapsed, and thus did not survive (Greer, 2008). The Classical Maya civilization (250 A.D. – 900 A.D.) undetook a relatively short period of massive growth in
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building, agriculture and population. That particular civilization was not sustainable, it grew then collapsed. However, hundreds of thousands of individuals obviously survived throughout the whole period of decline. Indeed, Maya culture and Maya people are alive and well today, despite disease, warfare and slavery imposed by Spanish colonization from the 15th Century. The people of the Maya have adapted to everything from empire building and collapse to colonization to tourism.

**THEORY: SURVIVAL MEANS NOT FAILING AT SAFETY, SECURITY OR SUSTAINABILITY**

The law of survival must be applied to a specific dynamic entity, which was described as an individual, an organization or a civilization. This is because survival has three-dimensional scales of time, location and relationship as shown in Figure 1. Individuals survive another day or another year if their immediate habitat and work places have a good degree of safety. Safe handling of water, food, refuse and fire has reduced the most immediate risks to health that have threatened survival for most of human history. The industrial revolution brought a vast array of new safety issues in the home, transport system and workplaces.

Human organizations and towns will survive if the supply of resources and trade goods is secure, and if they can recover from natural disasters or conflicts. Security is a longer-term survival issue, on the scale of lifetimes or generations. Security risks involve relationships with local resources and with trading partners. To some extent, international and interregional trade reduces exposure to risks of local crop failure or lack of local access to vital materials and nutrients. Infrastructure planning is key to reducing risks of natural disasters. Diplomacy and communication reduce the risks of hostilities and war. The security scale is also appropriate for organizations like businesses and religions.

Civilizations and species survive for very long, even continuous time frames if they overcome the risks of collapse or extinction. One way this can happen is for the species to fit into their habitat successfully regardless of global changes. Sharks seem to be a good example of this in the natural world, and aboriginal Australians have had a continuous civilization for over 30,000 years. Part of the reason for the sustainability of the aborigines may have been luck of location, as Australia was
not covered by ice during the past ice ages. Australia was also isolated from other humans, so the pressures for change were not present that have led to adaptation and change in other civilizations. Extermination is a sustainability risk to species and peoples that of course precludes the possibility for successful adaptation. Gradual changes in climate and global systems, both human and natural, will either drive adaptations or they will drive decline and collapse. Survival in the long term, known as sustainability, is either achieved through adaptation or it is not.

**Definition of Sustainability**

In the introduction the argument was presented that sustainability is a self-defining term that is defined and measured by its negative. The reason people keep asking this question is because they do not like the answer. Sustainability is not a particular state or set of technologies or even policies. Sustainability is survival in the long term through adaptation. Resource use, energy use, agriculture, technology, values and behaviors adapt so that the civilization’s activity systems fit with what is available, or they fail and are replaced by different activity systems, or different civilizations. Rich countries have adopted a belief that they are not susceptible to failure because of their economic practice and their technology innovation. Transition Engineering requires objective assessment of the risks being created by the politically and economically successful engineered systems, and undertaking change projects to adapt these societies to live within the local and planetary limits.

Adaptive changes for survival represent a balance between benefit and risk. At any given time, individuals and populations have particular characteristics that are the result of cumulative historical adaptations. These characteristics include everything from language, knowledge, tradition, religion and shared cultural values to technology, infrastructure, skills, domesticated species and materials. There cannot be any adaptive change without taking some kind of risk. Industrial revolution changes created risk by changing environmental energy balance and ecosystems in unforeseen ways. Industrial history is full of these unintended consequences. The unintended consequences are usually on a different scale than the benefits. Benefits of a change or development are usually immediate and local, but the negative consequences may affect people in other regions, later generations, other species, or may accumulate over time on a global scale. Accurate modeling and communication by Transition Engineers who find ways to include complex systems connections in their risk-benefit analysis will be vital to the successful adaptation of our activity systems in this
century. Using the different time scales in the continuum of safety, Transition Engineering proposes that engineering analysis, modeling and design can innovate adaptations to reduce the risks of unsustainability by adapting man-made systems to downshift of energy and material consumption.

**Role of Engineering in Survival**

The role of engineering in survival has probably always been profound, particularly if you consider engineers to include anyone who applies scientific observation and testing to figure out how to do useful things. Think about the people who figured out how to preserve the food value of milk in the form of cheese, or the carbohydrates in grapes as wine. There have been countless technical and processing innovations that have increased capacity, reduced spoilage risk, increased efficiency and, it seems, inevitably increased human footprint. A large number of engineering developments of the past four hundred years have been adaptations to growth in resource extraction and use, and growth in a range of capabilities, i.e. communication, computing, medical treatment and warfare. The immediate benefits to particular businesses and consumers are obvious, but the longer-term and larger scale environmental risks and the pressures on different populations and ecosystems have led to a range of problems.

These problems of un-sustainability have been obvious for many years. The engineering professions have responded by pursuing innovation and development in clean energy and clean technologies. There have been many successful developments like emissions control on coal power plants that reduce particulates and replacement refrigerants that don’t deplete stratospheric ozone. However, it is clear that even with all of the clean technology improvements conceivable, industrial society as we know it will have to change dramatically to adapt to reductions in fossil fuels consumption and depletion of material. According to the Law of Survival, the activity systems dependent on continuous growth of consumption will thus either adapt to decline of consumption or they will fail.

It seems obvious that the role of engineering in the future will involve the work of changing existing complex systems in order to adapt and survive by downshifting unsustainable energy and consumption practices. The problem definition in all fields will include *constraints* on energy and materials supply and constraints on environmental and social impacts. Engineering to constraints is not a problem when only technology considerations are involved. But because of the complex nature
of the energy and material systems, behavior, politics, economics and social values are also involved. How can engineers from every discipline possibly take on projects that significantly change the way things are done when there are not direct political or market drivers? The answer is simple; it is the right thing to do and researchers will develop a methodology that works to achieve the objectives.

**History of Safety Engineering**

The growth of extractive and manufacturing industries by the turn of the 20\textsuperscript{th} Century was generating immense profits, pollution and social problems. Safety, particularly workplace safety, was so poor that deaths and injuries were commonplace. For example, in the four years prior to 1911, worker deaths in American coalmines totaled 13,228. On March 12, 1911, the Triangle Shirtwaist Factory in New York City had a fire that cost 146 workers their lives (MacDonald, 2011). Fires and accidents were common in factories at the time, but this tragedy became a focal point for public outrage over the state of workplace safety, and a trigger for change in the engineering profession. At the time of the fire, 27 buckets of water were the only safety measures provided to workers and there were no fire or workplace safety regulations in place. When the fire broke out, workers found most of the buckets empty. When the workers, most of whom were young women and girls, tried to escape the flames, they found the only un-locked doors opened inward, effectively being held shut by the press of people trying to escape. The ninth-floor fire escape led nowhere and collapsed when workers climbed onto it. The ladders of the municipal fire department were too short to reach the upper floors, and the water pumps could only get water to the sixth floor.

Over the course of several hours the people of New York looked on in horror as most of the young women jumped over 100 feet to the street below rather than burn to death, many of them in groups holding on to each other. Over the days following the tragedy, more than 100,000 people marched through the streets of New York City, mostly in protest, and more than twice that number lined the streets in support of the marchers. Later that year a group of mostly factory engineers founded the United Society of Casualty Inspectors with 62 members and declared that all of the deaths were preventable. In response to the public outrage over the Triangle Shirtwaist Factory Fire, the USCI set out some of the most basic fire safety regulations we now take for granted, and which were soon after adopted by New York State.
In 1914 the USCI became a national engineering organization, the present American Society of Safety Engineers (ASEE), as state after state passed the fire safety regulations. The practitioner’s commitment to increasing workplace safety increased apace with public awareness and the worker’s movement. In 1921 research led to the invention of eye protection goggles. In 1924 the first respirators replaced handkerchiefs in chemical factories. By 1933 safety manager training programs had grown in response to industry demand. In 1936 the first chemical exposure limit based on health hazards was set. In 1937 the industrial standards movement was underway and had moved into transportation and heavy machinery. Thirty years after its founding in New York, the ASSE had well over 2000 members and was producing data sheets, training materials, pamphlets, and posters, and many members were actually working in the insurance industry, helping companies to avoid workplace accidents (ASEE, 2011).

After World War II the work of the ASSE accelerated greatly, with research into fall protection, foot protection, eye protection, hard hats, visibility, etc.; virtually all of the things that now make the total safety approach a normal part of the work environment. The ASSE has grown into an international organization, which provides specialist and general training and certification of practitioners. Even though the ASSE focuses on research and specialist training, it is also important to understand that safety is seen throughout all engineering professions as a responsibility inherent to good practice. In 2000 an OSH study found that every $1 spent on safety saves $4-$6, but there is no suggestion that money is the reason for good safety practice. Rather, engineers put safety at the forefront of design and operating considerations because it is the right thing to do.
There are important lessons to be learned from the history of safety engineering.

- 100 years ago there were no safety regulations and safety was appalling
- Safety Engineering was born out of public outrage over a preventable tragedy
- A tenet of Safety Engineering is to be honest with businesses and the public about risks
- Safety changes and adaptations are not economic or market driven
- Safety innovations are developed through research and engineering
- Safety regulations came after safety engineering standards
- The public and businesses expect and trust engineers to address safety
- Behavior can be and is informed and managed for safety via training and signaling
- No one asks, “what do we mean by safety?”
- Engineers in all fields implement safety considerations by looking for unsafe elements

TRANSITION ENGINEERING

Transition Engineering is the research and application of state-of-the-art knowledge to bring about changes in existing engineered systems in order to improve the odds of survival (Krumdieck, 2014). These changes are largely adaptations to existing systems developed through research. Transition engineering projects are easily identified by risk analysis. Transition engineering projects focus on reducing the risks of unsustainable energy use, resource consumption, environmental impacts and social conditions.

Engineers are activated by the collective moral outrage of society when failures occur. Groups of engineering professionals and researchers respond to the un-acceptability of failure by organizing and getting to work on ways to change what is preventable. Market signals and policy directions follow Transition Engineering developments.
The theory of a continuum of engineering discipline to ensure survival has been set out. Safety Engineering is a field of Transition Engineering that addresses the near-term, immediate aspects of survival. Natural hazards engineering deals with prevention, response and resilience to rare, longer term disruptions. Environmental Engineering develops ways to reduce emissions and waste, usually in response to scientific findings of the harm being caused. These engineering fields are sanctioned by public outrage when failures occur. They are also carried out and advanced continuously through research and practice because they are the right things to do. Policy and regulation then require best practice in fire safety standards, earthquake building codes or stack emissions after the engineering professions develop them. None of the existing fields of Transition Engineering are stalled waiting for the market or social signals about what safety or security mean. Indeed, part of the engineering job is using the existing scientific evidence to set limits, then work on achieving them.

The difficulty experienced in the sustainability engineering area is that engineers, scientists, policymakers and stakeholders may be thinking about different parts of the transition engineering process, and thus often end up in communication impasse. Safety Engineering is a good model again because the systems approach, working with the big picture as well as the internal processes, is effective at transitioning existing facilities and operations to better safety outcomes. Safety engineering has a straightforward methodology that has widely trained and followed in all businesses and industries (Vincoli, 2014). Figure 3 illustrates the step methodology and engineering processes involved in Transition Engineering of complex systems. Firstly, the particular system to be subject to transition must be defined according to the specific place and the essential needs that it meets. This problem definition places the work into the context of survival. Because the failures of unsustainable systems are on a long timescale, the first step is to study the place and the provision of the essential need through the lens of engineering, but also considering the complexity of social, economic and political context. Another novel aspect is the third step with uses engineering calculations to model the scenarios for technology solutions that are considered as options by the population in the particular location. There has recently been scholarly work done to examine some of the politically vetted scenarios and pathways for technology development to provide sustained growth, and they have highlighted the problems with ideas such as hydrogen and carbon capture and storage (Mruphy, 2021). The other critical step is ‘time travel’ to the same place 100 years into the future where the society has not only survived but has thrived without exceeding environmental constraints and energy and material limits.
The diagram of the Transition Engineering processes in Figure 3 was first presented in conference discussions, and was the subject of more than 15 years of research into adapting transport systems to 80% lower oil use (Krumdieck and Dantas, 2008). Each of the steps is clear in considering the history of Safety Engineering. The first steps involve auditing records, monitoring and scientific investigation to understand where safety problems arise. Scenario thinking is used to explore possible future trends identify unacceptable risks of continuing business as usual without remedial changes.


The fourth project of path-break concepts is mostly the work of research and innovation, but in the case of Safety Engineering may have also included expression of a key idea, the preventability of failures, e.g. deaths in factory fires. The trigger in the case of factory worker safety was the
Triangle Shirtwaist Factory Fire tragedy. However, similar trigger events can be traced for other safety areas and security initiatives.

Back-casting points out what could have been done differently and what measures would most immediately reduce safety risks. Once on the path of preventing injury and death, the SE experience shows that progress toward a safe workplace involves many types of projects in all types of complex situations. However, we also see that the progress can be rapid and the transition remarkable when the engineering is done from a leadership position in response to social values. The final part of the transition is the enforcement of the new standards, training and equipment through policy and regulation.

**DISCUSSION**

Transition Engineering for long-term, global survival of people who live in a complex, democratic, industrial society has begun to emerge in response to realizations of environmental threats to survival as in the case of ozone depletion. A new trigger event for reducing oil consumption may have occurred on 20 April 2010 when an explosion on the Deep Water Horizon oil platform initiated the worst environmental disaster in the history of fossil fuel production. There is no question that oil spills, flaring and groundwater pollution have been continuous and disastrous for over the past seventy years. Until this point, like factory worker deaths in 1911, these environmental disasters were the price of progress and were tolerated in the face of powerful business and political interests. Hopefully, the Deep Water Horizon oil spill is a big enough disaster, and a larger one, like a nuclear power plant melt-down, will not be required as the trigger for the initiation of Transition Engineering.

This paper presented several ideas and an argument. The first idea is that survival is an absolute condition defined by its failure not by any particular characteristics. Survival was explained to be accomplished by the mechanism of adaptation. This led to the description of the *Survival Spectrum* as having multiple dimensions; safety, security and sustainability, and scales; time, location and relationship. The argument was made that safety cannot be defined except by failures, and that this is true for the other dimensions of survival. A brief history of safety engineering was presented to illustrate how engineering to reduce the risks to survival due to preventable failures has developed. Importantly, it was shown how the initiation of safety engineering was in response to public outrage.
over a tragic factory fire in 1911, and how policy and regulation followed the engineering work. Finally, the safety history illustrates how economic or market signals are not effective or necessary signals for survival.

The conclusion of this discussion is that no further time should be wasted trying to define sustainability because the *Survival Spectrum* shows how addressing un-sustainability, and in particular preventable failures, is the top-priority for Transition Engineering projects. The un-sustainable aspects caused by the technology enterprise of our current industrial civilization can be addressed by adaptation of the existing systems to reduce the un-sustainability risks through the new discipline of duty of care for transition amongst the professionals engaged in the technology enterprise. This argument leads to the conclusion that the critical Transition Engineering projects today are reducing energy and materials demands. Further, this argument suggests that the technology enterprise could begin working on these projects in a similar manner to Safety Engineers – because it is the right thing to do. The technology enterprise, including academia, corporate and public organizations cannot take the approach of waiting for government leaders to find solutions, or for the market to send the right signals, as this would present a high risk of system failure, otherwise known as collapse.

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**REFERENCES**

ASEE ‘A brief history of the American Society of Safety Engineers’


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Murphy, T.W. Jr., Energy and Human Ambitions on a Finite Planet, 2021, online textbook accessed 28 May 2021 at: https://escholarship.org/uc/energy_ambitions
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