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AN INTRODUCTION TO TRANSITION ENGINEERING AND ITS IMPLICATIONS FOR THE PRACTICE OF STRUCTURAL ENGINEERING IN NEW ZEALAND FROM 2021-2035

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SUMMARY

The “Zero Carbon Act” will be implemented from 2021, gradually altering the objectives and constraints driving professional engineering practice in New Zealand. Sluggish reductions in New Zealand’s emissions to date indicate that we are yet to:

a) recognise and adopt the engineering constraints associated with the climate crisis,
b) envision and evaluate future options for preserving the climate, and
c) generate practical projects that result in a significant reduction in fossil energy use.

Transition Engineering is the interdisciplinary field that addresses these problems. Key Transition Engineering concepts are summarised in this paper, then used to identify implications for structural engineers over the coming decade.

INTRODUCTION TO TRANSITION ENGINEERING

What is Transition Engineering?

Transition Engineering is a field of research and practice that applies engineering principles to the task of shifting development away from unsustainable activities. It is an inter-disciplinary field with its own fundamental concepts, methodologies, and techniques, and has emerged from the related disciplines of sustainability and renewable energy.

The methodologies of Transition Engineering have been developed to address the mega-issue of global climate change by implementing an “energy transition” away from the use of fossil fuels, but the same tools are capable of being applied to a wide variety of social and environmental challenges. Transition Engineering is at its best when it is used to implement a clear future vision of ‘te whai oranga’ (‘possessing wellbeing’, Freeland 2020), leading to the regeneration of existing systems to achieve multiple benefits through one project investment.

Transition Engineering speaks to the engineering work of the energy transition – what engineers will be able to do and how we will do it – rather than sitting back and waiting for politicians, economists, companies, or consumers to act. However, the InTIME Methodology is also proving to be a useful tool for helping communities and organisations to explore big shifts in development away from unsustainable activities. Key milestones in the emergence of Transition Engineering are outlined in Figure 1.

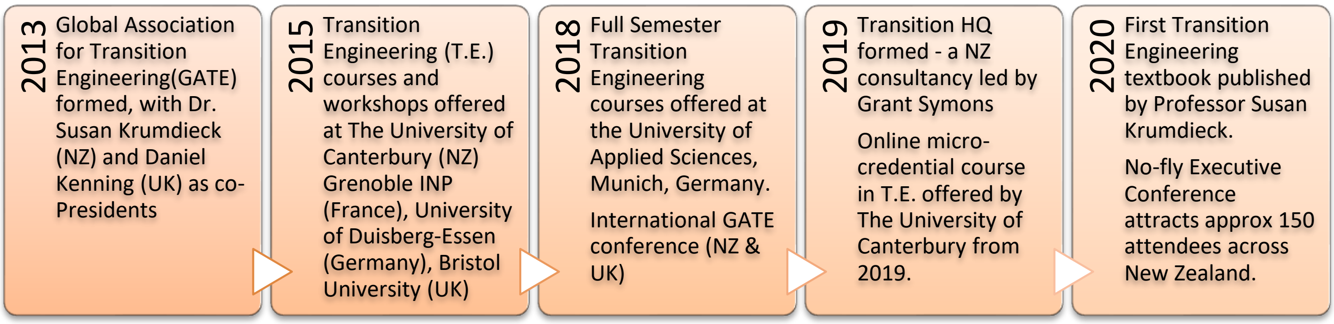

Figure 1. Milestone dates in Transition Engineering (Krumdieck 2020a)

<u>The Problem of the Climate Crisis – Recognising & Adopting the Engineering Constraints</u>

Engineering Concept 1: Know the problem you are working on

There are many environmental constraints that engineers may need to consider in the course of their work; issues such as loss of habitats and biodiversity, waste generation and pollution, water conservation and quality, energy efficiency, unsustainable resource use and climate change form a complex and interrelated web of concerns.

Scientific consensus is that exceeding 2°C average global heating due to CO_2 concentration exceeding 450ppm is more than 60% likely to result in 'catastrophic climate change': extinction of the Great Barrier Reef, melting of the Greenland Ice Sheet, die-off of around 50% of wild species and sea level rise and extreme weather that could threaten at least 80% of human-made structures. To stay within this failure limit of 450ppm atmospheric carbon, 90% of the known economically producible hydrocarbon must remain in the ground (Krumdieck 2020a). Since more than 90% of the world's energy supply comes from fossil fuel, compared with 60% in New Zealand (MBIE 2020a), the challenge of de-carbonisation will affect all sectors of the economies and societies of every nation on earth.

In many respects the climate is analogous to a mechanical system that has an increasingly higher probability of failure the further you push the system beyond its region of stability. For structural engineering audiences, the analogy of a bridge is instructive (see Figure 2). The calculated "safe working load" limit of 350ppm atmospheric carbon was exceeded around the year 1990, and measurements hit 410ppm in 2018. The "Zero Carbon Act" (2019) has the stated purpose of contributing "to the global effort under the Paris Agreement to limit the global average temperature increase to 1.5° Celsius above pre-industrial levels", and this correlates to approximately 430ppm atmospheric carbon (Pearce 2016).

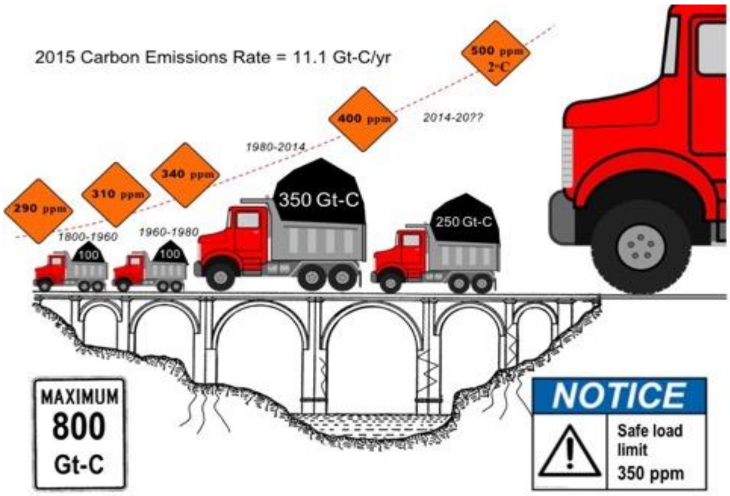

Figure 2. Bridge structure analogy to illustrate capacity of global climate (Krumdieck 2020a)

To meet this objective, which provides a small factor of safety below the 2°C failure limit, our energy transition must be delivered faster than we might prefer; the IPCC panel calculated that we must reduce emissions by 45% by 2030 and reach net zero by 2050 (IPCC 2018).

To meet the requirements for the safety of humanity's infrastructure and the wellbeing and sustainability of natural ecosystems and species, **Transition Engineering adopts an 80% reduction in fossil fuel use as its design criteria** for engineering projects. The scale and urgency of transition required means that the climate crisis is given a preeminent position in consideration of sustainability, although this by no means precludes the simultaneous pursuit of other social and environmental benefits that stakeholders might wish to achieve as a result of their investment.

Engineering Concept 2: Define the system and relationships to other systems

Transition Engineering recognises that energy systems are used to provide for the essential needs of individuals, families, groups or communities, and the effectiveness of these systems is an important measure of prosperity. Human needs are met through a variety of human activities – such as farming, building, manufacturing, providing services, education, leisure, participation in cultural and religious events, and transporting ourselves to the activity centres where these activities take place. Transition Engineering starts by mapping the activity systems that are essential to a community. A key observation relating to activity systems is that energy and material use are determined by the technology and built environment that already exist, and if the technology or infrastructure changes, the activity system adapts quickly. For example, demand for postal mail services has declined rapidly since the technology and infrastructure was made available to support widespread access to email services.

Once essential activities are defined and understood, Transition Engineering takes the important step of defining the "wicked problems" associated with those activities. Wikipedia defines a wicked problem as one that that is difficult or impossible to solve because of incomplete, contradictory and changing requirements that are often difficult to recognise. It refers to a problem that cannot be fixed, or where there is no single solution to the problem. At this stage in the process, we face up to the genuine social, political, economic and engineering reasons why we have not managed to make any meaningful emissions reductions to date.

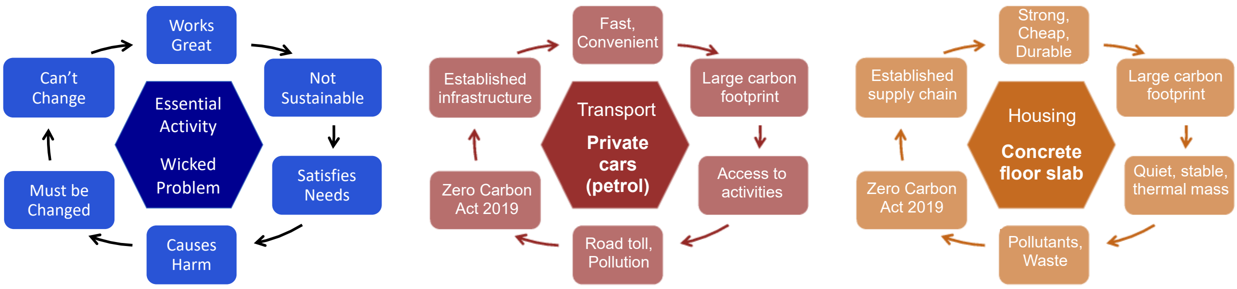

Figure 3. Diagram to illustrate wicked problems that must change, but resist change

<u>The "Solutions" to the Climate Crisis</u>

When describing the origins of Transition Engineering, Professor Susan Krumdieck (2020b) recalls her experience of being invited to a government sponsored multi-disciplinary workshop to develop solutions to the climate crisis. While brainstorming solutions, a number of the workshop participants strongly favoured a return to the low-emissions technology of 100+ years ago (e.g. bicycles, windmills, electric trams). Others firmly believed that we must look to future technology to solve the problem (e.g. LED light bulbs, electric vehicles, nuclear fusion). Others called for ethical consumer behaviour to revolutionise our activities. Echoing the parable of the blind men and the elephant (see Figure 4), each person solved the problem based on their own experience and observations, but no consensus was reached.

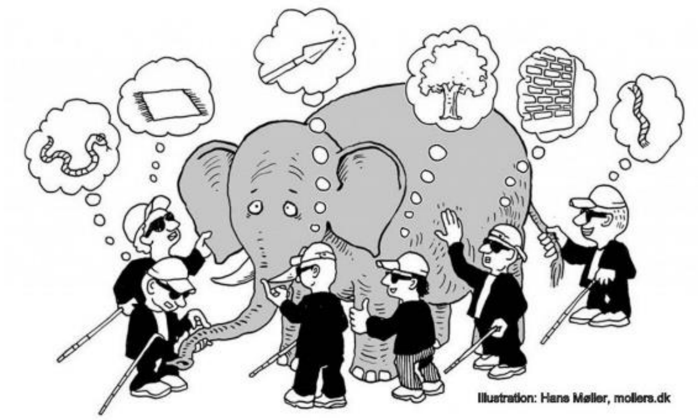

Figure 4. Parable of the blind men and the elephant

The Transition Engineering methodology insists that our history and our present must be clearly understood in order to plot an optimal course into the future ('Kia whakatōmuri te haere whakamua' - I walk backwards into the future with my eyes fixed on my past). From here, a range of future scenarios are interrogated by calculation, typically using simple spreadsheet methods. For example, past trends can be quantified and then extrapolated using appropriate growth rates to predict the future uptake of emissions reduction technology (refer to Equations 1 & 2). Sensitivity analysis is encouraged to test the results of such evaluation.

Parameter value at time, t: $N(t) = N_0(1+r)^t$ for exponential growth (1)

Parameter value at time, t: $N(t) = N_0 + tN_c$ for linear growth (2)

Where N_0 is the initial value; r is the growth rate per unit time. N_c is the constant amount added per unit of time. Other equations can be used to investigate more complex growth and depletion scenarios. The outcome of this investigation is usually a clearer picture of the options that will not succeed in meeting emissions reductions targets due to fundamental constraints.

Transition Engineering avoids reference to "solutions". This is based on a recognition that the "wicked problems" we are considering are, by definition, too complex and difficult to solve with a single solution. It is also based on the observation that people have a strong tendency to jump rapidly to a perceived solution, then subconsciously relax their efforts believing the job to be virtually done, thereby overlooking the need for rigorous evaluation and missing the opportunity for more effective innovation.

For example, the "solution" of timber buildings. A report by Kāinga Ora (2020) postulates the construction of a three-storey block of six units using $200m^3$ of CLT. This sequesters 120 tonnes of CO_2, which can be used to offset the 20 tonnes of CO_2 emitted by the concrete foundation, leaving a budget of 100 tonnes of CO_2 for the remaining building elements to achieve carbon neutrality. At this point, the layperson might believe the problem is solved. The next engineering challenge is to allow for the operational emissions from the building, and the carbon that will be released to the atmosphere at the end of the building life (unless it can be recycled or stored permanently in a sealed landfill). When these factors are taken into account, studies indicate the cradle-to-grave benefit of timber construction is in the order of 15-20% when compared to the carbon emissions for business as usual (John et al 2020). Timber construction would need to be supplemented by major investments and innovation in renewable energy, operational efficiency, materials recycling, and retrofitting to improve the hygrothermal performance of the existing building stock to meet the objective of 80% emissions reduction by 2050 or sooner. A reduction in the number, average size, and/or partition density of new buildings is also likely to be needed.

Envisioning and Evaluating Future Options

Time Travel - a powerful thought experiment is used by Transition Engineers to investigate the *Forward Operating Environment* for a specific location and activity system. The project team transports themselves 100 years forward to visualise a future where we have successfully achieved the energy transition away from fossil hydrocarbons. To guide this brainstorming endeavour, various constraints are established to reflect fundamental suppositions about the forward operating environment, including but not limited to the following (Krumdieck 2020a):

- Oil is not available in quantities or at prices that support private vehicle use.
- Metals and minerals will be available primarily from recovered and recycled sources.
- Population will be static or declining compared with the population in 2020.
- Infrastructure and buildings durable enough to last 100 years will still be used.
- Prosperity will not depend on growth in consumption.

As a reality check on our vision of a prosperous future, and to evaluate potential technologies and projects for getting there, Transition Engineers use a variety of evaluation tools, such as:

- Feedback Control Theory – to test the behaviour of anthropogenic systems.
- Development Vector Analysis – to investigate potential blocks to technology roll-out.
- Strategic Analysis of Complex Systems (SACS) – a matrix-based options assessment.
- Economics and Financial Analysis – such as net present value, payback period, LCA.
- Quantifying biophysical constraints such as Energy Return on Investment (EROI).

Energy Return on Investment (EROI) – is an important biophysical parameter affecting economic prosperity. Also known as Energy Return on Energy Invested, EROI provides an indication of the surplus energy available for the economy to meet current demand, to provide maintenance and replacement, and to supply manufacturing and new construction. EROI can be calculated using Equation 3, where P is the primary energy production in MWh, S_1 is the energy diverted from production for primary production and distribution, and S_2 is the embedded energy in the production plant, all in consistent units.

$$\text{EROI} = \frac{\text{Energy Delivered}}{\text{Energy Required to Deliver that Energy}} = \frac{P}{S_1 + S_2} \quad (3)$$

Researchers estimate that the EROI required to run modern industrial-consumer societies is probably 10:1 to 15:1 at a minimum if we are to support families, health care, education, the more complex arts, and so on (Hall 2017). This concept is illustrated in Figure 5.

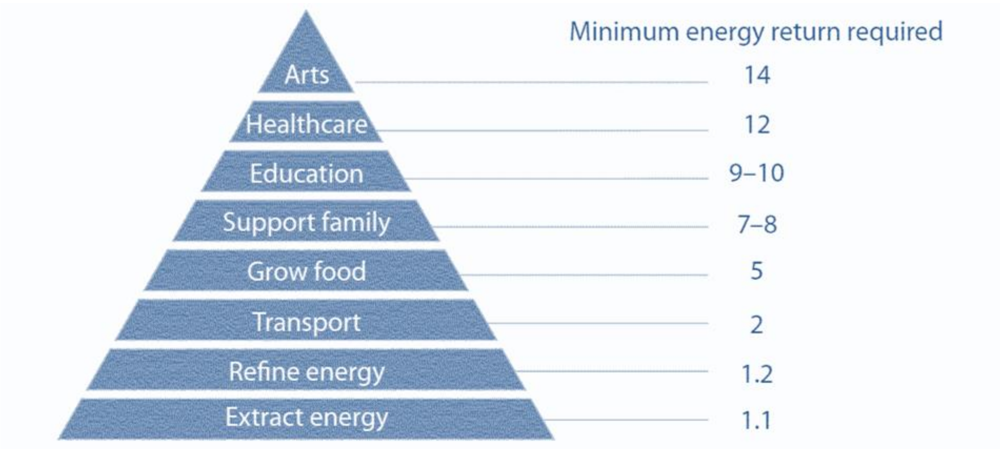

Figure 5. EROI required for human welfare (Prieto & Hall 2013)

Fossil fuels like oil had an EROI ratio of around 50 in the 1950's, meaning that for each unit of energy invested in production and distribution, 50 units of energy are delivered to the external economy. However, this EROI has gradually declined to 3-4 today, as the resource mix includes smaller reservoirs and deeper or less permeable oil fields (Cleveland, 2005).

The Energy Return on Energy Invested for various energy sources is illustrated in Figure 6.

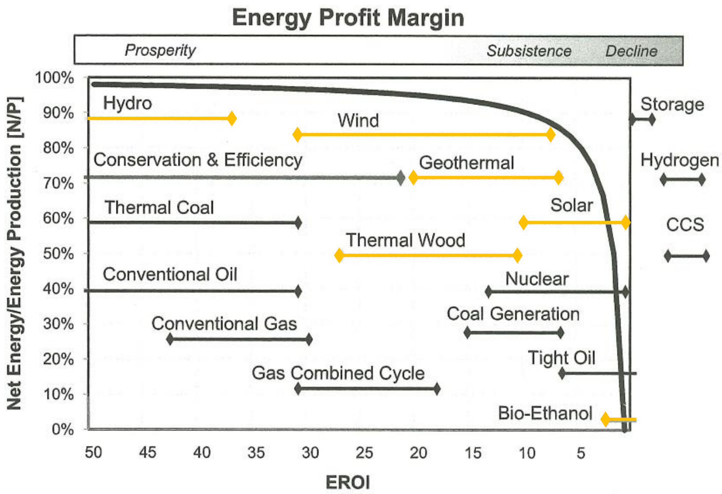

Figure 6. EROI for various energy sources (Krumdieck 2020a)

Figure 7 illustrates three possible ways of structuring our economy in terms of energy supply and utilisation, helping us to evaluate various energy transition options (Krumdieck 2020a):

1) **Unsustainable Prosperity** – high energy supply relies on fossil fuels, enabling high consumption, this is the business-as-usual scenario.
2) **Green Decline** – massive increase in renewable generation to maintain current energy supply, but EROI is significantly reduced. If consumption continues unabated, there is insufficient energy for maintenance and replacement of buildings & infrastructure.
3) **Transition Prosperity** – 80% reduction in fossil fuel production, relying predominantly on renewable resources with high EROI (hydroelectricity). Acceptance of a decline in both energy supply and material consumption, leaving sufficient energy surplus for ongoing regeneration of buildings and infrastructure.

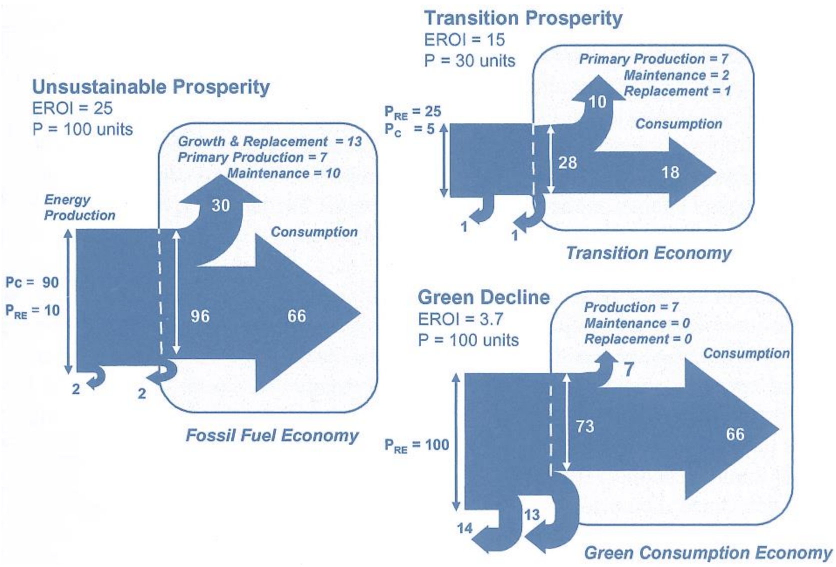

Figure 7. Three energy supply options for the economy (Krumdieck 2020a)

Generating “Shift Projects” to Reduce Fossil Energy Use

Definition of a Shift Project - energy transition is achieved for different activity systems and in different locations through an engineering change project. For Transition Engineering practitioners, a project that results in downshift of fossil energy use is called a “Shift Project”. A shift project will require financing or investment like any project, and releases value to the business or organization by reducing the energy used and the exposure to energy risks. Shift projects usually involve innovations in technology, services, IT or operations. Shift projects often are a redevelopment or regeneration of an old system (Krumdieck 2020b).

InTIME method - we have now touched on most aspects of the Interdisciplinary Transition Innovation, Management and Engineering (InTIME) methodology, a 7-step framework which has been developed through 15 years of research and practice (Krumdieck 2020a). After defining a wicked problem that relates to a specific location and activity system(s), these steps are intended to help flip people’s perspective, and then develop shift projects (Figure 8):

1. Study History – investigate how the essential activity was carried out 100 years ago.
2. Understand the present – gather data, explore related systems and the socio-political context.
3. Explore the future – test various scenarios within the forward operating environment.
4. Time travel – envision a believable picture of a sustainable future.
5. Back cast & Trigger – find a path to change, use lessons learned from past, present, future.
6. Downshift Project – evaluate options, develop a project to mitigate risk, provide benefits.
7. System Transition – develop plans for change management and successful implementation.

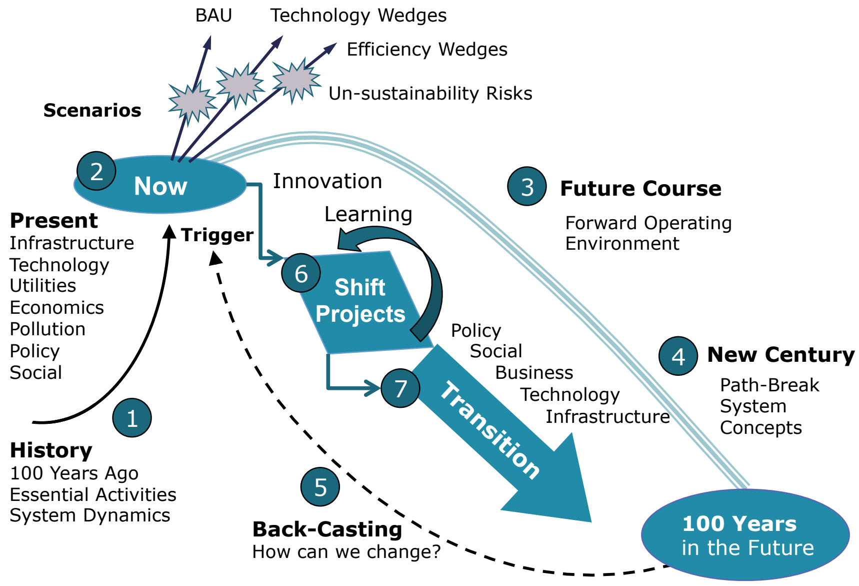

Figure 8. Diagram illustrating the InTIME methodology (Krumdieck 2020a)

THE DRAFT BUILDING FOR CLIMATE CHANGE FRAMEWORK

The Ministry of Business, Innovation & Employment (MBIE) have identified that the Building & Construction Sector contributes around 20% of New Zealand’s greenhouse gas emissions, and that the existing Building Code will not be able to deliver on the government target of net zero emissions by 2050 (MBIE 2020b).

MBIE propose to introduce more stringent requirements for operational efficiency, along with a requirement for whole-of-life embodied carbon assessment, as part of the building consent process. They have indicated that these requirements would be introduced in stages as outlined in Table 1 (MBIE 2020c).

Table 1. Staged Building Code requirements for emissions reduction (proposed)

Embodied Carbon Requirements	Step 1	Step 2	Step 3	Step 4	Step 5
	New public sector buildings to report Whole Life Embodied Carbon.	All new buildings to report Whole Life Embodied Carbon.	All new buildings to meet Whole Life Embodied Carbon initial caps.	All new buildings to meet Whole Life Embodied Carbon intermediate caps.	All new buildings to meet Whole Life Embodied Carbon caps that achieve net zero emissions for New Zealand.

Energy Efficiency Requirement	Step 1	Step 2	Step 3	Step 4
	Operational Efficiency Requirements Launched	Initial Operational Efficiency Requirements come into force	Intermediate Operational Efficiency Requirements come into force	Final Operational Efficiency Requirements come into force

It is intended that a cap will be placed on operational emissions (CO_2/m^2/annum) which will be tightened in a series of steps, reaching a final cap by 2035. MBIE are still deliberating on the scope and timeframe for introduction of embodied carbon limits (CO_2/m^2). MBIE's draft framework proposal suggested that new internal fitout elements, building refurbishment, and demolition stages may be excluded from the initial scope of the framework (MBIE 2020c).

IMPLICATIONS FOR STRUCTURAL ENGINEERING IN THE NEXT 15 YEARS

During the industrial revolution - our previous energy transition - economies were booming and corporations were growing in influence, but workplace safety was nearly non-existent, and politicians were not responding to protests about unsafe conditions (Krumdieck 2020a). This changed in 1911 when a catastrophic fire at the Triangle Shirtwaist Factory in New York killed 146 young women and girls, many of whom jumped 9 floors into the city street as they became engulfed in flames. This incident triggered 62 industrial engineers to form the American Society of Safety Engineering. They set professional design standards to supersede factory owner preferences, which the insurance industry soon mandated for all factories (Walter 2011). Today, fire safety engineering dictates fundamental design criteria that influence structural engineering design, and a similar trajectory can be predicted for transition engineering as we address the risks associated with operational and embodied carbon emissions.

<u>Embodied carbon assessments</u> – under the proposed framework, embodied carbon will need to be calculated by building designers in order to demonstrate compliance with the Building Code. This process may develop along similar lines to fire safety engineering – some structural engineers may pursue a personal and/or financial interest to become experts in this area, with specialist consultants serving those who prefer to outsource this work. Within a 5-year timeframe, structural engineers could well be signing co-ordination statements for Building Consent submissions to confirm that their design complies with the Whole-of-Life Embodied Carbon Assessment report that has been prepared.

<u>Construction materials</u> - Timber construction is likely to be one of the low hanging fruit that generate initial emissions reductions in the sector. Within a 10-year timeframe, commercial buildings with steel and concrete primary structures could be as rare as timber structures are currently. There is an opportunity for engineers to learn the easy way – by proactively investing in the ongoing development of design guides and standards, verification methods, and acceptable solutions to address issues like fire protection, acoustics and vibration, diaphragm design, hygro-thermal analysis, and durability – rather than learning from project failures.

Other structural materials will need to undergo their own transition. Steel is the most recyclable material on the planet (WSA 2021), and the return of domestic steel recycling using an electric arc furnace seems inevitable at some stage. This would significantly lower the embodied carbon for steel materials, although competition for recycled steel supply would increase construction costs. Concrete will be a valuable resource to be used sparingly, with increased focus on lean design and design life. As an example, bridges and wastewater treatment plants may be prioritised over footpaths, driveways and floor slabs.

Changing form of structures and their urban environments – as outlined in the previous discussion of EROI, a significant reduction in energy and material supply will be needed if we want an economy with sufficient energy surplus for regeneration of buildings and infrastructure. This would require a reduction in new building development. The improvement of existing buildings is expected to continue beyond the current regime of seismic retrofitting, regenerating the built environment to suit new uses and performance requirements.

Emissions constraints are likely to affect the location and structural form of new buildings. Planning regulations may promote high-density construction along public transport corridors. Underground carparking would be abandoned if we drive fewer cars, and cannot offset the carbon embodied in a concrete basement. Operational efficiency requirements will influence building layouts and fabric. It may be difficult to justify extensive concrete foundations on sites with poor ground conditions, so larger buildings may be constrained to sites with good ground. Lifecycle embodied emissions plans will rely on specific levels of maintenance and resource recovery, which may necessitate specific design for disassembly or proportionate repair.

Loadings standards – may also need to evolve, encouraging lean design through more sophisticated serviceability and live loading criteria (Watson 2020), and allowing for the increased frequency of extreme weather in our wind and snow loading allowances.

CONCLUSIONS & PROFESSIONAL DEVELOPMENT OPPORTUNITIES

- Design criteria: an energy transition is required in order to reduce fossil fuel use by 80% before 2050. This will affect all sectors of the economy and change the trajectory of engineering practice in a way that has not been experienced for many generations.

- Significant reduction in energy and material supply: EROI analysis demonstrates that this will be needed if we want to generate sufficient energy surplus to enable prosperous lifestyles, and allow for ongoing regeneration of buildings and infrastructure.

- Structural engineering practice: energy transition is likely to have significant impacts over the next 15 years, with risks and opportunities arising from the following changes:
  - Scope: embodied carbon assessments, more building retrofits, fewer new builds
  - Methodology: revised loadings, lean analysis, timber design, new structure forms
  - Ethics: competency and training, leadership, whistleblowing, intergenerational equity

- Professional Development: the following opportunities are available to structural engineers:
  - Reading: Transition Engineering, Building a Sustainable Future, CRC Press, 2020
  - Achieve NetZero Applying InTIME, 4-Week Short Course, available at The University of Canterbury. This is an online, self-paced course, available any time.
  - Transition Engineering - Energy InTIME, 6-module course for Engineers – available at The University of Canterbury.
  - Join a professional organisation that offers webinars, newsletters, or networking with specific relevance to energy transition (e.g. Global Association for Transition Engineering, Engineers for Social Responsibility, The Sustainability Society, Timber Design Society).

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