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NOT TO BE QUOTED WITHOUT THE AUTHORS' PERMISSION

Industrial Ecology and Spaces of Innovation

Ken Green and Sally Randles (with Chris Foster, Eugeos); acknowledgements to Andrew McMeekin

ABSTRACT

Industrial Ecology (IE) seeks to understand how we can minimise the ecological impacts of materials flows. It derives partly from a desire to see societies endogenise these impacts through new models of economic development and conceptualisations of societal 'progress'. When groups of firms/institutions operate collectively, this has the potential (it is argued) to produce new, radical forms of industrial/ manufacturing organisation. To date, social scientists in Innovation Studies have not engaged with the IE community, to see what can be gained from bringing in understandings about the innovation process. Yet there is clear scope for some fruitful debate between the IE and IS communities. The key idea we wish to introduce in this paper is how we can re-think the link between the *flow of materials*, a flow which IE is especially skilled at analyzing, with the *social, economic, and organizational structures* which cause physical flows to be and become 'clumped' (concentrated/dispersed) in particular ways. We can refer to this structuring of flows as *instituted process* exhibiting spatial and historical variety. We can also proceed to identify empirically the location(s) of *actual innovative* change within those structures. We can further identify *potential* sites for innovation, together with, importantly, constraints to change and reasons for resisting change.

The paper starts with a brief discussion of what IE is; it then summarizes the 'basics' of IS, at least as seen from the 'Manchester' perspective. Using an example of technological innovation and sustainability in a Food System, specifically on the *frozen pea*, it illustrates how the IE and IS perspectives might have something to offer each other. It finishes with some suggestions for the questions which are prompted by seeking to link IE and IS perspectives.

1. Introduction

Industrial Ecology (IE) is a recognised discipline, with its own journals and communities of scholars, concerned primarily with seeking an understanding of how we can minimise the ecological impacts of materials flows. It derives partly from a desire to see societies endogenise these impacts (including pollution and resource depletion) through new models of economic development and conceptualisations of societal 'progress'. Of course, there is also a strong economic impetus within competitive capitalist economies making firms seek the most efficient use of resource and energy flows, reduce waste and energy costs and turn waste streams into revenue streams. When groups of firms/institutions operate collectively to achieve these aims, this has the potential (it is argued) to produce new, radical forms of industrial/ manufacturing organisation.

We recognise that the term 'industrial ecology' has some different meanings in its different (disciplinary) usages. For example in the sense of 'the ecology of industry' it can be used to refer to the way 'industries' comprise a variety of differentiated firm-types. Though independent, these differentiated firms none-the-less co-exist in interdependent 'bundles' mediated through various forms of (market and non-market) exchange occurring across firm boundaries, to form recognisable multiplexes or 'ecologies' of firms. This meaning is quite different to the resource and material-flows analysis usually and traditionally associated with the term Industrial Ecology. Of course an understanding of both the 'Ecologies of Industries' and 'Industrial Ecology' is important to the study of both. This is because the organisation of resources, materials and components flows determines, to an extent, 'the ecology of industry' whilst the ways firms come to orientate their activities vis-à-vis other firms determines not only the shifting patterns and structures of industries, but also determines (often limits or constrains) scope for more 'sustainable' material flows. A discussion of these different usages, and their inter-linkages, could therefore be profitable, though this paper discusses IE in its 'environmental' guise.

To date, social scientists studying innovation (which we will call the 'Innovation Studies', IS, community) have not pro-actively and systematically engaged with the IE community, to see what can be gained from bringing in understandings about the innovation process. Yet there is clear scope for some fruitful debate between the IE and IS communities. Robert White, then President of the US National Academy of Engineering defined Industrial Ecology in 1994 as "the study of the flows of material and energy in industrial and consumer activities, of the effects of these flows on the environment and of the *influences* of economic, political, regulatory and social factors on the flow, use and transformation of resources."(emphasis added) The direction of flow between the 'physical'/'material' world and the 'social/economic/political' world is, in this definition, one in which the social 'influences' the physical. But – as work in innovation studies continues to show – it is possible to see the physical-social relation in a different way, with the process of innovation being 'embedded' in structures of social relations (including those that inform consumption patterns and practices), inter-industrial relations, technological relations, and capital/investment relations. How this

can be related to the perspectives already well developed by IE scholars will be explored in this workshop.

The key idea we wish to introduce in this paper is how we can re-think the link between the *flow of materials*, a flow which IE is especially skilled at analyzing, with the *social, economic, and organizational structures* which cause physical flows to be and become 'clumped' (concentrated/dispersed) in particular ways. Drawing on Polanyian perspectives (Polanyi, 1957) we can refer to this structuring of flows as *instituted process* exhibiting spatial and historical variety. We can also proceed to identify empirically the location(s) of *actual innovative* change within those structures. We can further identify *potential* sites for innovation, together with, importantly, constraints to change and reasons for resisting change.

To elaborate, we can conceive four structural domains which together provide organisational logic to the system. They are: the structuring of materials flow; the structuring and organisation of economic activity together with the pecuniary redistributions which arise from the processing of those materials; the social structures and structuring of relations (including power relations) which demarcate classes of agent (Bourdieu …) and, finally, the production of structures and meanings of knowledge including how that knowledge (and its associated symbolic significance, the ways meanings are produced and interpreted) is generated and applied. Thus, as noted by some geographers, inspired by Lefebvre, flows of the economy, whether flows of materials, goods, money, people or ideas cannot be considered frictionless. On the contrary the direction and form that these flows take is materially influenced by social and economic structures and structuring processes which sit astride, refract, and shape flows of energy, commodities and capital (Lefebvre 1991, Brenner 1998, 1999, Randles 2001).

Of course we are not dealing with static systems; in a primarily capitalist/market organised society we are talking about 'restless' ones (Metcalfe and Foster 2003,). In fact we are dealing with open, non-linear, and *ex-ante* indeterminate complex systems (Metcalfe *et al*, Allen …, Allen *et al.,* 2002, Randles 2002). These are also systems where existing inter-systemic and intra-systemic boundaries cannot be taken for granted but are continually contested by different classes of agent (Randles 2003). Here we must also include the influence of mobilised non-firm interest groups (McMeekin 2001). Each part or interface of the system can therefore be conceptualised as *instituted* as an outcome of struggle between different interest groups mobilised (to a greater or lesser extent) to a position of recognisable solidarity. Furthermore, these interests are institutionally captured in a range of possible and actual organisational forms in 'normalised' social behaviours, firms and institutions of the State from where policy making and the legislative process/apparatus exert a particularly powerful influence. Analysis must therefore focus on the instituted construction of the separate parts of the system, but it must also pay attention to the *relational interdependency* of the system. It must identify what and which individual interests and logics press heavily on the whole system. It must also identify how pressures for change in some parts of the system confront pressures for stability and stasis in

others, and how these tensions are resolved or accommodated, giving rise to variously stable or unstable outcomes.

Using this conceptual framework, we hope to gain an explanatory handle on the total *interdependent* logic of the system, as well as appreciating how particular interfaces of (market and non-market) exchange come into being (Harvey and Randles 2002). We can also identify sites and classes of agent responsible for innovative change in the past, and potentialities that might enable changes in how a particular material flow could be re-constituted in the future.

The paper starts with a brief discussion of what IE is; it then summarizes the 'basics' of IS, at least as seen from the 'Manchester' perspective. Using an example of technological innovation and sustainability in a Food System, specifically on the *frozen pea*, it discusses how the IE and IS perspectives might have something to offer each other. It finishes with some suggestions for the questions which are prompted by seeking to link IE and IS perspectives.

2. What is industrial ecology?

As Lifset and Graedel (2002) point out, Industrial Ecology is 'industrial' in its interest in product design and processes of manufacture and distribution; it is 'ecological' both in its use of ecosystem analogies as models for environmental-friendly productive activity (or "human technological activity") and in its placing of that activity within the larger supporting ecosystems. Lifset and Graedel include under the term 'IE' a large quantity of analytical and policy work that has accumulated over the last 15 years, as Figure 1 displays. IE now incorporates a number of methods of analysis ('green' accounting, materials flow analysis, MFA, life cycle analysis, LCA) with a number of practical techniques for product and process redesign (Design for Environment, DfE, Eco-efficiency) and a number of broader frameworks for re-design of industrial collectives ('eco-parks', supply chain initiatives) and technological programmes (dematerialisation/de-carbonisation). As the Figure shows, Industrial Ecology then becomes a vital part of a mission to achieve 'sustainability'.

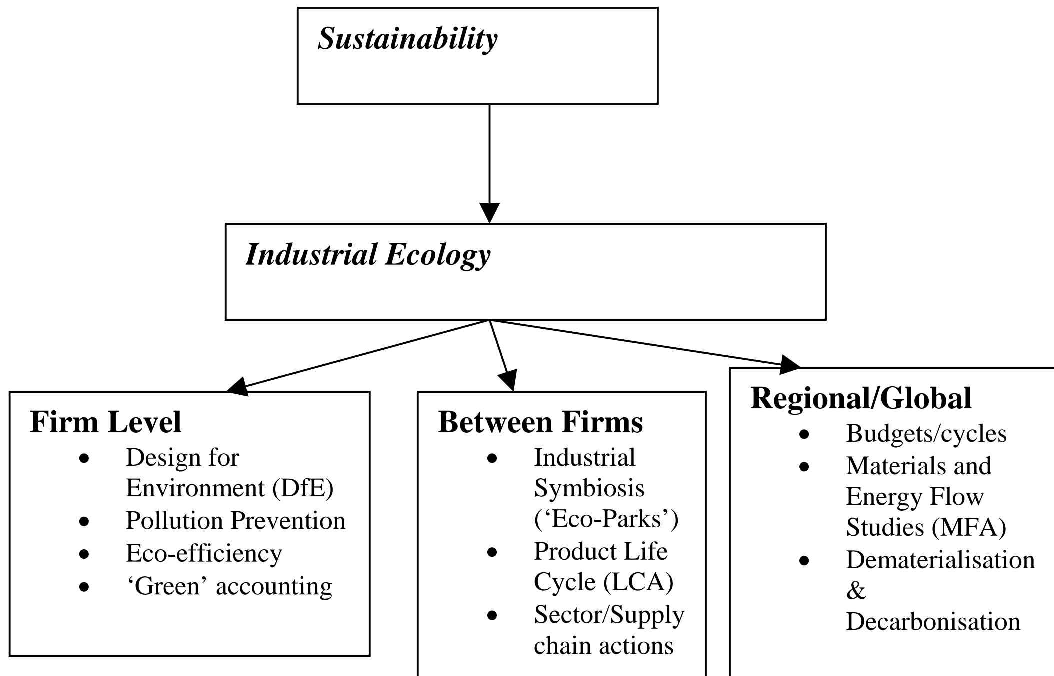


Figure 1 The elements of IE seen as operating at different levels (Lifset and Graedel, 2002,)

Interestingly, there is another approach to understanding environmental impacts which, it is claimed, has been converging with IE over the last five years. Thus, Jackson (2002) argues that the 1980s approach of 'Cleaner Production' – which seeks to redesign (with substantial new technological development) production processes to design out the generation of pollution and waste – has being expanding its remit so that it is now "an approach to environmental management which aims to encourage new processes, products and services which are [environmentally] cleaner and more resource efficient." (Jackson, 2002, p.36)). Jackson even claims that CP now "(takes) into account impacts over the whole life cycle of products and services". CP thus rivals IE for the same intellectual territory and, indeed, Jackson claims that CP *includes* IE within its remit...

Whatever the rivalries, the fact is that there is now agreement on a body of analytical approaches and industrial management techniques that is concerned with the whole set of extractive and manufacturing production process and product design activities that could be said to comprise particular 'industrial chains' (or 'supply chains'). As Vellinga *et al.* put it, research in IE (and, they could say, CP) is moving from "the earlier research into end-of-pipe and process efficiency" work to "efficiency and environmental impacts of the entire chain of resource use". This broadening of IE's remit should also include, say Vellinga *et al.,* issues related to "technological innovation, technology assessment and organisation." Though, in making this extension, they bring in yet another term –

industrial transformation (IT) - which extends the notion of IE towards policy action rather than just analysis.[ii] In particular, this broader setting of IT leads to a set of research questions such as:

> "How is the production and innovation process organised and managed?
> What is the nature of the interaction between producers within and across sectors?.....
> What are the promising technological developments and development trajectories, products and promising configurations/arrangements of production?
> What are the most efficient ways of organising the production process across the different sectors? "

They conclude that, "(Further) research should identify and analyse various possible technological and organisational trajectories that production units and entire sectors could go through, moving from one dominant way or producing goods and services to another way of doing things." This programme of research for IE/IT/CP brings its concerns close to those of researchers in Innovation Studies; though, as we will now argue, IS researchers add further dimensions for consideration.

3. Innovation and Sustainability: the Manchester View[iii].

We can take for granted that 'innovation', by which we mean technological innovation and the changes in supporting economic and social structures that come with it, in some form or other must be central to the achievement of sustainable production and consumption in all areas of human activity. If current systems of production and consumption are unsustainable in terms of their resource usage, ecological impact and long-term environmental effects, then new systems of provision have to be introduced, which will entail new processes, new products, new services and new management practices; if these do not exist, they will have to be invented and launched into social and economic use. Conversely, new forms of social relationships that are innovated with environmental improvement as their goal will inevitably use products and processes in new ways. There is thus a strong relationship between innovation in socio-economic arrangements and innovation in the material products and processes in which they are entwined – *sociotechnical systems of provision* as they could be called. The development of new products and services, new manufacturing and distribution processes, new recycling and disposal methods, based on new technologies or adaptations of existing ones, will strongly influence the sustainability of future systems of provision.

Consequently, understanding the processes that are likely to underpin these developments is crucial for policy intervention to achieve desirable forms of sustainability: in short we consider the processes of technological and social innovation and the means of guiding them into sustainable directions.

Understandings of the mechanisms of innovation have changed over the last 40 years, when innovation was usually seen as the private actions of individual firms carrying out 'R&D' by exploiting scientific 'discoveries' that emerged from public investment. Nowadays, though individual products and services may appear to emerge from individual firms, the process of innovation is seen as involving many social actors (Rothwell, 1994). Indeed, some innovations are seen as the result of 'social shaping' by actors outside firms (Williams, 2000). This happens as a result of interactive processes that involve the exchange of information and knowledge. It can be taken as obvious that these interactions are:

- between firms in the same sector, in partnerships and alliances;
- between firms within a particular supply chain, who act as suppliers and customers to each other;
- between firms and other organisations that regulate them and lobby them

In short, understanding the dynamics of innovation – where and how it takes place, how it links to sources of scientific and market knowledge – has taken on a systemic dimension. This might be seen as the IS equivalent to the IE understandings of the flow of materials through chains. However, crucial to an understanding of these systems is another element which has tended to be ignored by IS: namely, patterns of *consumption behaviour.* Understandings of consumption of and demand for new products and ways of providing and *using* them, as opposed to just design, production and supply of those products, is something that Innovation Studies is becoming increasingly aware of, especially in Manchester.[iv] So, to the three interactions listed above we can add a fourth:

- between firms and their customers, their consumers, their 'markets'

We call this set of interactions that are required for the introduction of new products and systems, "distributed innovation" (Coombs and Metcalfe, 2000). We see this as, what we have called elsewhere, a 'meso-level' process that looks at how the 'bottom-up' networks of heterogeneous actors that develop the new products and shape new markets and consumer behaviour are set within macro-structural shifts. (Green *et al.,* 1999). One of the central aspects of distributed innovation processes (DIPs) is the importance of interactions between innovating firms (or sets of firms) and between those firms and purchasers and users and others (e.g. regulators, intermediaries…..). With more intense international competition, and rising world incomes, firms have become increasingly sensitive to shifts in consumption behaviour, and many of them attempt to combine this knowledge about consumer demand and markets with knowledge of potential innovation opportunities. We would want to expand the notion of DIPs from a concentration on economic actors only, to include a wider range of social and political actors: regulatory and standard-setting bodies, lobby groups, professional associations, publicly-funded science institutes.

The processes through which demand for innovations is identified by firms and articulated by users/consumers and socio-political actors can be summarized thus[v]:

1. A multitude of actors is involved, making 'steering' apparently more complex but actually providing more opportunities for intervention, given that the process of innovation is both *prolonged* and *wide*.
2. Radical innovation is as much about *creating markets* as about creating things (involves creating *firms* as well for new technologies; see Green, 1991 on biotech)
3. There are system limitations to major transformations ('lock-in')
4. There are opportunities nevertheless for 'niche' exploration of new products ('Strategic Niche Management' or 'Social Niche Management')
5. Societal and political mobilisation against industrial regimes can disrupt markets, opening up new 'spaces' for innovation: *"destructive creation"* (McMeekin, 2001)
6. 'Consumers' should not be restricted to end-consumers (this is especially true for infrastructures - given large energy and water consumption of processing firms) (Green *et al.*, 2000)
7. Public procurement policies are especially significant (New *et al.,* 1999)
8. *State sponsored regulation* mediated by policy guidance or legislation remain of crucial importance in inducing, re-directing or suppressing innovation (see papers in this collection). These regulatory effects may be either direct or indirect in that they operate via their effects on changing demand and consumption practices..
9. Some organised groups of labour are able to carve out a particular occupational niche associated with a corpus of knowledge, competences, and status. Through the strategic endeavour of '*professionalisation projects'* these groups are able to exert influence on market regulatory processes, the legislative process, processes of technological development and innovation, and processes of opening and growing markets [vi]
10. Innovation and change occurring at one geographical scale has consequences for, or simultaneous *impacts on other scales* (e.g. Beauregard 1995). Further up-scaling and down-scaling are strategic options adopted by agents for exerting control over - 'taming'- resource flows and *disciplining boundaries* (Roberts 1994). Multi-scalar perspectives are therefore an essential part of a more enlarged understanding of the socio-economic and political consequences[vii] of innovation and change.[viii]

Our contention is that these ten summary points capture some of the processes and classes of agent which research in IS has already shown to occupy 'spaces of innovation'. Our second contention is that such an analysis might usefully complement existing IE perspectives providing scope for an enlarged IE-IS research agenda. Of course, many of these dimensions are already captured in many IE

models and applied case studies, but to our knowledge they are not formalised as such. On the other hand, the systemic holistic dimension integral to IE analysis is a powerful idea to complement much work in IS which is frequently more atomistic or partial in its analysis. A further observation is that the ten dimensions are interlinked. Each influences at least some, if not all, of the others. A methodological approach is therefore warranted (and indeed is already evident in several of the papers to be presented at the workshop) which captures not only the salience of these dimensions separately, but also and importantly outcomes arising from their *inter-connectedness*, which potentially gives rise to creativity, novelty and change. Of course, to suggest any one case study even tries to capture a cross-tabulation of all of these dimensions against all of the others is clearly nonsensical. Such an effort risks producing an interminable level of detail. However, what we find particularly interesting is that several of the workshop papers already capture a number of (different) examples of these inter-linked dimensions, regardless of the context of their application, i.e. whether 'sector' studies, corporate case studies, spatially organised studies, or insights into particular interfaces (consumption-production; regulation-production etc).

4. Peas: Industrial Ecology and Innovation

We are trying to bring together notions from Industrial Ecology and Innovation Studies in a study on the technological and social implications of the search for more "sustainable" food systems which is currently exercising many policymakers, industrialists and campaigners, as well as some farmers.[ix] This section uses the example of the *frozen pea* in the UK as an example to illustrate these notions.

4.1 Figure 2 presents a "system map" for the *frozen pea* in the UK. The frozen pea is especially important, symbolically if not quantitatively or nutritionally, for the UK diet. It is *the* green vegetable, the first one to be available in a frozen form (1950s?) and the first to have its consumption, in a 'fresh' form, detached from its seasonality.[x] It symbolizes other things as well – as something that might be considered 'unsustainable', both in growing it and in freezing and distributing it. As such it has become the subject of examination by its major processor in UK – Unilever/BirdsEye- through its work, in partnership with the Forum for the Future FftF (whose guru is Jonathan Porritt, the UK's leading sustainability campaigner and adviser to Princes and governments), on the Sustainable Pea.[xi] The focus of the FftF/Unilever initiative is in making the agricultural methods of pea production more sustainable by, for example, reducing the quantities of chemical inputs suggesting that there are or should be other, more 'organic' methods of agriculture. However, there are other aspects of the frozen pea's ecological impact which also need to be considered. From an IE viewpoint there needs to be consideration of *all* the resource inputs and ecological impact before assuming that *pea-growing* - the agricultural part of the system - is the (only) problem. And from an IS viewpoint, we need to identify the sources of technological control and possible innovation solutions in dealing with any of these unsustainabilities;

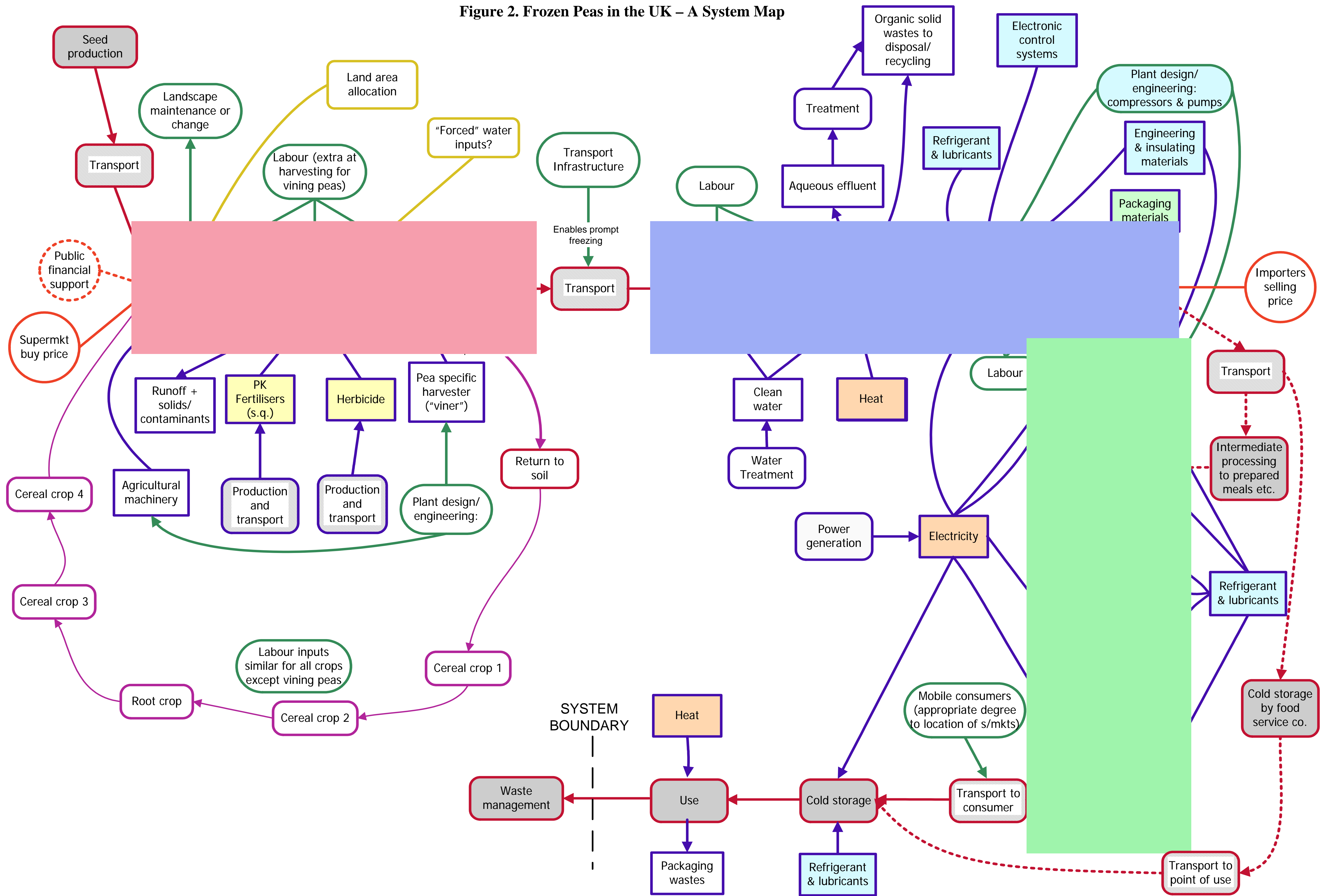
in particular we need to take account of the apparently only fixed point in the whole pea system map: the continued place of frozen peas, conveniently purchased year-round at a low price, in UK meals.

A food system is thought of here as a sequence of activities, starting with the production of plant seed, that link together to bring food to consumers' mouths.[xii] If we want to analyse the implications of the existence of a certain food system for society, the environment and technology we must start with three questions:

- what characteristics of society, technology and the environment enable the system to exist as it does?
- what are the consequences of its existence?
- what tensions within the system exist between pressures for change and pressures for stasis, and how are these resolved as outcomes/processes of adjustment and co-evolution?

Environmental life cycle assessment (LCA) is a useful starting point for an investigation of consequences and enabling factors.[xiii] We have therefore used this approach in building a map of the frozen pea system. The overall system map included as Figure 2 shows a string of basic activities.[xiv] However, we have not just drawn a flow diagram of the elements of the pea agricultural, processing and distribution system (something that we would expect from a straightforward IE-type study). To take account of the understandings of Innovation Studies we have added those elements that indicate how the system is controlled by a number of "core" organisations, with inputs from and outputs to its socio-economic environment, the "technosphere" and the natural environment. By technosphere we mean the set of human activities which transforms naturally-occurring resources into the forms used in the system under study, and turns wastes from that system back into substances that are released into nature. The catalogue of inputs and outputs is not exhaustive: there would not be space in a graphic representation of this sort for such a listing. We have tried to focus on "critical" inputs and outputs, namely those without which the system could not exist in this form.[xv]

Figure 2. Frozen Peas in the UK – A System Map



4.2 The Pea Consumption and Production System: the Materials Flow

Figure 3 shows the chain of basic activities that are the core of this system. The system centred on growers in the UK. The UK is both the largest grower and consumer of immature, or vining, peas (as distinct from dried, or combining, peas) in Europe. Some 35-40000 hectares are dedicated to their cultivation in this country, with this area tending to fall with time. Because of this selected focus, the geographical locations of some of the activities in this sequence are defined or constrained. Such activities are shown in Figure 3 as boxes with no shading. Many activities in the sequence entail transport or motor-powered vehicles: these are denoted by hatched boxes. Boxes with grey shading then denote activities which are static but are not geographically-constrained by virtue of our focus on UK grown peas.

On the farm: There are a number of seed suppliers from whom growers can source seed for peas. By definition the chain of activities from planting to harvesting is geographically fixed, but we draw attention to the fact that planting and harvesting are dependent on the use of motorised equipment.

A key aspect of the freezing of immature peas is the time that elapses between picking and freezing. This is portrayed as being a critical factor in determining the taste of the finished product. Indeed, the idea that no pea is packed more than 150 minutes after it has been picked features in the marketing of some brands. (As an old advertising jingle put it: BirdsEye peas are “Fresh as the moment when the pod went pop”.) While other processors have no specific commitment, all apparently aim for similar levels of performance. This has two implications for the system:

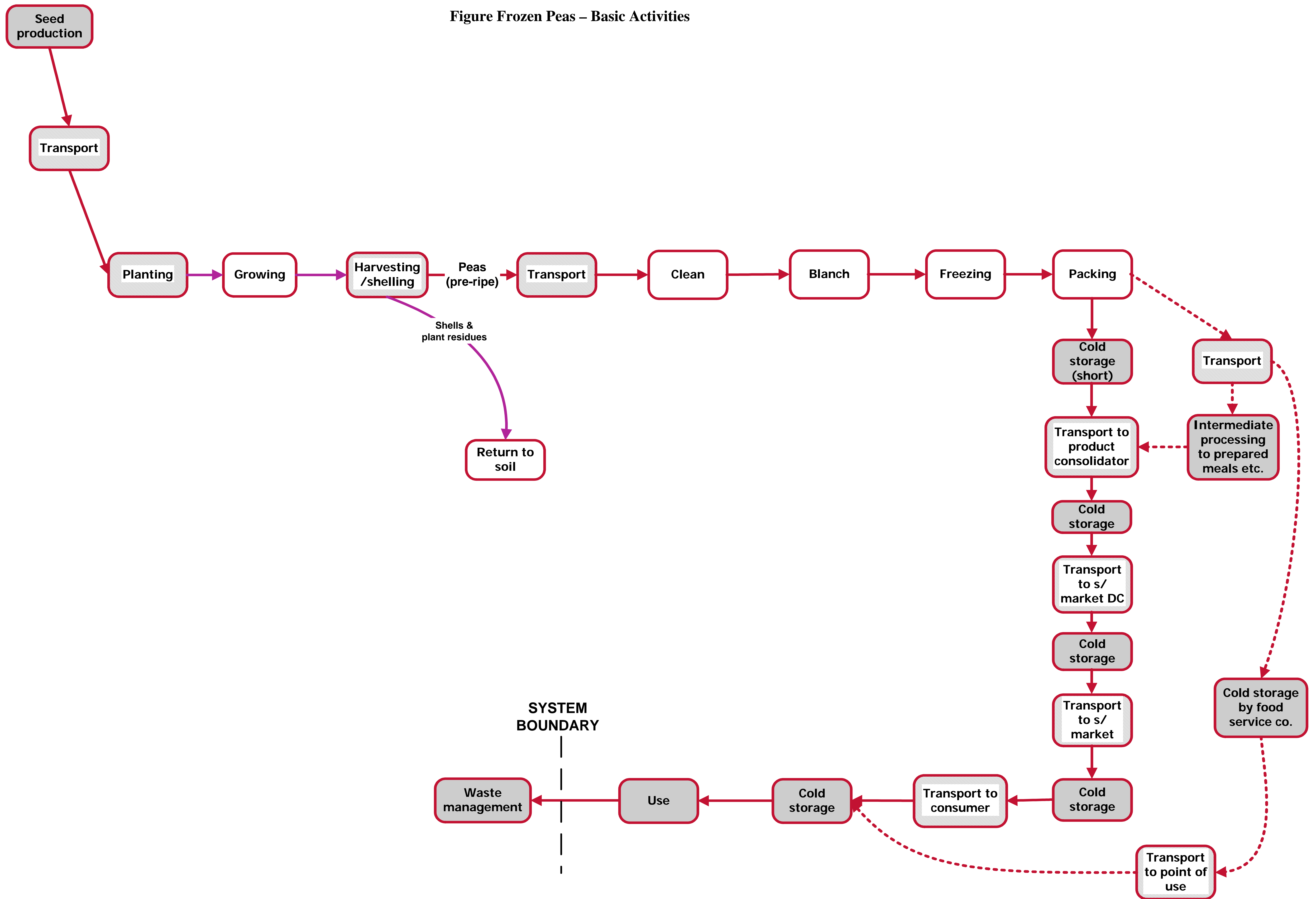
- harvesting involves many small vehicles to transfer peas quickly from field to bulk road haulage container, and
- the location of processing plants is geographically constrained to being reasonably close to the farms. We have not done sufficient research to establish a specific radius: however, since the 150 minutes must include time to fill a 40-foot trailer, and time to offload, wash, blanch and freeze the peas as well as actual travelling time, it seems unlikely that this would be greater than 100km.

The harvesting equipment (known as a *viner*) also separates the peas from their pods and the remainder of the plant. These residues are later returned to the soil.

Into the freezer : On arrival at the processing plant, peas are cleaned and checked, then blanched (partly cooked by immersion in very hot water – 90°C+) before being frozen and packed. Fluidised bed freezers[xvi] are used to allow efficient heat transfer from cold air to pea.

Through the distribution chain: The activities that follow processing are common to most food ingredients. A proportion will be shipped on to other food businesses that produce prepared foods such as ready meals, soup, etc. A further proportion goes to “food service” businesses – operators of canteens, restaurant chains, commercial caterers, and so on. The remainder[xvii] is delivered to shops for sale to individual consumers.

Figure Frozen Peas – Basic Activities



It is generally held that supermarkets account for some 80% of all food sales in the UK, so it is assumed that most peas pass through their logistics chains. These start with delivery to a product consolidator (a logistics firm), who feeds goods from a number of suppliers into a distribution centre from which they are sent out to the stores themselves. The last few activities in the sequence, those undertaken by individual consumers, will be familiar to all of us. With the exception of those lost in processing, all the peas that leave the farm pass through these activities, whether they reach the consumer via the supermarket directly, in a prepared food product or via a food-service business.

It is important to note that peas are not grown solely for their food value. Peas, along with other so-called "legume" crops, fix nitrogen and therefore serve to improve the fertility of soil as they grow. These crops therefore have an important place in agricultural systems and recent work on sustainable agricultural systems that include peas[xviii] has noted the need to take into account the impact on other parts of the rotation of any changes in pea husbandry made in the interests of sustainability. The rotation spans several years (5 to 8) and includes cereal crops and possibly uncultivated years. We suggest that the exact natures of the other steps in the rotation are less important to the further study of the pea system in this project than the fact that they exist, and any influence they may have on the choice of leguminous crop.

4.3 The Pea Consumption and Production System: 'Core Organisations'

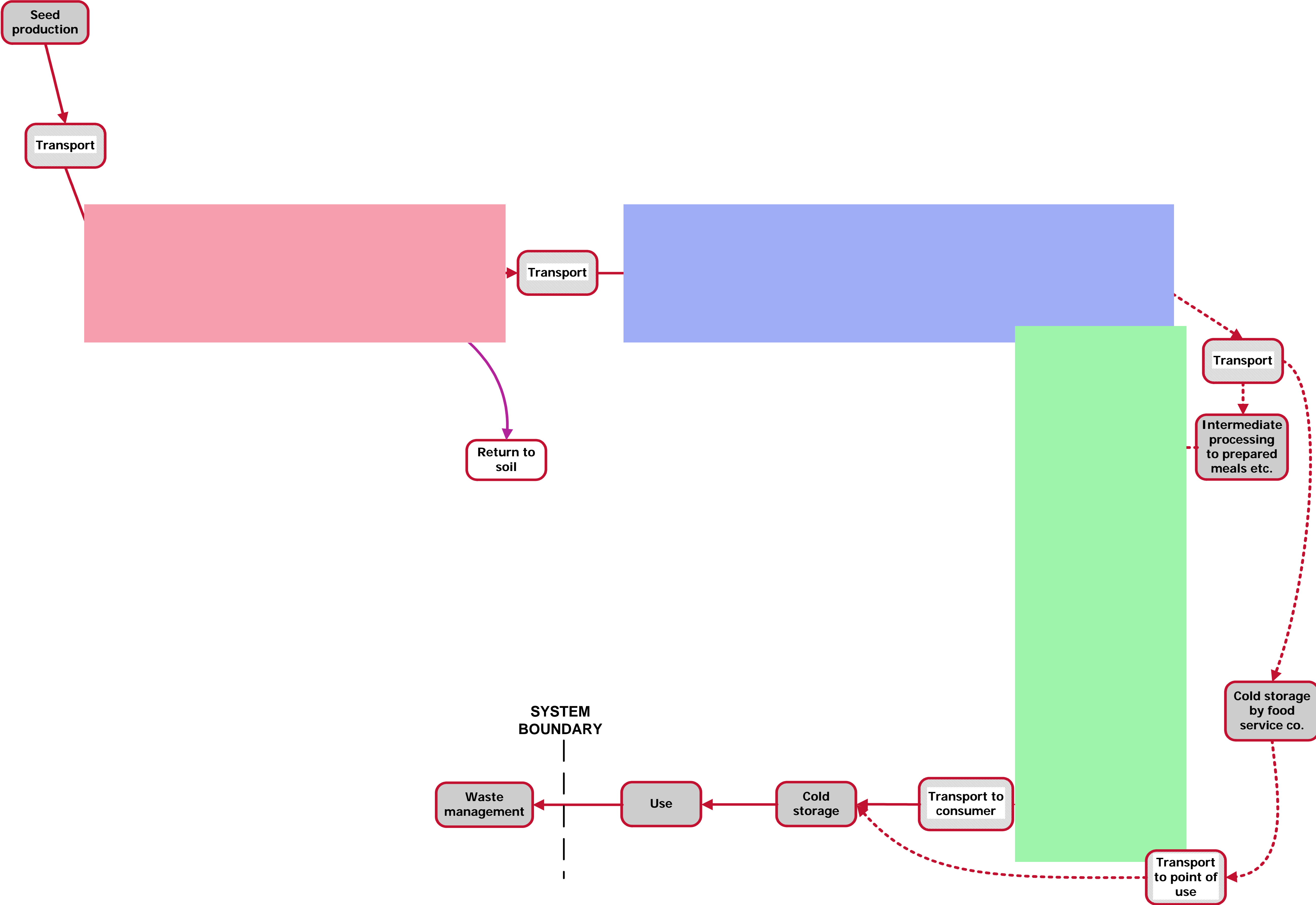
Any analysis of the implications of implementing one or another definition of sustainability must consider potential changes in the balance of power between organisations at different points in the "value chain". One of the contradictions associated with the promotion to business of, earlier, environmental and, more recently, sustainable good practice has been that it offers competitive advantage to all – 'win-win'. In the case of sustainability, different definitions have different implications for different actors: for example, stressing organic production would appear to favour *organic* producers and all those involved in moving products to consumers, while stressing *local* production would appear to provide opportunities for UK farmers and pose a number of threats to the existing food distribution system centred on chains of supermarkets with centralised purchasing.

Figure 4 shows the sections of the chain of basic activities in the pea system that are under the control of three groups. Farmers, or more accurately, "Growers' Groups" – formal co-operatives bringing together up to 50 farms and controlling cultivation of up to 4000 hectares – control the planting, growing and harvesting activities (pink shading in Figure 4). These Growers' Groups own the equipment needed for these activities and, for the most part, have in-house agronomy expertise. One large, well-known processor eats into this sphere of control by having its own agronomists work alongside producers contracted to supply its peas. There are reckoned to be some 10-15 of these Grower Groups in the UK now, and the tendency is for them to concentrate further in pursuit of economies of scale.

Moving downstream, the current level of concentration appears to be greater still. There are reported to be only three large pea-freezing operations in the UK, as well as a handful of smaller independents. Their sphere of control is shown by the blue shading in Figure 4. One of the large freezers produces branded peas under its own label, leaving the rest to cover other brands and all supermarket own-brands. (A single cannery also takes in some pea production).

Despite this high level of concentration, power seems to remain with the supermarkets, which control those activities contained within the pale green ellipse in Figure 4: the economic forces that account for this are discussed in Section 6. Supermarkets appear to have greater control over inbound logistics than processors: the latter specify times and dates at which product is to be delivered, leaving choice of haulier and negotiation over haulage rates to the Grower Group. Supermarkets, on the other hand, commonly fix all of these parameters “on behalf of” their suppliers.

Figure 4. Core Organisations



4.4 The Pea Consumption and Production System: inputs from the "Technosphere"

We now turn to consideration of the inputs and outputs that are necessary for it to function. The blue boxes in Figure 5 contain those inputs and outputs that are, in our judgement, significant for the purposes of this study. Also shown on Figure 5 are "forced" (i.e. non-rain!) inputs of water to the growing stage: we have not researched the extent of these but have assumed that water used for this purpose is drawn directly from nature rather than from the mains. This unmodified input from nature is distinguished by being shown in a yellow box.

The other inputs shown in Figure 5 all start out as natural resources in some form, but are modified by human intervention. It is convenient to think of these modified natural resources as products of the "Technosphere" whether they take the form of capital equipment or raw materials. The inputs shown do not constitute a comprehensive set: we do not, for example, show fuel inputs to transport activities – although these should not be neglected in future analysis. The inputs have been categorised to some extent according to source and type. Thus, those inputs bought in from the chemical industry are shown in boxes with yellow fill; those from the refrigeration industry in boxes shaded pale blue; those from the energy industry in boxes with orange shading, and those from the packaging industry in a box with shaded pale green. The inputs are described in generic terms because, for most, there is a choice.

On the farm: Since peas are planted to enrich the soil they do not, themselves, require inputs of nitrogenous fertilisers. Small quantities only of phosphorous and potassium fertilisers may be used to maintain mineral balances. Selection and application rates of crop protection chemicals (herbicides, fungicides, etc.) is case-specific and is often determined by drawing on suppliers' expertise.

Into the freezer: Clean water is used in large quantities in industrial-scale food processing, both for cooking and for cleaning. It is common practice to treat mains water further to minimise bacterial contamination, either by chlorination or by UV disinfection. The need for, and importance of, heat and electricity in a process which entails first immersion of peas in boiling water followed by freezing is self-evident. Some might argue that disinfectant chemical are a "sine qua non" for industrial food processing, but we have judged their significance to be somewhat lower in this case, partly in the light of the fact that frozen peas will receive further cooking (which should ensure fitness-for-consumption) and partly in the light of the expected scale of chemical use.

The components of the refrigeration system are clearly critical to the freezing activity. Although the consumables (refrigerants; lubricants) are shown here, we suggest that it is the equipment, enabling the compression-expansion cycle to be driven and harnessed to move heat energy, that is the critical input here. Know-how may therefore be a more important input than materiel, and some such inputs are discussed in the next section.

Through the distribution chain: In fact, the refrigeration process is critical to any frozen food system at every stage from initial freezing through to the point at which it is used, so the same inputs are shown to every basic activity (refrigeration is also used in the transport activities, of course, although not shown explicitly).

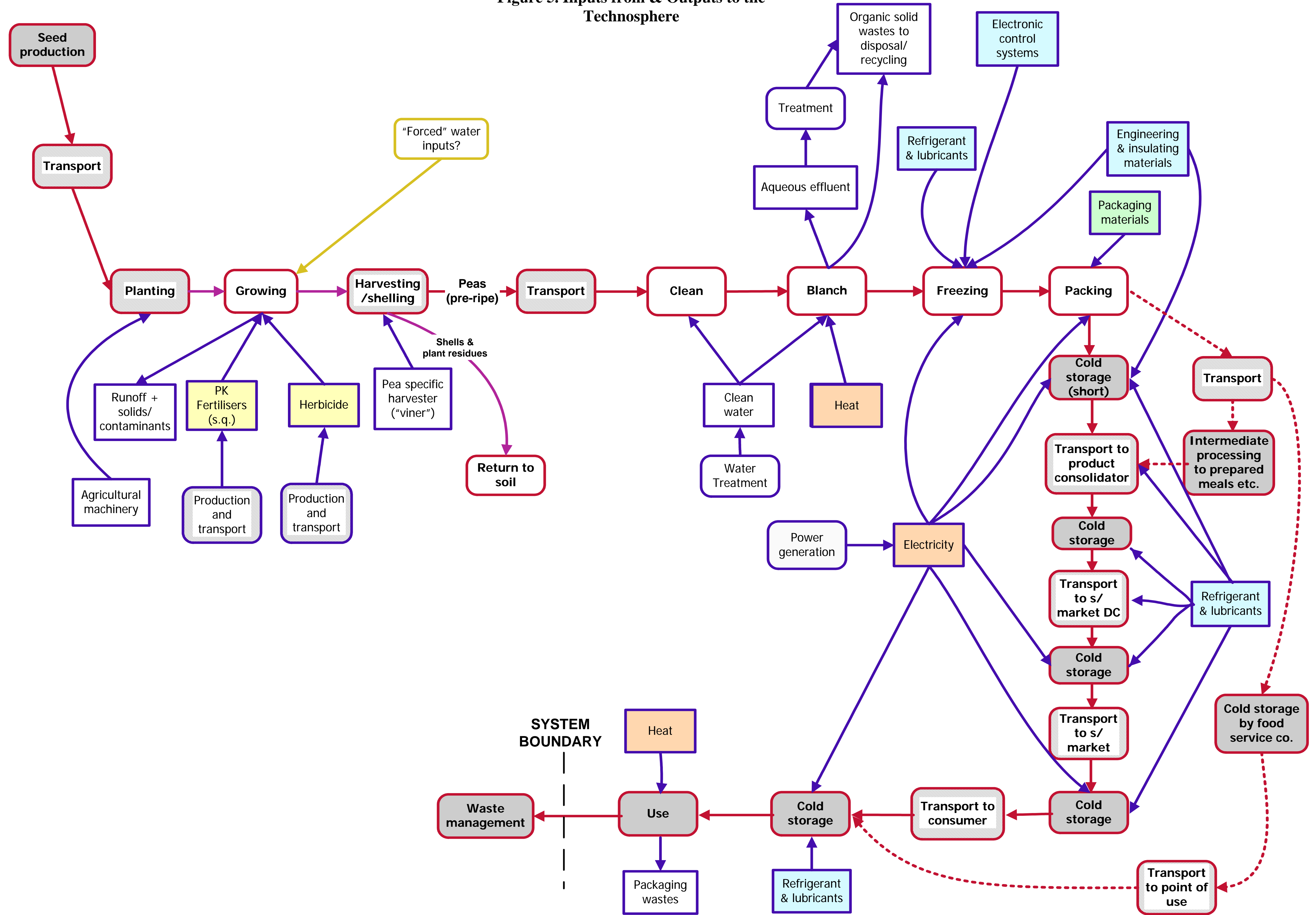


Figure 5. Inputs from & Outputs to the Technosphere
Seed production
Transport
"Forced" water inputs?
Planting
Growing
Harvesting /shelling
Peas (pre-ripe)
Transport
Clean
Blanch
Freezing
Packing
Organic solid wastes to disposal/ recycling
Treatment
Aqueous effluent
Electronic control systems
Refrigerant & lubricants
Engineering & insulating materials
Packaging materials
Shells & plant residues
Return to soil
Runoff + solids/ contaminants
PK Fertilisers (s.q.)
Herbicide
Pea specific harvester ("viner")
Agricultural machinery
Production and transport
Production and transport
Clean water
Water Treatment
Heat
Power generation
Electricity
Cold storage (short)
Transport
Transport to product consolidator
Intermediate processing to prepared meals etc.
Cold storage
Transport to s/ market DC
Refrigerant & lubricants
Cold storage
Transport to s/ market
Cold storage by food service co.
SYSTEM BOUNDARY
Heat
Waste management
Use
Cold storage
Transport to consumer
Cold storage
Packaging wastes
Refrigerant & lubricants
Transport to point of use

Packaging material inputs are only shown in the system map at the point where peas are packed into their sales packaging, which is most often printed plastic film but may also be waxed board. Secondary packing, such as cardboard cases, and tertiary or transit packing (shrink-wrap, pallets, wheeled cages, etc.) will be used – entering and leaving the system both at the initial packing stage and elsewhere.

Falling off the sides: The outputs highlighted in Figure 5 are wastes from the pea processing activity and contaminated runoff from farming (the latter may in fact enter the environment directly, rather than passing through some form of treatment as implied by its representation here as an output to the Technosphere). There are, of course, other commercial and industrial wastes from all the activities shown. These have not been included in the system map – partly for want of space, and also because they are judged to be of less significance to a study of food systems' particular characteristics.

4.5 Socio-economic Inputs and Structures

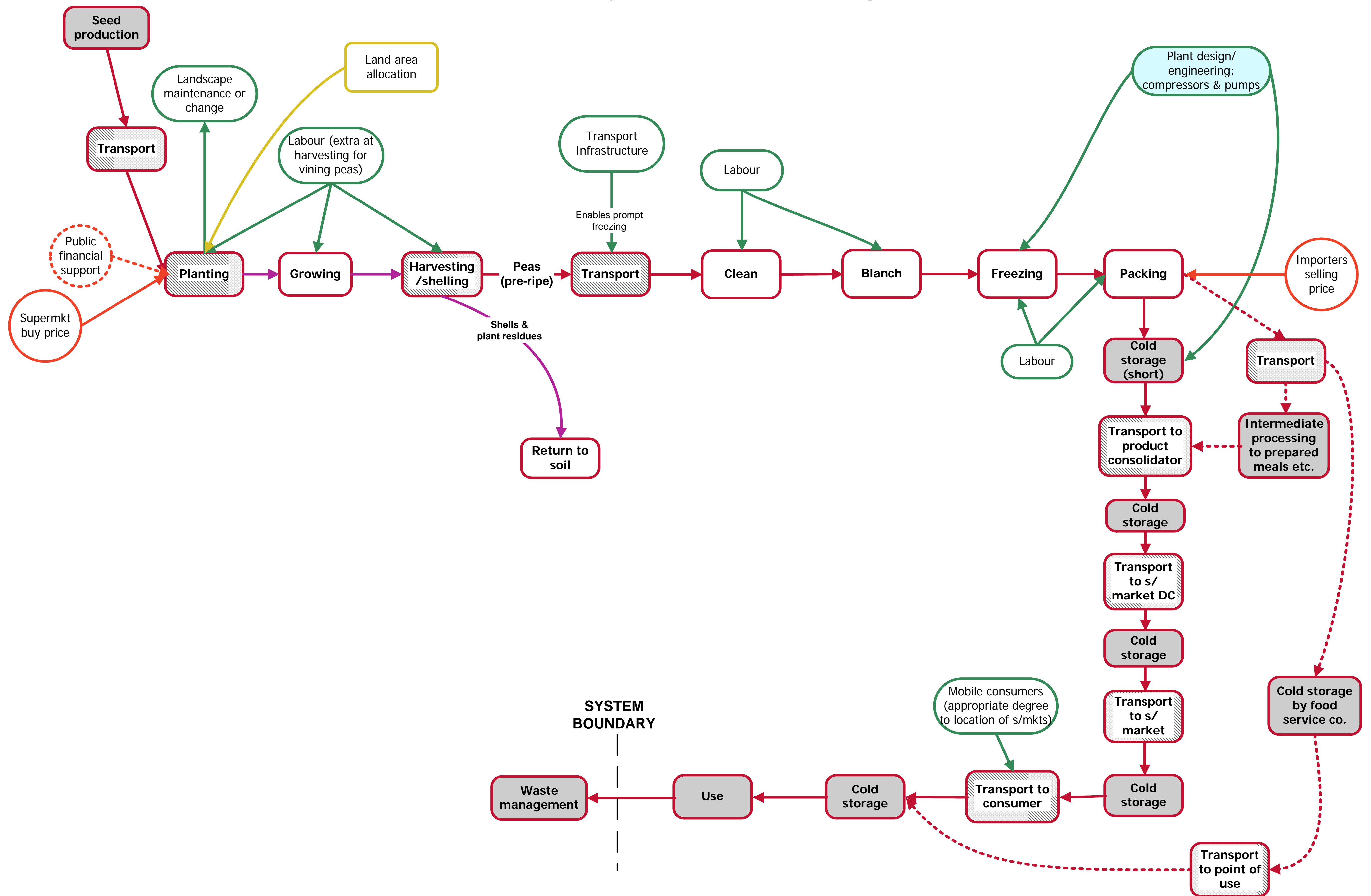
While physical resource flows are needed for the operation of the frozen pea system, a range of economic and societal inputs are also necessary. It is possible to identify a variety of these. Some, such as labour, can be seen as a potentially substitutable input, exhibiting differential mobility and different degrees of fixed/flexible supply, depending on the labour class involved, the levels of skill (and therefore training) involved, and the terms and conditions for hiring labour. The supply of labour does not typically nowadays have significant implications for natural resource consumption.[xix] Others are decisions, such as the decision to allocate land to agriculture or the decision to build transport infrastructure. Decisions like the latter obviously lead to natural resource consumption, so that the provision of road transport infrastructure could be represented as an input of built road from the Technosphere to the pea system. However, it is widely acknowledged by workers in the field of life cycle assessment (LCA) that the inclusion of capital goods in product systems makes no significant difference to the results of LCAs, because the impacts associated with the production of these goods is spread so thinly over their lifetime use. On the other hand without decisions to build the transport infrastructure in something like its current form the pea system as shown here could not function. In particular, we suggest that in this case the road network is essential for fulfillment, by a small number of processing centres, of the short time-to-frozen commitments that appear to be common in the industry. Further exploration of this aspect of the system may well be worthwhile as the project moves forward.

Figure 6 shows the chain of basic activities in the system with inputs from and outputs to society shown in green "boxes" and economic "inputs" (forces might be a better term here) in orange circles. Labour inputs at the farming and food-processing stages are shown, because the existence of jobs in rural areas is a significant factor to some parties in the sustainability debate. It seems, however, that labour inputs to pea cultivation are not very different from labour inputs to the cultivation of other crops, although the need for very rapid collection at harvest time requires some additional labour for a

short period on any individual farm (Grower Groups stagger planting across the land they operate so that harvesting continues for a period of weeks).

Land allocation is a direct input to the system from nature (denoted in the system map by a yellow “box”) but has been included as a socio-economic input because the *decision* to allocate the land is seen as a significant factor, as much as the occupancy of land by pea cultivation.

Figure 6. First-order Socio-Economic Inputs



The importance of compressor and pump technology to the refrigeration process has already been mentioned, and is shown here. Consumer mobility is also an important factor, although the penetration of the market for vegetables by the frozen form pre-dates the move of supermarkets to out-of-town and edge-of-town locations, so the car-bound consumer is not judged to be critical.

Only three economic factors are shown, all inputs (support payments, supermarket buying price and the price of imported frozen peas). Clearly the balance between what supermarkets, as buyers, are willing to pay growers for their product and what growers could receive for alternative crops would be expected to be an important factor influencing crop selection. The support payments available to growers for combining peas and field beans amount to some £260 per hectare currently. The selling price of combining peas is in the region of £80 per tonne, with crop yields of the order of 5 tonne/hectare, so that a hectare of this alternative crop may yield some £650 in income, of which 40% is support payment. This alternative might reasonably expected to set some lower limit on the price to which supermarket buyers can drive frozen pea growers down. The price at which imported peas are available imposes an upper limit on the price that growers and processors can obtain from supermarkets, although it has been reported that the supermarkets' desire to be seen to be supporting UK farming may allow growers in this country a slight premium for peas destined for direct sale to consumers. It should be noted that intermediate processors and food-service businesses, with lower public profiles, have no such sensitivities.

A further crucial economic input (though it is not shown in the Figure) is the availability and access to finance. Modern market economies only exist according to the precondition that there exists a flow of investment capital and credit facility to 'lubricate' the productive system, enabling production to take place in the absence of, but in the expectation that, consumption will follow in the future. A working and workable integrated financial system is often taken for granted and rendered invisible in resource-flow models. History shows however that when financial systems enter crisis this can have catastrophic and often amplifying contagious effects across the system.

Economic outputs have not been included in the system map. While they can readily be identified (payments to workers, business profits, taxes), investigating their relative significance (say in terms of which organisations get which proportions of the selling price of a pea, and how much is profit in each case) would require more detailed research than is possible in a preliminary work such as this.

Also not yet the subject of focused research in the particular pea case, but receiving growing attention particularly in the 'Sociology of Consumption' literature, are the underpinning structures and meanings that inform consumption as *practice* (Warde refs, Southerton and Shove) and which then have an iterative or complicit effect on production (CRIC 2001). We have already identified that pea consumption has a geographic structure, peas being a 'staple' of the UK diet. We can also conjecture social class, age, and 'occasion' dimensions of the structuring of pea-eating practices. We have identified the pea as a 'stand-by' freezer food, therefore integrated and dependent for its existence and meaning on a whole range and combination of household domestic appliances, notably freezers and cookers (Southerton, Warde 1992 …). We can also conjecture that peas are eaten primarily as a complement to other, equally taken for granted foods (chips, fish, chicken, burgers) as staples of the UK diet. Perhaps they are more likely to be eaten as a mid-week rather than weekend meal, as a children's rather than an adult meal, and for everyday occasions rather than special candle-lit dinners. All these ways of appropriating peas into the mundane everyday lives (Warde 2002) of ordinary people have profound impacts on the way peas have come to be used, understood, bought and stored (and thus produced, and most importantly, transported). Furthermore, producers do not passively accept these structures of consumption, rather, through their marketing 'segmentation' and communication strategies they proactively seek to reinforce stratified consumption patterns (evocative of Bourdieu's familiar 'distinction' theory, Bourdieu refs..). Alternatively, producers may use product differentiation and product variety generation strategies to push appeal into new segments and ratchet up total consumption. Thus, although peas have arguably not been subjected to the same variety generation processes as the 'humble tomato' (Harvey 2002), we are nevertheless familiar with the distinction, exaggerated by producers, between the ordinary 'garden pea' on the one hand and the special '*petit pois'* on the other.

4.6 So?

The system map presented here is intended to provide a basis for further research into the implications for the system and the actors within it of working towards different definitions of sustainability. In drawing up a description and graphic representation that cover all elements of the frozen pea system from seed to consumption but are at the same time reasonably concise, some judgment and selectivity has been essential. This selection process has endeavoured to focus on factors (which we believe can usefully be classified as inputs or outputs) that either enable or constrain the system as it operates now. It has tried to pick out technological knowledge, societal characteristics, resource flows and economic conditions which, if changed

significantly or taken away, would cause peas – if they were grown at all – to be handled very differently.

The continued survival and reproduction of the UK frozen pea system we have described depends on a number of conditions that are both social and technological. To present some of these:

1) It is clear that, at the level of system actors, if there is to be one actor with a central structuring role and qualitative asymmetric power it is Unilever. This is not always the case within Food Consumption and Production Systems. In other systems, organisational actors at other points in the chain could be more influential. For example, it can be argued that supermarkets, especially in the UK, are the key system shapers in many fresh foods (such as milk or meat); fast food restaurants have been identified as the system shapers in processed meat and potatoes. In other words, different systems display different symmetries of power to manage, and therefore to change, the chain of activities in the system. This is especially important when we look at the sources of knowledge in the system. Unilever's expenditure on R&D and its ability to mobilise knowledge of agriculture, the freezing process and the logistics of pea distribution make it the key location for any innovation within the system (or the breaker of other innovations that might adversely change the system). Unilever is thus the key agent in producing and interpreting knowledge about 'sustainability', that is what should be considered as worth investigating and acting on to bring about more 'sustainable' pea production. Unilever's interest in sustainability is connected with the maintenance of its power in the pea system. So far, this interest in sustainability has been confined to an investigation of agricultural practices of pea-growing. This can be seen either as the 'first step' in an examination of the sustainability of the pea system as a whole, or as an attempt to define sustainability as just being about agriculture.

2) As we have sought to show there are a number of features of the pea system that deserve investigation if we are to think more systemically about sustainability. These could be called the 'bottlenecks'/'pinch-points' for the sustainable reconstruction of the chain:

- the influence on the system of the notion that peas have to be moved from 'field to frozen in a relatively short period of time

- the central position of the pea in the everyday eating habits of the UK populace

- the centrality of the refrigeration process, at numerous sites as well as in transit.

However, if we can identify *one* element of the system that structures the rest of it, it is the transport infrastructure for the necessary *prompt freezing* of the pea. This in turn is set by the instituted consumption practice that puts the frozen pea as a cheap, year-round convenient component of green vegetables in the average UK diet. Sustainable reconstruction of the chain might depend on basic changes in some of the current system conditions, such as the possibility of higher prices (necessary if all peas were to be 'organic') or the shift back to *seasonality* for the vegetable (a contrary trend at the moment for virtually *all* fruits and vegetables) or the assumption that it can be delivered in long food chains alters. These would certainly require some change in the place of the pea in UK diets.

Organic advocates would expect that some of these changes would be necessary throughout UK agriculture and food consumption practices. However, there are other more 'neo-industrial' strategies that can also be imagined.[xx] In this strategy, you could envisage *new* varieties of peas that travel better, overcoming the transport/prompt freezing bottleneck. This would then reduce the need for peas to be grown very near to freezing plants thus opening the possibility of changing the economies of scale of the industry, opening up the possibility of local agriculture and local freezing. Such ideas are purely speculative at the moment.

5. Conclusion

Our conclusions are tentative, representing simply a set of further questions intended to stimulate debate and inform/assist the identification of further issues to be researched on IE-IS linkages and overlaps. It is no accident (indeed it was a conscious aim and hope of the workshop organisers) that many of the papers at the workshop touch on or directly address some of the following questions and issues. These can be organised around six subheadings:

1) IE and Innovation

- What new forms of economic/non-economic exchange and *intermediation* are evident in applied IE case studies? How have exchange and intermediation changed over time, and what evidence is there that 'missing intermediaries' are preventing the establishment of more desirable material-money exchanges and material flows.

- What *technological* (including information technology hardware and software) innovations are emerging to facilitate, measure and monitor resource and information flows?
- What *new services* are/could emerge to aggregate/disaggregate or re-scale resource and waste streams to re-package waste into 'right-size' units for market/non-market exchange?
- What *new markets* are emerging or being intentionally created for re-usable materials, and to what uses are they being put?
- What *new consumption patterns* and practices are emerging to take up 'recyclable' industrial materials, who is the discerning user of recycled materials. (For example the domestic re-user in gardens, the public sector re-user in municipal parks & play areas. The re-use of 'waste' materials in construction, in art, in design.)?
- What evidence is there of innovation as *new forms of industrial organisation*, *new relationships, new classes of economic/non- economic agent, new 'business models' and new economic/non economic roles and activities?*

2) Governance, institutions, geo-political specificity, ethics and 'deep' approaches to IE

- Can we better understand and integrate the role of State and self-regulation and ` systemic governance issues in IE models.
- Why do (for example) industrial symbiosis arrangements 'appear' (self organise?) in some places and not others?
- What real societal-institutional constraints and limits are there to the practical application of IE models?
- Is 'Closing the Loop' part of the solution or part of the problem?
- How can questions of scale and multi-scalarity be integrally captured or taken account of in IE models and analyses?
- How do people change their behaviours from less to more environmentally sustainable? How are the interests of different stakeholder groups included/excluded and negotiated in the process?
- What role and degree of influence do financial systems (the availability and access to investment capital, shareholder influence etc) have on encouraging environmental and social responsibility on the part of corporate producers?

4) IE and Consumption

- How can we move beyond a 'black-box' representation of consumption in IE models and analyses?
- Can we better understand consumption practices of IE systems including recycling and re-use?
- Can we better understand inter-organisational buying behaviours and consumption?

5) IE in Action

- What opportunities and barriers exist for translating theory into practice?
- Can we help build portfolios of case studies – of products, materials, companies, territories, collections of firms/institutions?

6) IE and Policy

- What are the implications for such questions and perspectives for the evaluation of existing legislation and the development of 'new' policy?

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[i] We recognise that the term 'industrial ecology' has quite different meanings in its different (disciplinary) usages. For example in the sense of 'the ecology of industry' it can be used to refer to the way 'industries' comprise a variety of differentiated firm-types. Though independent, these differentiated firms none-the-less co-exist in interdependent 'bundles' mediated through various forms of (market and non-market) exchange occurring across firm boundaries, to form recognisable multiplexes or 'ecologies' of firms. This meaning is quite different to the resource and material-flows analysis usually and traditionally associated with the term Industrial Ecology. Of course an understanding of both the 'Ecologies of Industries' and 'Industrial Ecology' is important to the study of both. This is because the organisation of resources, materials and components flows determines, to an extent, 'the ecology of industry' whilst the ways firms come to orientate their activities vis-a-vis other firms determines not only the shifting patterns and structures of industries, but also determines (often limits or constrains) scope for more 'sustainable' material flows. A discussion of these different usages, and their inter-linkages, could therefore be profitable, though this paper discusses IE in its 'environmental' guise.

[ii] The concept of 'Industrial Transformation' has a wider international currency as a subject of one of the Programmes of the IHDP... See IHDP-IT *Science Plan*

[iii] Adapted from a presentation to *Winter Workshop on Infrastructures of Consumption and the Environment, Wageningen, November 2000,* Ken Green and Andrew McMeekin, "Consumption and Sustainability: An Innovation Perspective"

[iv] see A. McMeekin, K. Green, M. Tomlinson and V. Walsh (eds), *Innovation by Demand***,** 2002, Manchester University Press; R.Coombs, K.Green, A.Richards and V.Walsh (Eds), *Technology and the Market: Demand, Users and Markets*, 2001, Edward Elgar; Metcalfe book……..

[v] From these, we draw conclusions as to the appropriateness of current understandings of distributed innovation, in enabling innovations for more sustainable consumption patterns to occur. Our conclusion is that, whilst they may be suitable for Factor Four innovative transformations, if more radical transformations are required (Factor Ten and beyond) then new methods of involving all stakeholders, including consumers, in the innovation process have to be developed; but that's another story….. (Quist, Knot, Young, Green and Vergragt, 2001)

[vi] See Warde, Randles & McMeekin 2001, Randles, McMeekin & Warde 2002, McMeekin, Randles & Warde 2003 on the origins and professionalisation of market research practice, see Randles and Tether 2002 on the emergence of a new 'profession' of practitioners in environmental services and technologies)

[vii] Smith 1993, 1996, Swyngedow 1997a, 1997b, Jones 1998, Brenner 1998,1999, 2000, Randles 2000, Randles and Dicken 2000

[viii] Arguably, such multi-scalar perspectives are not typically or traditionally captured by IE models.

[ix] Ref to ESRC Sustainable Technologies Programme

[x] Its symbolism might be illustrated by the dust-jacket of the recent book by Felipe Fernandez-Armesto, *Food: A History*, Macmillan: London, 2001; F F-A, an Argentinean academic, works in the US and Europe. His publisher has chosen to depict an opened pea-pod on the front of the book, despite the fact that the pea is never mentioned in the book!

[xi] Forum for the Future/ Birds Eye/ Unilever, *In pursuit of the sustainable Pea*, London: Forum for the Future, n.d.

[xii] We have, at this stage, excluded from the system the treatment of human wastes. The environmental impacts of food production systems may conceivably be reduced by recycling human wastes (suitably treated) to agriculture as fertiliser, so this is a somewhat arbitrary boundary. However, in no case is this

recycling food-specific (i.e. we do not separate pea-derived human waste for return to the pea system), so inputs of sewage-derived fertiliser to agriculture are probably best regarded as completely separate from any wastes leaving the system, although their use may have implications for chemical fertiliser demand and for the technologies needed in waste water treatment.

[xiii] For a further discussion see "The Eco-indicator 99: A damage oriented method for Life Cycle Impact Assessment. Methodology Report" PRé Consultants B.V. 2000.

[xiv] The picture of the frozen pea system presented here has been developed by reference to a variety of published material supplemented by interviews with growers' representatives, processors and a small number of other food industry sources.

[xv] For example, industrial and domestic refrigeration is achieved through the compression of liquids and their expansion into gases, with the associated harnessing of the latent heat of vaporisation. So compressor technology is identified as a key input. This idea of studying the effects of complex, extended systems by concentrating on selected inputs and outputs was pioneered in the "ExternE"[xv] project which investigated the economic costs associated with environmental externalities of energy systems. In that case only physical flows of substances were considered: here we have also noted less concrete inputs and outputs. Indeed, we have used the term "input" rather loosely, counting the provision of transport infrastructure as an "input" to the system, although it is a good provided to society at large, not specifically the pea production system. Since our objective is not the compilation of a quantitative inventory of substance flows, this difference in usage is not expected to be of great consequence.

[xvi] "Food Processing" M.Bartlett, 2002

[xvii] Research at this stage has not been sufficiently detailed to establish a percentage, but reports on the economics of the food industry stress the fact that individual consumers are a minority market for food ingredients whose share is falling as that of prepared-meal producers is rising. The following quote from The Economist's "Survey of Biotechnology", 27 March 2003, gives some idea of relative importance in the food sector: "…in the West, where most crops are used in processed foodstuffs rather than sold as raw ingredients. The retail market for raw ingredients is simply too small to justify spending money on the development & approval of [genetically] modified versions."

[xviii] Forum for the Future, op.cit.

[xix] This is not strictly true of course. History shows that mass migrations of peoples in search of work has significant impacts on the natural environment and the consumption of natural resources, as the growth of cities during the 18th century textiles-driven Industrial Revolution testifies (Randles 2000).

[xx] See Green et al, in JEPP