‘She’ll Be Right’: Complexity, Energy, and the Urban Metabolism of a Fragile Melbourne

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This paper discusses the vulnerability of Melbourne’s food and fuel supply within the interconnected frameworks of complexity and systems theory. This approach starts from the acceptance that this complex adaptive socio-technological system we label ‘Melbourne’ cannot ever be truly reified, as its composite infrastructures and subsystems, often labelled its eco-footprint, exist across an array of nested scales and spatial locations. This implies that the boundary delineation of such complex systems is therefore always a contingent and contested political act, rather than an exercise in identifying and cataloguing some Platonic True Form. From the viewpoint of ‘far-from-equilibrium’ thermodynamics, Melbourne can instead be seen as an open system which only maintains its contingent existence through the continual input and dissipation of energy. This urban metabolism involves the continual input of food, energy, fuel, air and sunlight (and the export of related waste by-products) to sustain the consumption practices of nearly 4.5 million people with no spatial proximity to either fuel or food in any meaningful sense. This paper looks at the interconnected networks of fuel and food supply and distribution within which Melbourne is sustained, arguing that Graham and Thrift’s (2007) discussion of ‘tools only becoming visible when they are broken’ best explains a broader social reluctance engage with the fragility of these highly interconnected and spatially diffuse networks.

Keywords — energy; fragility; complex adaptive systems; thermodynamics.

INTRODUCTION

This paper argues that any discussion around the ‘remaking’ of a city such as Melbourne must acknowledge the relationship between the complexity of such an urban system and the energy which makes that complexity possible. Using the example of Melbourne’s food supply, and the complex systems which make it possible, its central claim is that any discussion of the history, present or possible future of Melbourne which does not consider this nexus between complexity and energy is missing a crucial part of the picture. Melbourne’s complex food supply system, like all its constituent systems, is dependent upon energy for its maintenance or further development, and if this premise is accepted then it becomes clear that Melbourne is fragile in ways that are neither widely known or clearly acknowledged. It is the author’s contention that this fragility should be a crucial element in any consideration of the development trajectories of Melbourne.

To make this argument, this paper use the example of Melbourne’s food supply to make three connected claims about this city; the first being that Melbourne can be clearly identified as an open and complex adaptive system (CAS), which is subject to the dynamics of ‘far from equilibrium’ (FFE) thermodynamics. Secondly, Melbourne’s sustainability (its persistence through time) is inescapably contingent upon access to uninterrupted and ever-increasing energy supplies to both promote and sustain the increasing complexity of the constituent systems which make up this city. This is the central element of Melbourne’s fragility; its urban metabolism involves the continual input of food, energy, fuel, air and sunlight (and the export of related waste by-products) to sustain the consumption practices of nearly 4 million people with no spatial proximity to either fuel or food in any meaningful sense. The final claim is that there are clear cultural, social and ideological reasons why this inherent fragility is not merely overlooked but consciously rejected. No consideration of the possible trajectory of Melbourne’s ‘remaking’ will meaningfully acknowledge this fragility without first acknowledging these impediments.

ENERGY, THERMODYNAMICS AND COMPLEX SYSTEMS

The overall concern of this paper is energy and its relationship with complex systems – and in particular the concept of ‘far from equilibrium’ (FFE) thermodynamics as a lens through which to view the complexity of contemporary Melbourne. Since the first quarter of the 20th century theorists have approached energy and the social and technological systems that access to energy is a limiting factor on the development or maintenance of urban socio-technological systems (Suddly 1912, 1922, 1926; Georgescu-Roegen, 1970, 1977; Daly, 1974; Reader, 2004; Steele, 2008; Pfeiffer, 2006). The Second Law of Thermodynamics concerns the interaction between energy and time and states that, in a closed system over time, energy irreversibly dissipates across energy gradients. Eddington’s concept of ‘the arrow of time’ (1928) encapsulates the inevitable and irreversible nature of this process. However, it is the reformulated Second Law (or ‘non-equilibrium thermodynamics’) proposed by Prigogine which is more relevant here. This describes complex systems as open systems that process (dissipate) available or ‘free’ energy to maintain or increase their ordered structure in some sort of steady state, ‘far from equilibrium’ (Prigogine, 1978). They sustain themselves through time in the face of interactions with their environment which cause both their structure/form and function to fluctuate.

However, this sustainability is dependent upon the continual dissipation of energy as “all self-organising structures survive by continually degrading and dissipating available energy and matter” (Rees, 2012, p251) and then expelling the resultant entropy into their environment. This dissipated energy is used to construct more complexity - further subsystems which then better dissipate energy and thus allow the system to maintain its essential stability far from equilibrium (Schneider & Kay, 1994a/b; Schneider & Sagan, 2005; Raine et al, 2006; Brown et al, 2011; Rees, 2012). A perfect example of such a system is a cyclone which is driven by the warmth of the ocean. Warm air near the surface of the warm ocean rises and this resultant lower pressure sucks in cooler air which in turn rises as it is warmed by this ocean heat. This complex circular flow of air is fed by the dissipation of heat energy across an energy gradient (between the warm ocean water and the cooler air) which breaks down once it moves over land and the thermodynamic cycle is interrupted.

The insights of FFE thermodynamics have been used to identify the urban metabolism (the energy inputs and outputs) of specific historical, contemporary and future urban environments, whether to reduce the environmental impacts of such cities (SUME Project, 2011) or promote their resilience in the face of disruptions to these energy inputs (Barthel & Isendahl, 2013; Rees, 2012). There is an ‘urban metabolism’ tradition in urban studies that understands cities as complex socio-technological systems that are existentially dependent on energy to maintain their form and function (Nicolis & Prigogine, 1977; SUME Project, 2011; Rees, 2012; Barthel & Isendahl, 2013):

An appropriate example (of a dissipative structure) would be a town that can only survive as long as it is a centre of inflow of food, fuel and other commodities and sends out products and wastes. (Nicolis & Prigogine 1977, n.p.)

COMPLEX ADAPTIVE SYSTEMS (CAS) AND THE CHALLENGE OF BOUNDARY DELINEATION

However, before we consider the implications of treating Melbourne as a Complex Adaptive System (CAS), there is one
crucial challenge that arises. This complex ‘system of systems’ cannot ever be truly reified as its composite infrastructures and subsystems exist across an array of nested scales and spatial locations.

It is a foundational assumption of systems and/or complexity theory that all complex systems are nested within other systems (Gunderson & Holling, 2002; Giampetro, 1994; Simmon, 2005). Not only do such systems exist across a range of scales, but the dense interconnections between and across scales and spatial locations make it difficult to define where any particular system begins and another ends. The natural world for instance does not involve clear boundaries between ecosystems or environments (Odum, 1971; Fiscus, 2013) as energy, matter and living organisms all interact across such ecosystems. Thus the difficulties involved in separating the wisp from the orchid (Deleuze and Guattari 2004, p.10) or the causal relationships (trees causing rain or vice versa) within the hydrological cycle (Malhi et al., 2008).

Yet the challenge of boundary delineation is crucial: one cannot analyse or promote the resilience of any city or its constituent systems, identify its energy inputs and outputs, or measure the effects of thermodynamic dissipation upon it, without assigning some sort of boundary to it. A system must be defined, delineated, if it is to be considered as a discrete unit.

This challenge of system delineation is just as prevalent in the context of cities and urban conglomerations, and is only compounded by a consideration of thermodynamics and energy dissipation in the development of complex urban environments. For example, the concept of the ‘eco-footprint’ (Wackernagel & Rees, 1996) applies this concern with boundaries to the intersection of non-equilibrium thermodynamics and urban systems by demonstrating how the systems, effects and energy inputs of any particular city or household extend far beyond the commonly defined physical boundaries of such entities (many thousands of kilometres in the case of a large developed city such as Melbourne). Here the difficulty of boundary delineation becomes obvious in any attempt to analyse a complex socio-technological system such as Melbourne or the interconnected components which comprise it.

One possible way out of this theoretical impasse is offered by recourse to systems theory in general (Wells, 2013), and in particular the work of Luhmann (2012). He sees a complex system as fundamentally separate, in terms of its organisation, from its environment; in fact it can only be defined in opposition to this environment. The ontological reality of such a system is contained in this boundary, or in this act of delineation, so that “we speak no longer of objects but of distinctions” (p.28). Thus, a dichotomy between system and environment is conceived in which one cannot exist without the other but any objective reality of ‘the system’ is not accepted; there is no reified Platonic ‘True Form’ to be identified and addressed here. Instead, this difference between system and environment is continually renegotiated and restated by the internal operations of the system itself. Any system is therefore autopoietic (emergent) and self-referential in that it defines itself as existing apart from, and in opposition to, the environment in which it is nested:

...only operationally closed systems can develop a higher level of inner-complexity, which can then serve to specify the respects in which the system reacts to conditions of its environment (p34).

Such systems should be seen as both thermodynamically open and organisationally closed:

*If we consider a living system, from the perspective of its interaction with the environment; it is a complex adaptive system [CAS], and it is an open system; it exchanges energy and information with the environment it co-evolves with. So in terms of explaining the complexity of its dynamic interactions, we can observe them from the perspective of CAS. When we observe the same complex system from a cybernetic perspective, what we are dealing with is an ‘organisationally closed system’. It is open to energy and information, co-evolves with the environment, but is organisationally closed (Exponosa & Walker, 2011, p14-15)*

This explains the historical role of walls in a city siege – as a far from equilibrium system the city must remain open or energy depletion will be an issue (ie they will run out of food and water) and it will collapse, while in organisational terms it must remain closed or it will be subsumed (conquered) by an opposing socio-technological system.

**Cities: Increasing Complexity + Increasing Energy Costs = Fragility**

At this point we can understand Melbourne as complex adaptive system that only maintains itself by the continual input of energy (food, petrochemicals, electricity) from its environment – and the existential importance of such energy inputs constitutes one of this city’s major sources of fragility. Here this paper turns to the work of the historian Joseph Tainter on the collapse of complex social systems like civilisations (or, at a smaller scale, cities), which sees the sustainability of such systems as totally dependent on the dissipation of energy. Tainter starts from the orthodox definition of sustainability as the ability of a system to sustain itself through time, and he sees (1990; 1992; 1995a/b; 1996; 2006; 2011b) all human societies (whether at the scale of villages, cities or states) as problem-solving systems that meet the challenges they face by implementing increasingly complex solutions. Examples include the need to increase agricultural yields to feed growing populations (Boserup, 1965; 1981), the response to the 9/11 attacks in New York (Tainter, 2011a) or the never-ending need for new medical advances to address disease (Tainter, 1990). In Melbourne, the use of vehicles as weapons or illicit drug use are further examples of problems requiring solutions. Attempts to solve these problems (whether successful or not) usually involve the introduction of further complexity and resultant costs. While this can mean increased technological or infrastructural complexity, such as the introduction of bollards across the city (Tennison, 2017), it could also mean the implementation of further organisational or bureaucratic systems such as increased prison capacity or support systems for drug users (Collins et al., 2007). In both cases there are increased costs which must be borne by those implementing the solution.

This drive for increasing complexity has been an ever-present element of the development of human societies primarily because it has been, and remains, a successful tactic for addressing the challenges (whether military, environmental, social, geographical, economic or political) which inevitably face societies as they persist through time. In a sense, this is merely another way of understanding the march of ‘Progress’.

The problem with this dynamic of ever-increasing social and urban complexity is the universal tendency of complex socio-technological systems to face increasing energy costs as they become ever more complex. Reflecting the primary insight of non-equilibrium thermodynamics, system complexity is dependent on the existence of energy resources (energy gradients) which can be dissipated by such systems to both maintain and increase such complexity:

Energy flow and socio-political organisation are opposite sides of an equation... Not only is energy flow required to maintain a socio-political system, but the amount of energy must be sufficient for the complexity of that system. (Tainter 1990, p91)

Tainter’s crucial insight is that as system complexity increases, the ‘return on investment’ these systems gain from their investment in complexity falls; there is an inverse relationship between increasing complexity and decreasing returns on that investment in complexity. The example of traditional agriculture vs modern industrial agriculture outlined below nicely demonstrates the somewhat counter-intuitive nature of this insight – modern farming methods produce more food per unit of land, but require more energy invested for each calorie of food produced. Thus, as farming has become more industrialised it demonstrates a declining return on energy invested (Boserup, 1965; 1981). This Law of Diminishing Returns applies to all the examples of socio-technological complexity provided above; the more complex societies or organisations get the less relative return they get for all their investment in that complexity. Furthermore, this dynamic implies fragility; either due to over-complexity making the cost of sustaining a system prohibitive, or through disruptions to the energy supply leading to that system’s collapse.

This relationship between energy and complexity is one of the primary reasons for the vulnerability of contemporary cities like Melbourne: they are increasingly dependent on ever-increasing inputs of energy to implement solutions to the endless parade of issues and challenges that they face.
MELBOURNE: PETROCHEMICALS AND FOOD

Melbourne’s food distribution systems demonstrate Tainter’s dynamic; we are highly dependent upon oil-based fertilisers and mechanised labour and transport for the agricultural produce we consume. Contemporary intensive farming is possible only because of the use of hydrocarbon energy (originally coal but now petrol and gas) to replace the traditional inputs of human and animal energy and thus ‘pay’ for the increasingly complex systems. Such inputs include the fuel for farm machinery (such as tractors) and equipment, as well as fertilisers and pesticides (these last two inputs are increasingly based on hydrocarbons) (Pfeiffer, 2006).

Yet this hydrocarbon-intensive farming clearly demonstrates Tainter’s dynamic of declining returns on investment in complexity; while the modern farm can produce much more food on the same amount of land (the solution to feeding growing populations), it needs much more energy (in this case provided by hydrocarbons) to produce the same amount of food energy (calories) as the traditional farm (Craumer, 1979; Baylis-Smith, 1982). Indeed, by some calculations modern industrial agriculture uses ten units of energy for every one unit of food energy it produces (Giampietro & Pimentel, 1993). This is a clear example of falling returns on energy investment: from 20 units of energy for every 1 unit invested in the pre-industrial farm to one tenth of a unit of energy return for every unit invested.

Furthermore, this is only the farming side of the equation. The history of Melbourne’s growth is the story of the encroachment of urban development into agricultural land (Peel, 1974), and of the related logistical challenge of feeding a growing population. Today only 41% of our food is produced within Melbourne’s ‘foodbowl’ (the urban fringe and hinterland), and this predicted to be only 18% by 2050 at current rates of population growth (Urban Analyst, 2015).

The (successful!) solution has been to import and distribute food from further and further afield through the increasingly complex and efficient distribution networks that themselves require increasing amounts of energy; from bullock carts to steam trains, and from trucks to planes (Peel, 1974). The majority of our food is now brought in from suppliers as close as rural Victoria and as distant as California or Denmark. Table 1 shows the food distribution chain for Australian supermarkets - imported food requires a further chain of overseas intermediaries.

![Food distribution chain](image)

**Table 1: Full service supermarket channel map** (Spencer, S & Kneebone, M (2007), p57).

**Key**

- NDC - National and Distribution Centres
- RDC - Regional Distribution Centres

Much of the food currently purchased in Melbourne is distributed through the energy-intensive centralised food depots that supply our supermarkets and therefore passes through two or three intermediaries before consumption. While the Woolworths and Coles duopoly strangle alternative production or distribution channels through their combined purchasing power, even food from an independent organic producer passes through two intermediaries and each transition from intermediary to intermediary requires the internal combustion engine. This modern food distribution system, global in scale and highly efficient, is incredibly expensive in terms of energy use. Only 20% of the energy used to put our food on our plate is used for agriculture, as 80% is used for transport, processing, packaging, marketing, and food preparation and storage (Brown, 2008, p35). We have produced a highly complex system to solve the issues of food production and distribution for our rapidly expanding populations - yet this complexity is absolutely dependent on increasing supplies of (hydrocarbon) energy to sustain our increasing population.

At the same time the complex food storage and information technologies that allow such a complex distribution system to function are themselves also reliant on electricity; an energy source which in this country is also facing supply security challenges for a range of reasons (Wood et al, 2017).

OIL: THE QUESTION OF SUPPLY

We are on a trajectory of ever-increasing complexity to provide food for our burgeoning urban population, which is itself reliant upon an ever-increasing supply of oil. Unfortunately, there are serious shortcomings with the second assumption that oil supplies can be ‘ever-increasing’. The concept of Peak Oil, often misunderstood to mean that hydrocarbons (primarily oil and gas) are ‘running out’, was first outlined by geophysicist M. K. Hubbert in relation to US domestic oil production. Hubbert argued that the amount of petroleum produced (whether from an individual oil field, a country or the planet as a whole) will over time resemble a bell curve (1956). That is, it will increase at first, level off when approximately half the oil has been extracted, and then decline. With this dynamic in mind he predicted that overall conventional petroleum production in the US would peak sometime between the late 1960s and the early 1970s. While he was first ridiculed for this prediction, he became famous when it was in fact proved correct in 1970 (the year US conventional oil production peaked and started the decline which has continued to this day) (Hall & Klitgaard, 2012).

Another factor affecting oil supplies and prices is that of supply security. Now that the ‘easy’ oil is depletion, more and more of the world’s supply is coming from areas of political/military/ethnic tension and conflict (Klare, 2004, 2012), or from more technically difficult and thus risky sources (Capalino et al, 2014). For example, the competition for access to oil supplies between China, the US, India, Japan and other countries becomes more important and more intense a number of areas around the world face the possibility of armed conflict. As well as the perennial potential flashpoint in the Persian Gulf, there are other areas such as the Spratly and Senkaku/Diaoyu islands, East Africa and the gas pipelines from Russia through the Caucasus where military conflict has occurred or may well occur in the future (Klare, 2004; 2012). As well, as the global energy supply network grows more complex and more geographically dispersed the more inherently fragile these supply chains become (Korowicz et al, 2010; Guerrero et al, 2008; Feldhoff, 2011). All these connected issues again make disruptions more likely and thus could affect Australia’s supply.

Two connected reports (Blackburn, 2013; 2014) commissioned by the NRMA, outline the challenging dynamic between the complexity of interconnected food and transport systems and our existential reliance on geographically dispersed oil supply chains. They outline a situation in which Australia:

- is closing all its oil refineries by 2030 with no consideration or even apparent awareness of the implications for supply security (we will be 100% reliant on imports) (2014, p10)
- is the only OECD member which does not have 90 days reserve supply of petrol in case of disruptions or other emergencies (2013, p9)
- will be 100% reliant on long supply chains for our refined petrol and much of this which will pass through areas over which we have no control (in particular through the Indonesian archipelago) (2014, p13)
- will rapidly face shortfalls in the supplies of food and pharmaceutical products in the event of any supply disruptions (2014, p7)

The damning conclusion to the second report clearly outlines the salient challenges:
Our oil and fuel stockholdings are below the levels we are obliged to maintain as a member country of the IEA…

The Government has responded to recently announced reductions in Australia’s oil refining capability in a blasé fashion and has not defined any minimum level of refining capacity for Australia…

Our Government appears unlikely to act on the loss of Australian oil refining capacity and is content to rely on market forces to assure our fuel security…

In essence, we have adopted a ‘she’ll be right’ approach to fuel security, relying on the historical performance of global oil and fuel markets to provide in all cases. Unfortunately, as a result of our limited and decreasing refining capacity, our small stockholdings and long supply chains, our society is at significant risk if any of the assumptions contained in the vulnerability assessments made to date prove false. (Blackburn 2014, p21)

Without the regular arrival of oil tankers in our major cities (perhaps disrupted by political insecurity or a terrorist attack in the Indonesian archipelago) we cannot power our agriculture or distribute the resultant produce and therefore within a matter of days we will be unable to feed ourselves - like a cyclone crossing the coast our biggest cities will not be able to sustain themselves once these energy inputs are removed.

**Identifying Other Related Reasons for the Existential Fragility of Melbourne**

There are several other dynamics (from the field of systems and complexity theory) which only increase the fragility of Melbourne. These are the dynamics of path dependency (or sunk costs) in which the future development of any complex system is bound by its past development trajectory; the challenge posed by a lack of diversity (particularly in terms of energy inputs; a situation into which Australia seems determined to sleepwalk) and thus system flexibility; and the tendency to cascading failures in which disruptions to fuel supplies will have wide-ranging social and economic effects (Blackburn 2014; Korowicz et al, 2010). Due to space constraints, these will not be addressed in this paper. However, it should be noted that they only accentuate Melbourne’s fragility.

**Whistling Past the (Closed) Refineries: Why This Fragility Is Ignored or Rejected**

So why is this fragility of Melbourne not accepted? It is the contention of this paper that there is one primary reason why this fragility is overlooked or consciously rejected: there is a political, social and ideological tendency to either overlook or consciously ignore potential problems until they become actual problems.

The myriad and interconnected socio-technological systems that make Melbourne function are ubiquitous, absolutely essential and essentially invisible. They create a ‘world’ of functionality where ‘business as usual’ is the default setting:

> When somebody uses a tool or piece of equipment, a referential structure comes about in which the object produced, the material out of which it is made, the future user, and the environment in which it has a place are related to each other. But that this is so, according to Heidegger, generally appears only when a handy or ready to hand tool or piece of equipment breaks down. When this happens, the tool suddenly demands attention for itself. The reliable dealings we are used to having with the tool are ruptured, and instead of withdrawing from our attention the tool suddenly forces itself upon us (Verbeek, 2004, p 79-80 (quoted in Graham & Thrift 2007, p3)).

Given such a relationship with our tools and the complex systems through which our urban reality is maintained, it is generally difficult, bar some serious disruption to those same systems, to be aware of their existence and possible vulnerability. Our reliance on systems, and by extension the energy inputs that make them possible, is driven by the ease with which their presence becomes ubiquitous, unmarked, and essential within our everyday lives: “Civilization advances by extending the number of important operations which we can perform without thinking about them” (Whitehead 1911, p61)

This non-reflexive social reality has been labelled the dozo (Bourdieu, 1995). The complex and world-spanning suite of technologies and systems through which we buy $2.50 salmon and wasabi hand rolls for lunch is an example of a doxic social reality Melbournians. It is often only the failures of these background systems, whether these involve merely delays or inconvenience, which bring them into the foreground (Graham & Thrift 2007; Berger & Luckmann, 1982). Absent such disruptions the dictates of efficiency or our own complacency hold sway and broad systemic change is unlikely. Why fix what isn’t broken?

It is important to note here that on a deeper societal level this dynamic isn’t broken; our trajectory of ever-increasing complexity driven by ever-increasing energy consumption is the very essence of civilisational progress (Tainter, 1990). Given its success, such a societal truism is never going to be easily challenged. We have invested so many of our resources to setting up this incredibly efficient and complex society that any thought of making deep structural changes is simply intolerable (and doubly so when there is no crisis underway).

Yet any socially constructed orthodoxy can be challenged by interruptions to its normal functioning (Berger & Luckmann 1966; Bourdieu, 1995). In the case of contemporary complex cities, familiar certainties are naturally undermined by disasters or collapse, or even a widely acknowledged ‘close call’. What is necessary in such cases, however, is the ready availability of a suitable narrative through which new social realities can be established – a narrative which replaces the powerful orthodoxy of ‘Increasing complexity = Progress’. There is no space in this paper to address this challenge in any detail, although promoting the awareness of systems fragility through alternative narratives (in popular media) might be a good place to start. The first step in addressing the fragility of Melbourne is imagining it.

**Conclusion**

In the end the greatest challenge to the complex yet fragile systems which make up Melbourne is the deeply held belief in the forward movement of progress (leading to ever more marvels of complexity) through which our society fulfils its primary role as a problem solving system. The paradox is that we will not make changes until forced to by circumstances, but those same circumstances (a disruption or break in supply) threaten the energy surpluses needed to introduce new complex solutions (whether a meaningful switch to other sources of energy or the reorganisation of the systems which make Melbourne possible). We need to imagine the unimaginable to have any hope of addressing this fragility.

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