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NESTA Making Innovation Flourish

Game-Changing China

Lessons from China about Disruptive Low Carbon Innovation

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About the project

Game-Changing China was commissioned by NESTA and written by David Tyfield (Lancaster University), JIN Jun (Zhejiang University) and Tyler Rooker (Oxford University). The work was carried out over a period of eight months in conjunction with the organisation of a workshop on the theme of 'Disruptive Low Carbon Innovation in China', held at Zhejiang University, Hangzhou and co-hosted by Lancaster University in November 2009. The research has involved a mix of desk research, interviews and field visits to our seven case studies. The case studies were selected to reflect a range of initiatives across China. The project was overseen by an advisory group of experts, drawn from policy, academia and the business community.

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Our aim is to transform the UK's capacity for innovation. We invest in early-stage companies, inform innovation policy and encourage a culture that helps innovation to flourish.

Executive summary

Big hydro, big solar photovoltaic (PV) and big wind – these are the usual focus of accounts of low carbon technologies in China. But a very different type of innovation – ranging from a farm cooperative in Yunnan, to woodchip and corn pellets in rural Beijing and air-conditioning using just salt and water in Hangzhou and Shenzhen – could be even more significant as examples of how to achieve a low carbon economy and society for China and the world.

Radical reductions in greenhouse gas emissions are needed if we are to mitigate climate change. This will require low carbon innovations that transform not only energy-intensive industrial processes but also how we go about everyday practices. For high carbon economic growth is not merely a matter of market failure – albeit the 'greatest example' of such, as Lord Stern has noted – but of systems failure. Regulations, financial structures and incentives, technologies, cultural expectations and established learning agendas all condition continued lock-in to a model that presupposes the unsustainable consumption of cheap and abundant fossil fuels.

Low carbon innovation in China is an issue of key global significance in this regard. This is not just because of the large and growing carbon footprint of the Chinese economy as a whole, but also because China's spectacular social and economic growth represents a unique opportunity to develop and roll out low carbon innovations. China's capacities in science and innovation are also improving rapidly, so that it is reasonable to expect that Chinese low carbon innovation will be of growing global significance in the coming decades. And, following the financial crash of 2008, it is clear that China's growing geopolitical influence has entered a new phase, which will be a crucial determinant of global efforts to respond to climate change.

This report explores the importance of one form of low carbon innovation that offers considerable opportunities both to China and the world, but that is usually overlooked: 'disruptive innovation'. The notion of disruptive innovation was originally developed by Harvard researcher Clayton Christensen and has subsequently been applied in many fields, including low carbon innovation. Disruptive innovation challenges many of our common assumptions about innovation; it produces cheaper, easier-to-use alternatives to existing products and services, which target previously ignored customers. Such innovations are often produced by non-traditional players, and sometimes they exploit existing technologies in novel contexts and combinations.

This report follows a 2007 NESTA report that profiled eight disruptive low carbon innovators from the UK, and explores the particular importance of this type of innovation to China with seven case studies. These are the Chinese 'Game-Changers', each of which has developed a low carbon innovation that has the potential to make a significant contribution to emissions reductions and the move to a low carbon society. In five years time, five of these innovations could together be saving up to 66 million tonnes of carbon dioxide per year, while the other two will be important players in markets that could have total savings of 270 million tonnes of CO_2 per year. These are equivalent to the greenhouse gas emissions of 25 million and 100 million Chinese homes respectively, or 4 per cent and 16 per cent of total Chinese emissions in 2006.

Greater attention to this form of innovation alongside extant programmes of hi-tech innovation would capitalise on current Chinese strengths and so accelerate moves to a low carbon economy and society, while also incubating the world-beating Chinese low carbon firms of the future. It will also maximise the climate impact of the already-existing technologies that will have to deliver the vast majority of emissions reductions to 2050. Lastly, by demanding a definition of innovation that is much broader than high-technology alone, disruptive low carbon innovation highlights the need to consider the wider social and political aspects of innovation that are so crucial to its successful implementation.

Current policy – in China and many other countries – tends to focus on research and development for high-technology 'solutions'. The innovations highlighted in this report instead suggest that waiting for 'perfect' technologies would be a mistake. A broader understanding of innovation would also be particularly compatible with the needs of developing countries such as China; these innovations are more appropriate to the Chinese domestic market and that of other developing countries. A greater focus on such technologies would help to engage all stakeholders, including the world's poorest, in low carbon innovation. It would also overturn the assumption in vital international collaborations that developing countries can only follow the lead of developed nations. In collaboration with its partners, disruptive low carbon innovation represents an opportunity for China to set the agenda.

- First, policy could **create more opportunities for these types of innovation** to develop and spread. The diversity of China's provinces and the relatively devolved government structure could be a significant strength in incubating a wide range of experiments, with successful ones leading to broader support at higher tiers of government – a process that would match the pragmatic approach of the last three decades of economic 'reform and opening up'. Current financial support and initiatives establishing 'low carbon zones' could also be opened to these forms of innovation, beyond the familiar focus on hi-tech innovation and R&D.

- Second, policymakers could **provide the right kind of governance**, that is, as an enabler rather than director or controller. This will require new ways for government, innovators and stakeholders to interact, regardless of their existing guanxi (connections or relationships). Refocusing of fiscal and other supports from 'hi-tech' to 'innovative' companies, more broadly defined, could also significantly help many innovative companies that are excluded under current definitions.

- Third, policymakers could also **exploit the opportunities of low carbon innovation policy to improve governance**. Traditional modes of governance are seriously challenged by the need for wide social participation in the transition to a low carbon society. Building on China's indigenous strengths for low-cost and low carbon innovation and encouraging widespread participation could help to develop governance in the medium term.

- Finally, policymakers both within and outside China (including the UK) could **maximise the opportunities for intra-national and international learning** by involving SMEs such as these in partnerships, rather than just academics and large multinational corporations. This will require establishment of new platforms for both formal and informal interactions on a regular basis that can in turn stimulate substantive international collaborations in innovation, not just R&D projects.

By explicitly addressing these issues and developing its existing strengths in low carbon innovation, China could lead the global low carbon transition that we need in the next 40 years.

Introducing the Game-Changers

GEI is a Chinese NGO that has set up a full low carbon agriculture system for poor farmers in the south-western province of Yunnan. There have been many national and international programmes to encourage the use of anaerobic biodigesters by Chinese farmers to produce methane from animal slurry that can then be used for cooking and heating. Many of these projects, however, have failed or have had only temporary effect because the use of the biodigester has not been successfully integrated into the farmers' everyday practices. GEI has therefore established the necessary institutional mechanisms to make use of biogas socially sustainable, in the process also shifting these farms to organic agriculture with further emissions reductions.

Himin is one of China's largest producers of solar thermal water tanks, a market that is in turn dominated globally by Chinese companies. The business strategy has been to produce low-cost solutions to energy and heating that directly attract customers and so do not depend upon government subsidy. In the process, Himin has transformed the local economy of its home town, Dezhou in Shandong province, with over 90 per cent of families now using solar thermal energy in the area and 30 per cent of the workforce in industries related to the sector. The real challenge for the future, says CEO and founder Huang Ming, is whether the company is ready for the continuing growth in demand over the next decades.

ISAW has a range of products that build on CEO Yuan Yijun's scientific expertise to exploit 'psychrometric' principles, regarding the different physical and thermodynamic properties of vapour mixtures, to provide low-cost, relatively low-tech and low carbon alternatives to a range of processes that are usually extremely energy intensive, such as air-conditioning and solar desalination of salt water. These innovations have attracted the attention of the major Chinese real estate company, Vanke, and Masdar eco-city in the Persian Gulf.

Lüyuan is a major manufacturer of electric bicycles and was the first Chinese company to develop an e-bike. The e-bike is a hugely popular form of transport in a country in which commuting distances are growing as people move to the burgeoning mega-cities but cars are too expensive and, in any case, face daily gridlock. 120 million e-bikes are estimated to be on China's roads, and Lüyuan is a major player in this market. And with annual savings of about 1 tonne CO_2e per year, this adds up to a huge overall saving in emissions, even before systemic effects of discouraging private car ownership are included.

Pearl Hydrogen is also targeting the e-bike sector, amongst its various products, but using its innovative, but low-cost and simplified, fuel cell technology. Recognising the extraordinary challenges associated with the familiar goal of a fuel cell vehicle that could compete with existing car models, CEO Brian Tian and team have been focusing on novel uses for their fuel cell, including providing back-up power to telecom base stations needing the guarantee of uninterrupted power supply (UPS). And in collaboration with an Italian partner, they have been busy creating a full energy system for their fuel cell bicycle that allows production of the hydrogen fuel from high pressure electrolysis of tap water in the user's home.

Shengchang Bioenergy is making high-quality pellets from agricultural residues that would otherwise simply be burned in the field, as well as the stoves and boilers to maximise the efficiency of combustion. By offering an attractive substitute for current coal burners, therefore, a double emissions reduction is provided. Furthermore, by positioning pelleting factories to service farmers within a short 20 km distance, from whom the stalks and husks are also sourced, Shengchang is establishing a model of reliable and locally-sourced energy.

ZNHK (Beijing Sin-entech) offers a water purification system that allows the high-temperature recycling of water in industrial processes. By keeping the water at elevated temperatures, energy that is normally wasted through cooling and reheating the water is saved, while the purity of the filtered water meets the highest national standards. And by allowing for efficient water recycling, the water demands of the industrial processes are also reduced. Cost savings from reduced energy and water use typically allow recovery of the capital expenditure of fitting the equipment within one year.

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Part 1: The case for disruptive low carbon innovation in China

1.1 Climate change, low carbon innovation and the crucial case of China

As we enter the new decade, it is clear that we are living in a period of tectonic social upheaval. Three important trends can be identified that converge in an issue of singular global significance: low carbon innovation in China. First, climate change remains the single greatest global challenge, regardless of the current overheating of controversies about the science, demanding an unprecedented transformation of global socio-economic activity towards low carbon social systems. Indeed, global heating (as James Lovelock more bluntly describes it) is merely one part of a broader ecological crisis that demands urgent but long-term action.[1]

Secondly, the rise of China is entering a new phase in which its global effects are becoming increasingly apparent. This has been particularly accelerated by the Great Crash of 2008 and its continuing fall-out for the developed economies and their geopolitical dominance, especially the US. Chinese demands will thus progressively shape geopolitical debates, regulations and institutions. As the COP15 meeting of the UNFCCC in Copenhagen last December demonstrated, this is already the case regarding climate change. And, indeed, China is also pivotal regarding this global challenge. It is not simply that China's absolute emissions have overtaken the US to become the largest in the world and are continuing to grow at an extraordinary pace. But also, the incredible rate of economic growth, investment and social change in China provides an unparalleled opportunity to develop and introduce systems-changing low carbon innovations. As a huge country facing severe environmental pressures of its own, which will be hugely exacerbated by runaway warming, China also has plenty of incentive to tackle these issues.

In doing so, China, like all countries, will need to develop significant low carbon innovation, which brings us to the third major trend. New poles of excellence in science and innovation (S&I) are rising around the world, transforming the global geography of the globalised knowledge economy.[2] Furthermore, processes of innovation are themselves changing with this globalisation of innovation, becoming more mobile, dispersed but inter-related.[3] China is a principal agent and beneficiary of these changes, with numerous metrics of science and innovation – international peer-reviewed papers, graduate and post-graduate student numbers, expenditure on R&D in both public and private sectors, patents, major R&D labs of both domestic and multinational corporations etc. – growing at an extraordinary pace. Furthermore, these improvements are the result of intense policy efforts to build an 'innovation-based economy' by 2020 with globally competitive capacities for 'indigenous innovation' (*zizhu chuangxin*).[4] There is every reason, therefore, to expect that Chinese innovation capacities will continue to grow and that China will make major contributions to a global low carbon transition.

1.2 From silver bullets to systems transition

Given the sheer size of China, however, many of these S&I statistics are extremely difficult to interpret as they may still be small when converted into relative figures or may conceal 'long tails' of weak performance.[5] It must not

1. Lovelock, J. (2006) 'The Revenge of Gaia.' London: Allen Lane.
2. Leadbeater, C. and Wilsdon, J. (2007) 'The Atlas of Ideas: How Asian Innovation Can Benefit Us All.' London: Demos.
3. Bhidé, A. (2008) 'The Venturesome Economy.' Princeton, NJ: Princeton University Press.
4. State Council (2006) 'National Middle- and Long-Term Science and Technology Development Plan (2006-2020).' Beijing: State Council; OECD (2008) 'OECD Reviews of Innovation Policy: China.' Paris: OECD.
5. Wilsdon, J. and Keeley, J. (2007) 'The Next Science Superpower?' London: Demos.

be forgotten that China is still a developing country. Indeed, just as the US economy (let alone its military) continues overwhelmingly to dominate all other countries and is still over twice the size of China's with a population one-fifth as big, caution is needed not to exaggerate the current strength of China's science and innovation.

Moreover, 'innovation' is much more than is captured in these statistics and other crucial elements of a dynamic innovation system are developing more slowly in China. In particular, hi-tech innovation capacities, while undoubtedly improving, are still comparatively modest in most sectors.[6] Despite (or rather, precisely because of) these modest capacities, China's current policy regarding low carbon innovation focuses squarely on hi-tech innovation. To be sure, this focus is achieving some significant successes, as in China's global solar PV companies or its leading coal combustion technologies, such as ultra-super-critical combustion or gasification (IGCC – integrated gasification combined cycle). But these alone, even where they are widely adopted (and over 90 per cent of Chinese PV is currently exported), will be unable to produce the wholesale transition to low carbon systems that is needed.[7]

Indeed, the biggest problem with focusing on high-technology is not whether or not China has the capacity for such innovation, important though this is (see below). Dealing with climate change demands not just a marginal reduction of GHG emissions through energy efficiency improvements, but profound changes in every aspect of day-to-day life and the socio-economic systems that underpin these. Innovation is undoubtedly needed to produce these changes, but this cannot simply be the introduction of high-technology 'solutions'. Rather, the nature and scale of the challenge of the low carbon transition – and over a single generation – demands action and policy that responds to a much broader understanding of the innovation process than hi-tech improvements alone.

This perspective highlights how technological change occurs in inextricable parallel with social change. Technologies are only adopted where there are the social conditions to be able to use them, and they are altered and shaped in this process. Conversely, technologies introduce new capabilities to social action, thereby transforming social norms and practices. Innovation is thus always a matter of messy and complex *socio-technical* change. A great deal of important innovation – involving new institutions or social practices, the translation of existing technologies to novel social contexts or unusual combinations of existing technologies – is thus ignored by focusing on the cutting-edge of high-technology alone. Yet these alternative forms of innovation will be at least as crucial in a low carbon transition. Indeed, "an important general pattern in transition processes… is that the course of a transition is shaped to a considerable extent by the vicissitudes of the development of novelties in their early phases when most actors in a system tend to see them as irrelevant".[8] The innovations that will shape the low carbon transition are thus most likely to emerge from unexpected, indeed apparently unpromising, sources.

1.3 Disruptive low carbon innovation is an overlooked opportunity for China (and the world)

In this context, one particular form of innovation that may be particularly relevant for low carbon systems change is 'disruptive' innovation. As originally developed by Clayton Christensen and applied to low carbon innovation by a previous NESTA report, this involves "cheaper, easier-to-use alternatives to existing products or services often produced by non-traditional players that target previously ignored customers" and/or use in novel contexts and combinations.[9] Disruptive innovation is thus primarily characterised by a social redefinition of a technology, as opposed to improvement of the technology along established trajectories, and is thus an issue that is altogether different from whether the innovation incorporates high- or low-technology. The point is rather that, in the first instance at least, the disruptive innovation will likely offer *lower* than cutting edge functionality, according to established definitions, but for different uses and to neglected customers. Disruptive innovation thus exemplifies how conflating innovation with high-technology is something of a 'red herring', albeit one with potentially harmful consequences.

The 'disruptive' aspect of these innovations refers to their (potential) effects on established firms and even industrial political economies and socio-technical systems. While such social redefinition of technology often seems unremarkable to start with, in setting off on an alternative path it possesses the potential

6. Suttmeier, R.P., Cao, C. and Simon, D.F. (2006) China's innovation challenge and the remaking of the CAS. 'Innovations.' Summer, pp.78-97; Jakobson, L. (Ed.) (2007) 'Innovation with Chinese Characteristics.' Basingstoke: Palgrave Macmillan.
7. For example, Assadourian, E. (2010) 'The Rise and Fall of Consumer Cultures.' Worldwatch State of the World Report 2010. Washington, DC: Worldwatch. p.7.
8. Elzen, B., Geels, F. and Green, K. (2004) 'System Innovation and the Transition to Sustainability: Theory, Evidence and Policy.' Cheltenham & Northampton, MA: Edward Elgar. p.285.
9. Christensen, C. (1997) 'The Innovator's Dilemma.' Cambridge, MA: Harvard Business School Press; Willis, R., Webb, M. and Wilsdon, J. (2007) 'The Disrupters: Lessons for Low-Carbon Innovation from the New Wave of Environmental Pioneers.' London: NESTA.

in the medium-term to challenge the existing business models and become dominant. This is so even where such disruptive innovators may never catch up with the technological functionality offered by incumbent firms pursuing technological improvements along established innovation trajectories.

Such a change of innovation trajectories is precisely what is needed for a low carbon systems transition and the importance of 'small beginnings' to such profound socio-technical change also resonates strongly with disruptive innovation. This is not to argue that low carbon innovation and systems transition are themselves synonymous with disruptive innovation. Indeed, much important low carbon innovation is precisely the opposite, based on incremental but, in aggregate, significant improvements along established trajectories. Rather, disruptive innovation is an important, but generally overlooked, element of the route to the goal of a low carbon systems transition, and one moreover with particular relevance to China.

First, regarding disruptive low carbon innovation *per se*, the exceptionally tight time constraints for the needed low carbon systems transition entails that "only the low-carbon technologies that are already known can make a significant contribution to meeting the 2050 targets. They are already in the marketplace, close to it or close to being demonstrated at scale."[10] In short, we must do the best with what we have. But from the perspective of disruptive innovation, which makes use of just such established technologies, this maximisation of climate impact need not be limited to current uses and familiar sectoral definitions of these technologies. Rather, disruptive innovation offers a potential route to substantial improvements in the societal impact of low carbon technologies that is not dependent on their radical technological upgrade.

This argument becomes even more important in the case of China. This is not just because China's capacities for hi-tech low carbon innovation are not yet fully developed, as demonstrated by the continuing dominance of intellectual property ownership of major low carbon technologies by OECD-based companies.[11] But also because, on the other hand, Chinese companies are already transforming global competition through their low-cost disruptive innovations, as business scholars Ming Zeng and Peter Williamson have shown.[12]

For instance, Haier has developed a range of fridges with relatively low-tech adaptations that serve a variety of niche, but highly profitable, markets, including student rooms (doubling up as desks) and wine collectors. Similarly, China International Marine Containers Group (CIMC) has achieved unrivalled global dominance in their industry through a low-cost strategy. Other examples of successful low-cost disruptive innovators include car company Chery, piano maker Pearl River, consumer electronics maker TCL, computer company Dawning, port equipment manufacturer ZPMC, universal joint manufacturer Wanxian etc. The list goes on and on.

While these and other examples listed by Zeng and Williamson are not low carbon innovators (at least not in all cases and not yet), high profile examples of the latter are also increasingly apparent. BYD is using its global leadership in battery manufacturing and technology to develop low-cost electric cars and has won the attention (and investment!) of legendary investor, Warren Buffett. Himin Group, which we profile in more detail here, is now a global leader in solar thermal technology, a sector dominated as a whole by Chinese companies. But a large and growing number of small companies are emerging that are not just selling cheap versions of familiar low carbon technologies, but are developing innovative low-cost combinations or applications of technologies and the social or institutional innovations these require.

These initiatives have the potential to disrupt established business models and industrial boundaries in ways that introduce the crucial element of discontinuity needed for broader systems transitions. By focusing on low-cost products and services for the Chinese market, this also has the advantage of developing technologies that are appropriate not only for Chinese society but for other developing countries worldwide. And with over 70 per cent of total costs of abatement and hence low carbon investment to 2050 likely to come from developing countries, servicing this market would also be to focus on the major business opportunity, not merely to make a virtue of necessity by targeting secondary sources of demand.[13]

A policy that effectively supports the existing Chinese competitive strength of disruptive low carbon innovation would also expedite a Chinese low carbon systems transition, responding to the unprecedented timescale. Conversely, banking primarily on the

10. Royal Academy of Engineering (2010) 'Generating the Future: UK Energy Systems Fit for 2050.' London: RAE. p.4.
11. Lee, B., Iliev, I. and Preston, F. (2009) 'Who Owns Our Low Carbon Future? Intellectual Property and Energy Technologies.' London: Royal Institute of International Affairs.
12. Ming Zeng and Williamson, P. (2007) 'Dragons at Your Door: How Chinese Cost Innovation is Disrupting Global Competition.' Cambridge, MA: Harvard Business School Press.
13. Anderson, D. (2006) 'Costs and Finance of Abating Carbon Emissions in the Energy Sector.' Notes and Calculations prepared for the Stern Review. London: Imperial College. p.28.

improvement of hi-tech innovation capacities alone will incur substantial (and climatically consequential) delays, given the need to develop institutional, social and cultural conditions that are hard to short-circuit. Similarly, incorporating disruptive low carbon innovation into policy could also support a broader public redefinition of low carbon, away from its current identification with expensive equipment. This tends to embed a perceived opposition between low carbon innovation and socio-economic development, and hence to slow down the former, while it is clear that a low carbon shift must attend to both. China cannot and must not be forced to choose between 'environment' and 'economy', and disruptive low carbon innovation is an important way to sidestep this false choice.

Finally, disruptive innovation offers the most plausible route to world-beating companies, while simply pursuing existing leaders directly through hi-tech improvements along established pathways sets up a perpetual game of 'catch-up'. Paradoxically, therefore, globally competitive hi-tech companies may be more effectively fostered by sponsoring disruptive low-cost innovations than by focusing on high-technology itself. For instance, there is "not a *single* example in the history of technological innovation in the disk drive industry of an entrant firm leading the industry or securing a viable market position with a sustaining [non-disruptive] innovation".[14] The competitive 'attacker's advantage' of these entrant companies was not regarding technology itself but in "the relative flexibility of successful established firms versus entrant firms to change *strategies* and *cost structures*, not technologies" so that the latter can "disrupt or redefine the level, rate and direction of progress in an established technological trajectory". This has significant implications for national economic growth as much as it does for business strategy, and this, in turn, is crucial for China's low carbon shift.

1.4 Low carbon challenges are significantly different in China

China is certainly to be applauded for its efforts regarding mitigation; its continuing and seemingly inescapable dependence on coal and the unstoppable growth of its car market – overtaking the US in 2009 to become the largest in the world – being the indelible black marks against it. Energy efficiency has improved significantly in recent years, major reforestation and afforestation projects continue and the new commitments to a further 40-45 per cent improvement in emissions/GDP (as opposed to energy/GDP) intensity between 2005-2020 will be a major achievement if they are met.

Similarly, policy and institutional rearrangements, with the promotion of environmental protection to ministerial level in 2008, a climate change White Paper in the same year and the establishment of a National Leading group on climate change in 2007 and a National Energy Commission super-ministry in 2010, both chaired by Premier Wen Jiabao, show the importance the central government is attaching to these issues. Achievements in renewable energy are also impressive, backed by the Renewable Energy Law, which aims for 16 per cent renewable energy in 2020. For instance, the growth of the wind sector is simply staggering, heading for 100MW by 2020 or double total *global* capacity only a few years back, while big hydropower is the largest in the world and growing (more than doubling from 142GW or 14.3 per cent of total electricity in 2008 to 300GW or 21.2 per cent in 2020).[15] A significant percentage (about 40 per cent) of China's 2008-9 post-crash fiscal stimulus of RMB 4 trillion (US$ 580 billion) was also directed to 'green sectors'.[16]

Yet there remains widespread presumption, amongst policymakers, business and citizens alike, that low carbon innovation is synonymous with hi-tech solutions to problems of fossil fuel inefficiency. This is undoubtedly partly due to engrained conceptual associations between technological sophistication and geopolitical status. China is not simply rising passively, but rather as the result of a concerted national project. In this context, the identification of innovation, economic growth and global power with high-technology enshrines the latter as the goal in itself. That disruptive innovation may be, counter-intuitively, a more direct route to these goals than focusing on high-technology itself is thus one of the most important arguments in its favour in the Chinese policy context.

In short, China's disruptive low carbon innovators are key national assets that need significantly greater support from policy. How should they be supported and what form should this support take? The original 2007 report contains numerous insights regarding this question and we refer our readers to it, as these lessons remain as cogent and pertinent as ever in their original formulation.[17] But,

14. Christensen, C. (1997) 'The Innovator's Dilemma.' Cambridge, MA: Harvard Business School Press. p.46-8.
15. Climate Group (2008) 'China's Clean Revolution.' Beijing and London: The Climate Group; Climate Group (2009) 'China's Clean Revolution 2.' Beijing and London: The Climate Group.
16. Ibid.
17. It was on this basis that we held a workshop in Hangzhou in December 2009 to discuss disruptive low carbon innovation in China and introduce the 2007 report to a broader Chinese audience. The Executive Summary of the 2007 report was translated into Chinese for this event. If you would like a copy, please contact David Tyfield (d.tyfield@lancaster.ac.uk) or see the workshop's website: www.lums.lancs.ac.uk/lowcarbonchina . We thank BIS for funding this translation.

focusing on the UK and on British examples, the original report does not respond to the significantly different context and challenges regarding low carbon innovation in China; differences that reflect China's exceptional rates of urbanisation and industrialisation, its socio-economic structure, political constitution and governance institutions and distinctive and ancient cultural history. Nor does it explore the argument that disruptive low carbon innovation may be particularly important for developing countries such as China. These are the tasks of this report.

We have already encountered some of the ways in which the Chinese context alters the argument regarding disruptive low carbon innovation. First, there is the issue of current innovation and absorptive capacities, especially regarding hi-tech innovation. These could be largely taken for granted in the UK report (at least in those industries where the UK has significant presence), but this is not the case when moving to China. Indeed, secondly, developing hi-tech innovation capacity is a matter of earnest concern in the Chinese context, due to its connection with the preeminent national priority of socio-economic development, as just discussed. Thirdly, then, issues of development must be placed at the very heart of discussion about low carbon innovation in China, while they are often overlooked or tacitly presumed in developed country debates. Similarly, the international dimensions of low carbon innovation, including international collaboration, are also more transparently important in China – though they undoubtedly matter in the UK too.

Last, and by no means least, the very term 'disruptive' innovation needs to be translated sensitively given strong negative connotations of the standalone word 'disruptive' that are absent in English. In the Chinese game 'Go', a single unexceptional move may alter the direction of play such that it turns out to switch the game in a player's favour, no matter the odds against him when it is played.[18] This move is described as poju (破局) or 'game-changing'. In what follows, we present the lessons from seven Chinese low carbon game-changers in the hope that it will catalyze some even bigger changes towards low carbon systems both in China and beyond.

18. We thank Ye Weijia for this suggestion.

Part 2: Lessons from China for low carbon innovation

2.1 Follow existing opportunities, don't wait for 'perfect' technologies

Chinese water wheels
Many futuristic visions of a perfectly sustainable economy have evoked the idea of one based on hydrogen, with drinkable water dripping from your car's exhaust pipe. Such futures conjure up images of hyper-modern, gleaming cars and buildings, reflecting the blinding sun of the clear, blue sky. An unassuming industrial hanger in south Shanghai, reached after a long smoggy drive on the city's congested highways, thus seems an unlikely birthplace for this hydro-topia. Pearl Hydrogen, however, is tackling some of the most enduring problems of the hydrogen economy head-on – or rather through the back door.

Across the world, and for many years, there has been a great deal of research and commercial effort expended on the development of fuel cells. The usual goal is to test various types of fuel-stack, electrolytes and catalysts in order to create a fuel cell that has some chance of meeting power demands of existing technologies in a way that is economically viable – the quintessential challenge being a fuel-cell vehicle (FCV). Yet this goal remains elusive, even before the massive challenge of construction of the associated hydrogen infrastructure is considered. As a result, many have written hydrogen off for a low carbon transition, both for a near-term transition and even in the long term.

Perceiving these problems, however, Pearl set out to tackle the problem in the opposite direction, seeking out profitable opportunities for applications of their fuel cell. Finding such opportunities certainly depended upon technological development, but not in terms of improved functionality along established trajectories. Rather, the goal was the creation of an efficient low-cost fuel cell that could service power needs that had been overlooked in the past. The key here was the core technology, developed by CEO Brian Tian from three years of work at another Chinese fuel cell company: a catalysis-coated membrane. Setting out on his own in 2006, Brian noted that the fuel stack could be hugely simplified with this membrane by using the same channels both to provide air needed for the reaction and to cool the fuel stack. This air-cooled fuel cell could then dispense with the usual water-cooling apparatus, which added considerable bulk, expense and accessory energy costs. Moreover, it transpired that this lower-cost fuel cell remained highly efficient. By simplifying the technology in this way, hitherto neglected opportunities for fuel cells opened up.

In particular, following market research within China, three opportunities presented themselves: a fuel cell bicycle and niche transportation (for example, forklift trucks, golf carts, small boats); back-up emergency generators providing uninterrupted power supply (UPS); and a mobile or hand-held power source. In each case, Pearl has developed fuel cells of sufficient power (ranging from 200W for the electric bicycle up to a 10kW stack, due out this year) for the relevant application and has incorporated these into products, such as the bicycle or the hand-held power source, through collaboration with other companies and consultation with users, that are attractive to their target markets.

The strategy also appears to be working. The fuel cell bicycle (called Green Angel and developed with Chinese bicycle company

Celimo – whose name means 'horse that goes for 1,000 miles') was demonstrated at Zaragoza International Expo in 2008, and is now on sale in China and in Europe. Pearl also attracted the attention of an Italian company listed on London's AIM stock exchange, Acta, that produces a high-pressure electrolyser. Combining forces, the two companies are developing a full-system solution, with home generation of the hydrogen fuel source through electrolysis of tap water. Furthermore, future plans are to make this electrolyser run on solar power, closing the circle to make a fully renewable energy mobility option.

Similarly, regarding the UPS fuel cells, contracts have been signed, via private sub-contractors, with major Chinese telecom SOEs and other telecom substations across south east Asia, based on their 5kW stacks showing competitive pricing and reliability. Demonstration plants will be put into operation in 2010. The hand-held mobile power source is also now on sale, providing a low-cost and low carbon option for power that could serve numerous markets, including in remote areas of China. Finally, through collaboration with a team at Imperial College, London, Pearl is also involved in the development of a racing car for the Formula Zero race, providing the fuel cell on which the car runs. By building up the strength of their technology via the opportunities for profitable learning based on their low-cost fuel cell, Pearl may yet create the FCV of so many dreams.

Standing innovation back on its feet
Pearl's innovation certainly involves – indeed, depends upon – technological development but it has not been led by a vision that innovation amounts to technology alone. Unfortunately, this remains the dominant view, including in policy circles, which thereby focus almost entirely on advances at the cutting-edge of high-technology to the neglect of all other forms of innovation. As the predecessor to this report made clear, narrowly defining innovation as high-technology alone is associated with a pipeline or 'linear' model that displays "flawed but ingrained assumptions about the relationship between science, technology and innovation", in which science leads to technologies which are in turn successfully commercialised as innovations.[19]

19. Willis *et al.* p.14.

Such a model discounts many crucial factors in innovation and ignores many areas in which innovation occurs. In particular, it overlooks the irreducible social dimensions of innovation processes, where technologies are shaped and their uses defined within their diverse social contexts. Much innovation thus involves established technologies being used in novel ways or in novel combinations that serve (and create) particular social needs and demands, as well as much low- or medium-technology innovation. In these circumstances, it is the social, institutional and policy contexts of innovation that are at play – and it is just these factors, rather than technological challenges, that often also explain the failure of new technologies to be taken up and to flourish beyond their original niches.

Focusing only on the one-dimensional question of technological development also systematically excludes consideration of social factors in innovation processes. Thus innovation is generally understood in terms of new technologies fitting into pre-existing social systems, which are simply taken as given. Yet the mutual interaction of technological and social change means that such a perspective is not merely incomplete, but likely to be erroneous in any given case. The successful integration of new technology will almost certainly require adaptation and accommodation from the social conditions upon which it depends. Ignoring the socio-technical system, therefore, is a recipe for innovation failure.

This is evidently a particularly important problem for low carbon innovation and policy. For not only is a profound transformation of socio-technical systems required but there is also exceptional time pressure. There is thus simply no time for policymakers to discover that their favoured high-technology low carbon projects have failed for these reasons. The fuel cell vehicle is a classic example, but it is by no means alone. Carbon capture and storage (CCS) (both for electricity generation and for industrial plants), GM crops to tackle mitigation and adaptation, biofuels (especially 2nd generation), nuclear power and even geoengineering are all (or dependent upon) high-technologies that proponents generally hope will tackle global warming without the need for significant social and institutional change.

This is certainly not to argue that such technologies should themselves be simply discounted. For instance, given the overwhelming dependence of the Chinese grid on coal (but also India and increasingly the US and the EU as well), CCS would seem to be absolutely necessary in the medium-term for significant GHG emission reductions. But focusing on technology, as if it can simply be slotted into existing socio-technical systems without innovation in those social and institutional contexts themselves, imposes significant costs and delays on low carbon innovation, while also neglecting the significant opportunities for (possibly profound) socio-technical change that can occur by focusing on what can be done with existing technologies used in novel ways and contexts.

As Pearl demonstrates, this shift away from conflating innovation and high-technology alone is also especially compatible with the needs of a developing country such as China. In particular, focusing innovation (including the technological development this involves) on the development of low cost alternatives with strong, if not revolutionary, levels of functionality, provides the opportunity for these innovators to continue to strengthen their innovative capabilities. This is crucially dependent upon offering products that are economically attainable for their potential Chinese market, while also developing these products in ways that are relevant or appropriate technologies for China and other developing countries rather than for developed ones. It also builds on the current strengths of multiple Chinese companies, rather than demanding they tackle hi-tech innovation for which many are not yet equipped. And by exploiting existing market opportunities it is also a route that is relatively self-supporting and so does not have to wait for the significant financial and policy support on which many hi-tech low carbon innovations do depend.

Dezhou dynamism

There is perhaps no greater vision of success of this low-cost strategy than Himin Group and its domination of the Chinese market for the humble array of tubes that is the solar water heater. Established in the early 1990s by founder and CEO Huang Ming, Himin has grown to be a hugely profitable business with annual profits of RMB 68 million (£7 million) in 2007. Chinese companies increasingly dominate the global market for solar water heaters, and Himin is amongst the biggest companies, putting Huang Ming in the Sunday Times world's top 100 green rich list in 2009. Its massive Sun-Moon Mansion in Solar Valley is entirely heated by the solar thermal and solar PV building materials that cover its roof and walls. The impressive effect is redoubled once you remember you are in an unexceptional city that few have heard of in the West, albeit a city of 5.6 million. The city of Dezhou, two hours south of Beijing by train in the coastal province of Shandong, however, itself bears the marks of Himin's success. Solar thermal water tanks are increasingly common across China, but in Dezhou they are ubiquitous, with more than 90 per cent of families now using solar thermal tanks. And the solar thermal business and associated industries is an increasingly central part of the local economy, employing 800,000 people or 30 per cent of the local workforce.

Huang started the company following a decade of working as a research fellow in an institute of the Ministry of Mineral Resources studying petroleum drilling. Confronted by the evidence of a looming energy crisis and the big environmental problems associated with fossil fuels, he determined that he had to do something, his mission being to "give back the blue sky and the white clouds to the next generation". He therefore set up a company, initially under the name of his research institution, to develop solar thermal heaters in 1992.

Lacking any policy support, the only viable strategy was to rely on customers, finding an existing opportunity for a profitable business. Huang thus had to work with customers to develop products attractive to them, servicing their needs and at low cost. The latter was particularly important, given that cost effectiveness, including reliability of the technology, was the priority for the company's first customers of individual house-holders. This involved some technological development of its own, with existing foreign technologies unsuitable and too expensive for this nascent Chinese market. Installation of the heaters was also offered as standard inclusion in the price. As a result, a solar water heater was created that could last 20+ years and for which savings from reduced energy costs (i.e. zero) would reimburse the initial capital outlay in about 5.5 years, with 'free' heating thereafter.[20]

Building on the successes of sales within Dezhou and across Shandong, Himin continued to develop a variety of products suitable for different climates (for example, able to withstand the cold temperatures of winter) and different building or user types. Larger customers have also been targeted, including real estate companies, hotels and public buildings, such as hospitals. Himin has also established its own real estate company. Novel applications of solar thermal technology have been developed, creating full central heating systems that use intelligent electronic controls, rather than just providing hot water, and integrating solar thermal with solar PV for various applications.

20. See www.greenpeace.org/china/en/campaigns/countdown-to-copenhagen/dezhou-solar-story (Accessed 15/02/10).

To be sure, as Himin has grown, the extent of government support has also grown, and from all levels of government: municipal, provincial and central. For instance, rebates have been offered to customers for the purchase of solar thermal units, encouraging demand, while buildings over eight storeys are also mandated to fit them during construction. Similarly, governmental support for R&D projects has been secured. Yet at only 3-5 per cent of expenditure on capacity building within the company, Himin's strategy is still not dependent upon government support, with strong market demand, particularly in the 'home' market of Shandong province.

Indeed, Huang's commitment to a strategy that is not reliant on government is such that he takes an unusually positive and counter-intuitive line on the seemingly disappointing modesty of what was achieved at the UNFCCC's Copenhagen conference. A 'successful' conference, he argues, would only have bred complacency that would have undermined low carbon efforts, while deepening the mistaken presumption that governments can effect a low carbon transition. Conversely, a 'failure' keeps up the necessary pressure on the kind of bottom-up ventures that will in fact create a low carbon society. "Where was the international agreement underpinning the global success of mobile phones and their transformation of the economy?" he asks rhetorically.

2.2 Enable new relations

Scaling Snow Mountain

A consistent theme of the UK *The Disrupters*[21] report by NESTA was that low carbon innovation is not the sole preserve of large companies with strong R&D facilities. Rather a diversity of institutions and agencies are capable of introducing potentially significant disruptive innovations, including regarding the kind of institution itself. Baywind, for instance, was profiled not merely as a wind farm (hence 'low carbon'), but as one that is cooperatively owned, hence a *disruptive* innovation with the potential of stimulating the spread of further cooperatives across the UK, taking on responsibility for their own devolved energy needs and creating a distributed power system in the process.

21. NESTA (2007) 'The Disrupters.' London: NESTA.

Such institutional or relational innovations are equally crucial in the case of Chinese low carbon innovation, but with an added and essential twist. As GEI's work in Yunnan shows, establishing new relations can also unlock potential for socio-economic development. GEI itself is something of an institutional innovation. Founded in 2004, GEI (Global Environment Institute) is one of the growing number of Chinese environmental 'NGOs', a term that is an inexact translation of the Western concept as all NGOs must be registered with the government. Similarly, unlike many Western NGOs, GEI is not just a pressure group or policy think-tank. Rather, the particular focus of GEI is "on the use of market-based solutions to environmental problems to achieve sustainable development" with 'development', not *just* 'sustainability', as a key concern. Their work thus incorporates direct involvement and/or consultancy regarding development-related low carbon projects.

This has produced some considerable low carbon innovation, building the conditions for low carbon growth even in the poorest parts of the country. While these areas are highly unlikely to have the GHG emissions of industrial and urban areas (even *average* Chinese per capita emissions remain under one half of the UK's and about one fifth of the US's) and such emissions as are incurred relate largely to basic subsistence rather than consumerist lifestyles, bringing low carbon innovations to these areas allows them to move towards development along low carbon pathways, rather than first embedding high-carbon systems and then trying to escape them.

In this context of relatively (or even absolutely) poor rural farmers, the unsuitability of expensive, cutting-edge hi-tech modes of innovation is transparent. Accordingly, GEI has worked on bringing low carbon technologies to poor parts of China using a significantly different model, involving the simultaneous development of new interventions, both technological and social, at multiple levels that unlocks the potential for broader systems change. Such complete systems change is also particularly important in the context of poor and hence risk-averse individual farmers, providing comprehensive viable alternatives that do not demand that they change their habitual practices on the wishful promise that a better world awaits if only they took the leap. As a result, such development-relevant low carbon innovation has to involve prodigious efforts involving multiple sites of both technological and institutional innovation.

A striking example is provided by GEI's work in Lijiang in the south-western province of Yunnan. This has incorporated not only the introduction of biogas digesters, tailored to local needs, that reduce the carbon footprint of rural households, but also: the shift to organic agriculture using the slurry from the digesters; the creation of cooperatives to increase access to finance; and a further corporation acting as centralised merchant to the big markets on the east coast. Each of these has been in tight interdependency with the others – attempts simply to introduce the low carbon technology would have foundered without the wider social innovations on which it has depended.

This is not because the technology itself provides little rationale for farmers to change. Biogas digesters have significant advantages, both for the farmer users and regarding GHG emissions. By concentrating slurry in a single place and an anaerobic environment (a 'biogas digester'), methane production can be maximised and the gas collected and used to service the family's heating and cooking needs in an effectively inexhaustible and free supply of a natural resource that is otherwise wasted. Combustion of the gas is also much cleaner than conventional coal or wood burning, significantly improving the living environment; a major benefit especially for women and children. Regarding emissions, methane is also a GHG that is approximately 23 times more potent than CO_2. Hence by burning the methane rather than simply releasing it and substituting for coal or wood, including the mining and transport and deforestation these respectively entail, the overall carbon footprint of the household is significantly reduced.

But adopting any technology is a risk, and one that many farmers feel they cannot afford to take lest they find themselves in a worse position than before. After all, technologies break down or do not work as planned in the first place. The technology may also be incompatible with local conditions and practices, or have negative unforeseen consequences in a particular social context.

In its work in Lijiang, GEI has had to tackle just such complex and multi-dimensional challenges. First, it secured financial assistance, including from an American aid fund, for introduction of biogas digesters. Buying digesters from a Hunan company, it then set about adapting them to local needs. The primary concern regarding choice of digester is one of gas capacity, based on how many people and for what purpose the gas will be used. A digester volume of $1m^3$ can produce 0.15-$0.3m^3$ gas per day, depending on temperatures (the higher the better), so that a $10m^3$ digester is usually big enough to service the daily needs of a household of 3-4 people. This depends on local practices, however, including cooking habits. For instance, slow cooking for long periods by Beijing farmers, as opposed to the quick cooking of Tibetan meals, or the cooking of slops for pigs adds to the demand for gas.

Other technological choices are also affected by local circumstances. Hence digesters in cold climates, like Tibet, have to be buried deep in the ground if the gas production is not to drop too low. The choice of digester technology, of which there are at least four main types, is also a matter of local preference. In the case of Lijiang, a 'floating drum' digester with a separate gas storage tank was chosen in favour of the more common 'hydraulic pressured' digester on the basis that the latter demanded laborious and dirty work to empty it every three to four months; a task that was understandably unpopular with the farmers. By burying the digester directly underneath the pig sties, slurry could also be drained directly into the digester, though this evidently demanded space that not all farmers had.

Finally, the financial costs of introducing digesters are also borne by different parties in different parts of China. In the Lijiang case, half the cost was paid by the Lijiang local government, half demanded from farmers. Asking for outlay from the farmers themselves thus required the introduction of technology the farmers took to be reliable and economically beneficial. Tailoring the technology to local needs in the ways just discussed tackled the former, but the latter involved a further innovation: encouraging a shift to organic agriculture of lucrative vegetable crops, using the slurry from the digester.[22] As organic agriculture is itself a low carbon innovation, reducing the use of fossil fuel-based fertilisers that release N_2O, a GHG approximately 300 times as potent as CO_2 that accounts for up to 9 per cent of *total* emissions in China, this also served to increase the low carbon impact of GEI's innovation.[23]

This shift, however, itself entailed transformation of both agricultural practices and institutions. Regarding institutions, GEI facilitated the creation of new corporate bodies that served three purposes; what GEI calls its 'three-in-one' model.[24] First, it unlocked access to bank loans needed for the building

22. We note that whether or not this would precisely meet the UK criteria to be called 'organic' agriculture is a moot point, but China too has its own criteria, with gradations that rise through so-called 'green' to 'organic' agriculture.
23. Powlson, D. (2009) 'Improved nutrient management in agriculture: A key contribution to low carbon economy.' Presentation at the Inception Workshop of the China-UK Low Carbon Agriculture Project, Beijing, 27 April 2009.
24. An Xin and Chen Zhiping (2008) Solving the issue of sustainable development in rural China through a three-in-one mode. In: 'China Insight: Rural Financing, Energy Conservation & Forest Resources.' Beijing: Global Environment Institute.

of greenhouses and other equipment. This took the form of at least six farmers joining forces in a rural credit cooperative, so that any one of them had five others offering a guarantee for their loan; the demand of the banks for lending. But even where the farming infrastructure for organic agriculture could be financed, individual farmers could not produce enough to secure steady access to the wholesale markets for their organic vegetables that exist only far away in the big coastal cities, like Beijing or Guangzhou. This, in turn, made returns for the farmers too unpredictable to make the shift to organic agriculture viable. Accordingly, two cooperatives were established to aggregate produce and a private share-holding company, the Snow Mountain Organic Corporation, was established to centralise sales efforts of the organic produce. The two cooperatives contract with Snow Mountain, which thereby connects these remote farmers to the organic vegetable markets and provides a source of sufficient and stable demand.

Regarding agricultural practices, before being introduced to the idea by GEI, the farmers had not even heard of organic agriculture, let alone knew how to do it. The final piece of the jigsaw was thus consultancy – paid for by Snow Mountain – with experts familiar with local conditions from nearby Yunnan Agricultural University to train farmers in organic agriculture, including the appropriate growing regimes and technologies for different vegetables and varieties (for example, Japanese versus European versus Chinese cucumbers).

This set-up has survived since GEI's funding ended in December 2008, with Snow Mountain still selling organic vegetables from Lijiang, higher farmers' incomes and low carbon agriculture. However, coordinating the establishment of a fully functional alternative system of low carbon agriculture evidently faced significant hurdles. Moreover, there were barriers at each stage of the process. For instance, encouraging the farmers to join the cooperatives demanded significant encouragement, given the historical experiences of collective agriculture. Voluntary participation, choosing management by election and a clear share system for distribution of benefits was enough to overcome initial reluctance.

Furthermore, lack of governmental support for the projects has also been a significant problem. In particular, when the cooperatives were initially established in 2006, there was as yet no law conferring legal status upon them, though this followed luckily in October 2007. Finally, today significant challenges remain, including the lack of transport infrastructure for transporting the organic vegetables to the big city markets, and the discouraging effect this has on finding investors in developing the project and spreading the model further. Urbanisation and construction is also threatening some of the farms.

Development through new connections

Mainstream understanding of innovation, in its focus on high-technology and associated metrics of patents and R&D expenditures, tends to overlook numerous important aspects of the innovation process. According to a recent report from the STEPS centre at Sussex University, three such issues in particular merit greater attention, namely 'direction', 'distribution' and 'diversity' – the '3Ds'.[25] These are both important in their own right and particularly significant regarding sustainability, this by definition being a matter of sustainable flows, a process not an end-state, and one dependent upon participation and information input from across society. The call for broader civic engagement in innovation at the heart of the 3Ds agenda is thus also the 'essence of sustainability'.[26]

By 'direction' is meant the fact that socio-technical change necessarily involves broader normative social choices between possible trajectories regarding the kind of society that innovation is bringing about. Following this argument, 'distribution' refers to the questions of equity regarding who benefits and who loses from innovation trajectories – the status quo of gross and growing inequalities clearly being unjust and a significant contribution to ecological unsustainability. Finally, 'diversity' refers to the fact that addressing such issues need not presume a single and universally applicable best solution to any challenge addressed by innovation. Rather, a diverse set of context-sensitive innovation trajectories is itself a significant element of any attempt to address the prior two concerns.

Throughout these considerations, we may also note that a fourth 'D' is clearly central: development. Direction and distribution concern questions of who gains, while diversity refers to the fact that multiple models of innovation are needed to reflect the similarly diverse contexts and needs of developing countries. Such prioritisation of development is especially germane in the case of China. Despite the skyscrapers of Pudong, China remains largely a developing country. Even

25. Stirling, A. (2009) 'Direction, Distribution and Diversity! Pluralising progress in innovation, sustainability and development.' Working Paper 32. Brighton: STEPS Centre, University of Sussex; Tyfield, D., Urry, J., Wilsdon, J. and Wynne, B. (2008) 'China-EU Innovation Networks towards a 'Low-carbon' Society.' Working Paper. Lancaster: Lancaster University.
26. Smith, A., Stirling, A. and Berkhout, F. (2005) The governance of sustainable socio-technical transitions.' 'Research Policy.' 34, pp.1491-1510. p.1508.

while over 200 million people have risen out of poverty in China since 'reform and opening up' in 1978, there are still 150 million living on under $2 a day, average farmers' incomes are $756 p.a. and GDP per capita is $3,200 p.a. Furthermore, while the rural population is shrinking steadily as people move to burgeoning mega-cities, it still represents 67 per cent of the population. Development of rural and agricultural areas is one of the priorities in the 11th 5-year Plan, with central government attending to the *san nong* (or 'three rurals' of agriculture, village, and farmer) to promote the development of rural areas. Environmental pressures, particularly from water shortages, industrial pollution and land loss through urbanisation, are also serious challenges in rural areas that make sustainable development an imperative.

Socio-economic development is thus the absolutely top priority of Chinese policymakers at all levels of government. Unfortunately, this is too often identified with GDP growth alone, though the central government in particular is driving changes to incorporate other essential issues such as environmental sustainability and social equity under the slogans of 'circular economy' and 'harmonious development'. But it remains the case that any low carbon initiative that ignores development considerations is unlikely to take root in China. Furthermore, the utmost importance of China to global debates about responses to climate change does all developing countries – and, indeed, the world – the service of highlighting how development questions are inextricable from a global low carbon transition.

Low carbon innovation that takes issues of development – and hence direction, distribution and diversity – seriously are thus crucial in China. Engagement of poor farmers in low carbon innovation, however, clearly is not best served by focusing on hi-tech innovation. Rather, as GEI's Lijiang project illustrates perfectly, technologies are crucial but they must be low-cost and tailored to the specific social needs of that locality: suggesting '3Ls' – of low-cost, low-tech and low carbon innovation – that give practical expression to the '3D' principles. The most important forms of innovation, however, will often be institutional innovations, forging new but dependable relations that support the change in farmers' practices that are both socio-economically and ecologically sustainable, creating the necessary context for successful uptake of the low carbon technology. But Lijiang also illustrates how mediation assistance may well be needed to facilitate the formation of these new relations, as in the establishment of the cooperatives and their connections with organic vegetable wholesalers. Disruptive innovation, effecting a social redefinition of technologies, can thus unlock development-relevant innovation and user-centred innovation.

From coal to cotton stalks

Looking out of the window at the countryside below as you come into land in Beijing or Shanghai, one distinctive feature tells you you are in China: the flat blue and red roofs of the industrial buildings. As their ubiquity testifies, to talk of 'rural China' as if it were just a matter of agriculture is clearly mistaken. Rather, as MIT's Huang Yasheng has argued, the great success of Chinese growth in the 1980s is a story of growth by township and village enterprises (TVEs) engaged in 'rural'-based industries.[27] To define the countryside and industry as mutually exclusive is thus to overlook the backbone of China's recent meteoric economic growth.

The need to challenge understanding based on strict sectoral divisions is even greater in the context of a low carbon transition. Systems-changing innovation often involves the blurring or crossing of familiar boundaries between industries and sectors, just as it involves the formation of new social relations. Shengchang Bioenergy's business, for instance, brings together industrial manufacturing, energy and agriculture in the form of biomass pellets and their associated combustion equipment.

The established farming practice of burning crop residues is a significant source of GHGs and soot in China, but tackling this problem needs an alternative use for these stalks and husks. Converting these residues, from various crops, into easily handled and efficiently combustible pellets not only cleans this combustion process. But by putting it to useful work it can replace the combustion of coal by individual farmers and buildings, which itself is one of the most inefficient and polluting ways of burning the ubiquitous black stuff. Given the sheer number of Chinese farmers, shifting towards efficient combustion of biomass pellets thus could have a major impact on GHG emissions and air quality, while creating viable businesses and new sources of long-term employment.

Shengchang Bioenergy has made this vision its own. Starting in 2006, CEO Fu Youhong stepped away from his prior experience in

27. Huang Yasheng (2008) 'Capitalism with Chinese Characteristics: Entrepreneurship and the State.' Cambridge: Cambridge University Press.

pharmaceuticals motivated (like the other entrepreneurs profiled in this report) by concerns about the environment. Following significant research into the renewable energy options in Europe, he chose biomass as an issue that would be particularly significant in the Chinese context. The business has two main technological innovations: in the pelleting process and in construction of boilers. Regarding the former, issues of temperature and pressure control demanded significant adaptation and development of their own pelleting technologies, including pre-treatment techniques for the raw material. Biomass burning boilers also had to be developed if there was to be any demand for the pellets. Existing technologies from overseas were tried, but were found to be incompatible with pellets from local residues as these are not graded and standardised as they are in Europe. Accordingly, the company had to develop its own boilers, based on technologies from Beijing's Tsinghua University that already existed but were not being deployed for any commercial use.

As with GEI, however, the feasibility of these technological innovations depended upon forging new connections to transform farmers' habits and to encourage them both to deliver their residues for payment and then to substitute biomass for coal in their heating and cooking. Researching the viability of this business model in the initial markets of Beijing's rural counties, a transport feasibility study was conducted with local government support, involving 2,000 students over the summer of 2008. This established that all raw materials would have to come from under 20km or else farmers would not consider it worth their while to make the journey. This conclusion, however, has added an extra low carbon dimension to Shengchang's business strategy, providing a model for a locally distributed rural energy source.

Armed with this analysis, there were still the significant challenges of setting up the institutions and routines to persuade farmers actually to change their behaviour. Routine deliveries of biomass pellets were established, and local farmers were informed of the economic benefits available from selling their residues and transferring to biomass burners. New relations were also established with village government committees, who were approached for support in encouraging farmers to change over. Embedded systems of coal burning, including government support for the industry, also acted as a significant source of inertia.

Shengchang has itself received some significant support from various levels of government. The general efforts of government regarding environmental protection have helped raise awareness of the issues, encouraging demand for the pellets. More directly, the central Ministry of Agriculture and the Beijing city government both underwrote the transport feasibility study and an arm's-length assessment of the SO_2 and CO_2 emissions of the pellets, which showed significant environmental benefits in comparison to coal. Local government also provides a subsidy (on a per tonne basis) for sales of the biomass pellets. This subsidy has no explicit expiry date, but it could be ended at any time. It is likely, however, that the company will soon no longer depend upon it as the business is growing well and is shifting towards profit. There are now 160 employees working at three biomass pelleting plants (in Beijing and rural counties of Beijing municipality) with capacity for 20,000 tonnes of pellets per year made from wood chips, cornstalks, cotton stalks and peanut shells. These are packed into 50kg bags and delivered to farmers, or shipped by a specially adapted trailer for industrial customers.

In 2008, a machine factory was also established in Daxing Industrial Development Area in south Beijing, producing biomass combustion equipment specifically adapted for the pellets. These include hot water boilers for individual households, industrial boilers (from 0.7 to 7 MW) including for central heating systems, and – of perhaps greatest symbolic importance – a patented cooking stove costing under RMB 200 (£20) that directly competes with the coal briquette burners that are a staple feature of Chinese streets. More recently, the company has also moved further upstream in its supply chain, establishing its own pelleting machine factory in the northwest Beijing district of Haidian. This has already provided a further three pelleting plants to rural districts of Beijing, thereby spreading the model of locally sourced biomass.

Finally, as awareness of the environmental costs of coal and oil, as well as experience of natural gas shortages in recent cold snaps (for example, November 2009), spreads, the market for those looking for alternative and sustainable sources of energy is growing. Shengchang is thus receiving growing attention and sales requests from across the country, for both pellets and boilers. Negotiations are ongoing regarding five investments to establish locally-sourced biomass, and the company is already committed to investing in pellet factories in

Hubei (in central China) and Heilongjiang (in the north east). Building strong links with the farmers who are both consumers of its pellets and boilers and suppliers of the residue feedstocks has been, and will continue to be, the key to the business model.

2.3 Policy must keep pace

Green growth vs. Green lakes
Amongst the grievous environmental challenges facing China, water is undoubtedly one of the biggest and closest to crisis. Problems of scarcity, especially in the north and west of the country, are exacerbated by problems of pollution, which reduce even further the amount of potable water available to China's 1.3 billion people. Two images capture these problems particularly vividly: on the one hand, a dried up Yellow River, the cradle of Chinese civilisation and its agriculture, which now doesn't reach the sea for several months a year; on the other, the algal blooms that have occasionally painted Tai Hu, the country's largest fresh water lake, bright green.

While the former problem is largely due to wasteful water practices in agriculture, which accounts for more than two-thirds of water consumption, China's burgeoning industrialisation is both a significant contribution to scarcity – e.g. coal mining involves huge amounts of water, which may thus be the *de facto* limiting factor on coal, rather than GHG targets – and the most significant cause of water pollution. Polluted waste-water, however, also contributes to climate change in the form of the energy that is wasted by releasing heated water into rivers, or pre-cooling to clean the water before discharge in order to meet environmental regulations.

Beijing Sinen En-tech's (or *Zhong Neng Huan Ke* – China Energy Environment Technology Company – ZNHK) low carbon innovation directly tackles both of these problems through a system that allows high-efficiency cleaning of waste-water at elevated temperatures. The clean, still-hot water can then be recycled back into the industrial process, hence reducing energy use in heating and cooling, cleaning the water for eventual discharge and cutting water use.

The company is the brainchild of CEO Yang Yucheng, following more than 20 years working on energy saving and conservation at the major petrochemical SOE, Sinopec. In the 1990s, while still at Sinopec, Yang began to cooperate with a professor from China University of Petroleum (CUP) in research regarding energy saving technologies. This led, in 2002, to the establishment of a research institute in Beijing dedicated to these issues. It was here that Yang developed the chemical basis of ZNHK's core technology, a (now patented) chemical membrane and carbon fibre filter to remove inorganic and organic pollutants respectively. Without interest from his CUP partner in commercialisation, he set up his own company in 2004 to integrate the technology with other familiar technologies as a relatively low-cost product for high temperature waste-water recycling.

Funding for this venture was not easy to find. In 2004, environmental issues remained quite low on the political agenda and so there was no interest from government. Bank loans were also unavailable, while venture capital was still only embryonic in China. Nevertheless, greatly concerned about resources saving and environmental conservation from his work in these fields, he managed to find some partners and together they invested RMB 600,000 (£60,000) of their own money.

Since then, growth and investment have been strong. Establishment of the company was soon followed by RMB 2 million of investment from a Xinjiang-based investment company specifically interested in high temperature water recycling, which ZNHK alone was tackling. The company also succeeded in being certified as a 'high-tech enterprise' in Beijing's Zhongguancun district in 2004 and, at the end of 2008, as a 'national high-tech enterprise'. Both of these certifications were crucial for the business in these early stages, bringing significant financial support that is reserved for such 'hi-tech' companies, such as tax breaks, innovation funding and interest-free or prolonged payback loans. Access to this crucial source of finance, however, depended entirely upon the definition of 'hi-tech' employed by the government. It was thus of utmost importance for ZNHK that the environmental law of 2004 recognised energy conservation for the first time as a sector capable of hi-tech certification.

This is not to suggest that ZNHK's business is dependent upon government support. Rather, in classic disruptive innovation fashion, it is offering a low-cost alternative that services a demand hitherto neglected as unprofitable. The stand-alone economic case for its innovation is also strong, with cost savings from reduction of energy and water use offering payback on capital expenditure in most cases in less than 12 months. As a result, ZNHK reached profitability in 2006-7, and its revenues grew 262 per cent from 2006 to 2008, reaching RMB 35 million in 2008. To date, over 20 systems have been installed, mainly at SOE petrochemical plants, including Sinopec, and some chemical companies, though the service is suitable for many other industries, including steel, metallurgy, coal, textiles, fertiliser and pharmaceuticals, all of which have significant energy requirements. This success has also been recognised with various accolades and awards. For instance, in 2008 Yang and the company were a cover story in Forbes China, featured in an Al-Jazeera news report on greentech in China and were listed in the Deloitte's 'high-tech with high-growth' China top 50 and at 67 in the Asia-Pacific top 500.

ZNHK's low carbon innovation is disruptive in a number of ways. While it involves a new, high technology dependent on some considerable R&D, its commercialisation has been entirely dependent upon integrating this technology into a low-cost system, which also involves established technology. Indeed, ZNHK is a perfect example of how disruptive innovation is an issue that is largely orthogonal to the hi- or low-tech nature of the technologies it deploys. The substantive effect of ZNHK's innovation is also targeted at novel practices, disrupting the standard waste practices of many industrial firms and using familiar technologies to recycle hot waste-water back through the industrial process. As the only patented waste-water treatment that conforms with new, tighter government standards for water purity, the innovation also crosses the boundaries between energy, industry and water.

The particular lesson for low carbon innovation, however, is the crucial role of government and policy change to facilitate such disruptive low carbon innovation. First, there is the utter dependence of the company's fortunes in its early stages upon the recognition or not of energy-saving in the government's definition of 'hi-tech business'. Secondly, connections with the state have also been a key characteristic of ZNHK's success in the form of its initial contracts with SOEs. Certainly, after two decades in the business, Yang had some strong *guanxi* that he could mobilise in the case of Sinopec. But this was by no means the only reason for this strategy. The heightened demands for environmental improvements placed upon SOEs by the central government and their consequent demand for energy and resource efficiency measures also made them particularly good clients. As SOEs, these customers also had deeper pockets than private companies may have had, with performance rather than value for money being the primary consideration. Using SOEs as initial customers has thus given ZNHK the time and experience to improve their technology and services to the levels necessary before turning to the private and SME markets; for instance, reducing the time for installation from three months to one. In short, using the national incumbents as primary customers has facilitated the emergence and strengthening of these novel, *non-incumbent* disruptive innovators.

Bike to the future

An urban myth about China concerns a man who walks past a park on his way to work one morning, and returns at the end of the day to find a tower block. Whatever the veracity of the tale, there can be no doubt that China's landscape and the society it expresses and supports are changing at an extraordinary pace. Questions of development in China thus involve not only rural and agricultural issues, but also industrialisation (as per ZNHK) and a process of urbanisation the scale and pace of which is without precedent in human history.

It is in transport, rather than construction, however, that the daunting and dauntingly fast growth of China's cities is most easily visualised, in particular in the rapid emergence and paradoxical stasis of the increasingly congested urban highways. Only 20-plus years ago, the vision of Chinese roads was still a river of bicycles; the one-gear bicycle being the mode of transport of choice as cheap to buy and 'run', enabling of voluntaristic 'auto'-mobility and faster than travel by foot. However, as incomes have grown, particularly in the East, car ownership has also grown at an extraordinary pace, with a (preferably big) car becoming a sought-after status symbol. The automotive sector has also received significant central and local government support as a national pillar industry and a key element of many local economies (for example, in Shanghai, Beijing and Guangzhou).[28] As a result, in January 2009 the Chinese car market overtook the US to become the largest in the world – some 5-10 years before predictions published even in the previous December (though this was in part due to the post-crash collapse of the US market).

As the perpetual traffic jams of Beijing (and Shanghai and Wuhan and Kunming...) and problems of parking space demonstrate,

28. Thun, E. (2006) 'Changing Lanes in China.' Cambridge: Cambridge University Press; Gallagher, K.S. (2006) 'China Shifts Gears.' Cambridge, MA: MIT Press.

however, the density of population in China raises serious questions about the possibility of car ownership expanding much more. Even more importantly, GHG emissions from China's cars are also growing steeply. Indeed, car intensity per person equivalent to current US levels would place China's cars consuming all the oil produced in the world each year.[29] Yet with each passing day, China becomes more deeply embedded into the 'car system', roads have been rebuilt for vehicles, and bicycles – the former low carbon technology of choice – are increasingly driven (literally) off the roads.

Such growth is clearly not sustainable, in any sense of the term. So it is good news that bikes seem to be making something of a return, especially as it is in the disruptive low carbon form of the electric bicycle that may compete directly with the car. With 70 per cent of electric power generated through coal combustion, electricity from the grid is certainly not (yet) carbon-neutral. Yet even under current conditions, a shift from oil to electricity has a significantly positive effect on transport emissions.[30] This is even more marked where the vehicle is a bike of several kilos as opposed to a car of several tonnes.

Lüyuan (meaning 'green energy') is one of the oldest and strongest competitors in this market. In 1996, CEO Ni Jie visited a research institute in Beijing where they were working on electric vehicles. Struck by the technology but also its difficulties, he decided that development of an electric bicycle could be a more profitable route. Accordingly, back at his base in Jinhua, Zhejiang province, he began to conduct R&D with the support of local company Jin Xin Technological Venture Co. This led to establishment of the company in 1997, pioneering the sale of e-bikes in China. Financial difficulties were encountered in the following years, as problems with the battery emerged, but with these rectified, Lüyuan has experienced strong growth from 2001. This success has been acknowledged in a variety of awards including 2005 'top 10 businessman in Zhejiang' – the province that is often dubbed China's 'California' for its entrepreneurial success – Zhejiang famous brand in 2006, and top 50 'fast-growing' companies by 'Fast Company' magazine in 2007, alongside Nike and Honda.

The company now offers a whole range of e-bikes catering to a variety of customers. It is also in the process of developing 3-wheel models that are suitable for the disabled and for older users. In the future, the aim is to apply the company's technological know-how to develop a cheap and convenient system to re-equip normal cars as electric vehicles. In each case, Lüyuan is offering a low-cost and low carbon alternative to cars.

The success of Lüyuan mirrors the widespread growth of e-bikes across the country, of which there are now over 120 million. But this growth has been so great that it has also unleashed a regulatory backlash, which is the major barrier to Lüyuan's further expansion. Many e-bikes can reach top speeds of around 50km/h (35 mph). They are also often loaded up with heavy goods. This has led many to associate the e-bike with accidents, crime (theft both using the bike and of the bike) and even congestion. E-bikes have thus been increasingly regulated or banned outright by local governments across the country, including in Beijing, Fuzhou, Shenzhen and Guangzhou.

Working at a compromise to keep the market alive, Lüyuan has been participating in policy committees to establish a set of standards and regulations for their manufacture and use. In particular, a central government law was due to take force on 1st January this year. This would limit e-bikes to a maximum speed of 20 km/h and maximum mass of 20kg. E-bikes exceeding these limits would be reclassified as e-motorcycles and so would require users to pass a driving test. This law would certainly dramatically reduce the market for e-bikes, but it has yet to take effect, in fact, and is currently indefinitely postponed. Lüyuan's future thus remains highly uncertain.

States and standards

We have already considered above the importance to a low carbon transition of new connections that cross familiar boundaries, both in terms of social relations and regarding the novel conjunction of technologies. Indeed, as the veteran innovation scholar Brian Arthur has described in his most recent book, recombination of technologies is a key element of understanding the 'evolution of technology'.[31] Furthermore, business scholars Peter Williamson and Ming Zeng have argued in detail that recombination of technologies is a particular strength of Chinese innovation, as a route to providing low-cost options.[32] This strategy is also greatly supported by the modularity of many technologies in the context of globalisation.

Innovation, however, is always both a social and a technological process. And social factors include not only people and social life, but also

29. Dennis, K. and Urry, J. (2009) 'After the Car.' Cambridge: Polity.
30. Gao, P., Wang, A. and Wu, A. (2008) 'China Charges Up: The Electric Vehicle Opportunity.' McKinsey & Company.
31. Arthur, W.B. (2009) 'The Nature of Technology: What It Is and How It Evolves.' London: Allen Lane.
32. Ming Zeng, and Williamson, P. (2007) 'Dragons at Your Door: How Chinese Cost Innovation is Disrupting Global Competition.' Cambridge, MA: Harvard Business School Press.

politics and policy. The parallel development of the three factors of this 'technology-people-policy nexus' thus demands that policy also responds to and supports changes in technology and social practices.[33] The mixing of technologies and blurring of social boundaries thus may often confound the set definitions of policy and its institutional context in ways that significantly stall progressive socio-technical change. Indeed, on the flipside, the element of discontinuity in systems these changes represent is precisely their strength as regards systems transition.

The Chinese Game-Changers perfectly illustrate the need for regulatory support and for it to keep up with changing practices through new policies and redefinition of existing ones; as evidenced in the development of new connections between many of these innovative companies – for example ZNHK, Lüyuan and Shengchang – and government for the drafting of relevant regulations and standards. For example, it was only when environmental technologies could be classified as 'hi-tech' that ZNHK could access the support that made their business model viable in its early stages. Similarly, regulations could either support or undermine Lüyuan's e-bike, and legislation was needed to make GEI's vegetable cooperatives legal entities.

Standards are a further form of regulation upon which many of our case-studies explicitly commented. ZNHK noted the importance of tighter waste-water standards to stimulate demand for their product. Shengchang stated that national standards for biomass boilers would significantly assist their business, preventing farmers from having negative experiences with poorly made biomass combustion equipment that put them off the idea completely; a consideration that is also relevant regarding solar water heaters for Himin Group. Standards would also ensure that the potential low carbon benefits of biomass combustion are not squandered through cheaper, but less efficient, boilers. Similarly, formation of cooperatives for collection of agricultural residues together with standardised residue qualities would add considerable stability to prices for these materials, which would in turn further encourage farmers to participate in these markets.

In the Chinese context, however, the role of government has added significance given the continuing strong presence of the state in the economy. This both poses particular challenges and raises singular opportunities for disruptive low carbon innovation in China. In particular, in several cases, where there is a regulatory drive towards the environmental goals serviced by their innovation, a number of our examples have successfully identified SOEs as an important market opportunity, especially in the early stages of the business (for example, ZNHK's petrochemical SOEs and Pearl's telecom companies). As we discuss below, this suggests important ways in which disruptive low carbon innovation in China can build on, rather than challenge, the existing structure of the national economy.

Achieving the impossible?

Innovation has often been associated with mania and hype, often leading to financial bubbles.[34] Among the various philosopher's stones animating such exaggerated hopes and quests, a perpetual motion machine must surely be one of the most famous. An ancient Chinese 'water-drinking machine' (a bird-like contraption that sits above the water surface and is pivoted at the 'waist' with a weighted bottom and a long metal 'beak' that bobs back and forth), however, has perplexed many with its claims to be an example of one.

In fact, as Yuan Yijun, CEO of Hangzhou ISAW, explains, its seemingly 'perpetual motion' is scientifically explicable in terms of psychrometry. Psychrometry may itself sound like little more than a fancy name for 'magic'; we must certainly admit not to have heard the term before! But in fact it is "the field of engineering concerned with the determination of physical and thermodynamic properties of gas-vapour mixtures" or in Yuan's more accessible definition, the science of the "interaction of solar, air and water", hence 'ISAW'.

Exploiting knowledge of evaporation, Yuan has developed technologies for three main uses, all of which provide efficient low-cost ways to tackle significant low carbon issues for China and other developing countries, namely: industrial heat recovery; air-conditioning (cooling and heating); and solar desalination of salt water. In each case, the process is driven by exploiting the thermodynamics of evaporation between differing salt concentrations in water. For instance, the green air-conditioning process is a natural process under ambient pressure that involves no compressor or vacuum, just pure and salt water as working media. Conversely, industrial energy recovery, air-conditioning and desalination are conventionally all highly energy- (and so emission-) intensive.

33. Murphy, J. (2007) 'Governing Technology for Sustainability.' London: Earthscan.
34. Perez, C. (2002) 'Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages.' Cheltenham and Northampton, MA: Edward Elgar.

Yuan, as may be expected, is a scientist by background. Convinced of the opportunities for an energy-saving innovation based upon psychrometric principles, he first attempted a collaboration with an air-conditioning company in 2006. When this came to nought, he decided to set out on his own, establishing ISAW in 2007 and investing his own funds in the venture. His business strategy has been to exploit his psychrometric knowledge to create energy-saving technologies that are both low-cost in themselves and save expense through their energy efficiency. Developing a range of products for the three applications discussed above, he succeeded in 2008 in winning a contract with one of China's largest real estate companies, Vanke, to incorporate his air conditioning technology in a new housing development in Shenzhen. This has been followed by contracts with Shanghai Expo and an Indian research institute. The energy recovery process has also been successfully commercialised in several cigarette factories, which are also usually local state SOEs. And export of the solar desalination technology to the water-stressed Middle East began in 2009 with projects at American Beirut University and as part of the Masdar eco-city project, while negotiations are ongoing regarding an initiative in Yemen.

As a small company, not based in a designated hi-tech zone and offering equipment that, while scientifically sophisticated, tests the 'hi-tech' definition in its deliberate targeting of low-cost technology, ISAW has faced similar challenges to those of ZNHK regarding access to support for 'hi-tech' companies. Yet whereas ZNHK has been lucky in terms of the timing of changes of government policy and its connections with state institutions and enterprises, ISAW illustrates how this is not the case for every disruptive low carbon innovator. It thus provides a salutary reminder of the significant challenges many such initiatives face from policy and, conversely, the extraordinary challenges policymakers face in keeping up with all the developments in low carbon innovation.

In fact, ISAW has received some government funding for R&D, but the difficulty of accessing more general benefits and support for the business as a whole remains a major hurdle to the company's growth. This is exacerbated by the current policy focus on users of low carbon technologies, especially regarding energy efficiency, rather than offering incentives to the low carbon innovators themselves. Yuan is nevertheless determined to develop ISAW's marketing capacities – a crucial area of the business that, being a scientist, is not his own strength. Other near-term goals include building on collaborations and joint ventures to commercialise the air-conditioning technology as an integral part of green building practices and to expand the solar desalination business. The company will also continue to seek out larger investors to develop the business and to strengthen R&D.

2.4 Engage with the globalisation of innovation

Towards cosmopolitan innovation

Supported by major policy goals of an 'innovation-based economy' by 2020 and indigenous innovation (*zizhu chuangxin*), innovation capacities are undoubtedly improving in China. Together with similar analyses regarding other major developing countries, such as India or Brazil, this has led to widespread identification of a trend towards a much greater spread of significant innovation capacities around the world.[35] This has led some 'Western' commentators to express fearful visions of a race that is increasingly being lost to these up-and-coming contestants.[36]

Such techno-nationalist responses are both wrong and irresponsible; the latter because of the danger of self-fulfilling prophecy, the former because the understanding of innovation itself and its interaction with economic growth is, at best, partial in these analyses. In particular, the globalisation of innovation is not just a matter of new players in an unchanged game. The very nature of innovation is itself changing, as contributions from disparate parts of the globe come together in individual innovation processes. The classic example is the iPod, with innovation taking place not just in the US but across the world.[37] As a result, the rise of new global poles of innovation is likely to be a non-zero sum phenomenon with the potential for gains on all sides.

Such globalised processes also unlock extraordinary potential for innovation that it would be a catastrophe to ignore in efforts to deal with global climate change. For no individual country has the capacity alone to move towards a low carbon society. Yet in advocating the importance of the globalisation of innovation, the 3Ds must be observed. There are multiple possible models of globalisation,

35. Leadbeater, C. and Wilsdon, J. (2007) 'The Atlas of Ideas: How Asian Innovation Can Benefit Us All.' London: Demos.
36. For example, National Academies of Science (2005) 'Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future.' Washington DC: NAS.
37. Bhidé, A. (2008) 'The Venturesome Economy.' Princeton, NJ: Princeton University Press.

hence demanding that issues of direction are considered. 'Distribution' then raises the key question of 'who gains?', on a global scale, while 'diversity' reminds us that there is no single 'best' model of innovation, but rather a variety of regulations and concrete innovations are needed to serve the actual needs and capabilities of different localities and communities.

Recalling also the fourth 'D' of development, it is clear that a key question for global models of innovation is how innovation interacts with socio-economic development in particular places. Yet this relationship is highly complex and in no sense reducible to annual R&D expenditure or patent statistics. Rather it involves such fuzzy and slow-changing factors as cultures of experimentation and entrepreneurship, attractive living environments, transport and communication infrastructures and flows of financial profits.

As such, even while innovation capacities are growing in numerous developing countries with crucial non-zero sum implications, it is still easily imagined that the greatest gains from this innovation will accrue unevenly to the already wealthy. Indeed, current global rules, privileging strong global IPRs, overwhelmingly favour only a handful of highly concentrated industries, such as pharmaceuticals, agribusiness and media; or rather *protect* them, as these are all industries whose current business models are facing significant challenges from the globalisation of innovation. Current trends thus permit no guarantees regarding the effects on China's future in what really concerns it, namely the standard of living and the movement of its economy more broadly 'up the value chain'.

This is equally true of low carbon innovation, especially where it follows a hi-tech model. As a recent Chatham House report makes clear: "Brazil, China and India… have no companies or organisations in the top 10 positions in any of the sectors and sub-sectors analysed" and intellectual property in low carbon energy technologies is concentrated in the large incumbent multinationals from OECD countries.[38] As such, the growing geopolitical influence of these countries may thus be expected also to bring major shifts in the global rules of innovation in order to shape the emerging "international division of labour of innovation", in which low carbon innovation capacity will be a major factor, that will in turn be a major determinant of geopolitical power in the 21st century.

38. Lee, B., Iliev, I. and Preston, F. (2009) 'Who Owns Our Low Carbon Future? Intellectual Property and Energy Technologies.' London: Royal Institute of International Affairs. p.ix.

One possibility is a techno-nationalist future of aggressively competing 'blocs', each engaging in their own hedged and inadequate efforts at climate change mitigation and adaptation. Against this dystopic future, we advocate a 'cosmopolitan innovation' regime that supports innovation that is globally connected and concerned – hence engaged with the challenge of climate change and capitalising upon the opportunities for expedited transition from the globalisation of innovation – but locally relevant and sensitive – responding to the 3Ds. International collaboration, involving mutual learning, must clearly be a major element of any such regime.

From 'catch-up' to collaboration

The Chinese Game-Changers show the importance of international collaboration for disruptive low carbon innovation and the opportunities for international learning from this type of innovation. For example, Pearl Hydrogen's development of a full-system solution for its fuel cell bicycle is in collaboration with an Italian company, just as its work on a racing car is a joint project with Imperial College, London. Similarly, ISAW has benefitted from joint research with colleagues, including Chinese academics, at Nottingham University and work at the Masdar eco-city in Abu Dhabi. GEI's Snow Mountain Organic Corporation has also involved overseas investors, while its original project was partly funded by an American charity.

In each of these cases, the crucial factor has been that the mutual benefit underpinning the successful collaboration produces a relationship that is significantly different from that presupposed by the seemingly intractable arguments of low carbon technology transfer. Instead, regardless of the undoubted importance of these high-level discussions, these relationships act as the basis for a wholesale reframing of the challenge of international collaboration regarding climate change. No longer should this be conceived, quite falsely, in terms of leader and follower, developed and developing nations respectively, but as an opportunity for China to set, and not merely follow, the innovation trajectory of a low carbon transition in collaboration with its partners.

But the opportunities from the globalisation of innovation for low carbon disruptive innovation are not limited to international collaboration alone. Engagement with globalisation also allows these low-cost innovators to source products or inputs cheaply. For instance, Pearl

Hydrogen buys standard Nafion membranes from overseas which it then treats to fit into its own technology. Conversely, the problems of European boilers burning Chinese biomass pellets encountered by Shengchang remind us that this is not always possible and local innovation is often necessary.

On the other hand, globalisation opens up new markets for indigenous Chinese innovations. This may be in the form of 'South-South' sales, as for ISAW's use of the Middle East as an entry market in which to develop its desalination technologies or its exports of air-conditioning to Masdar eco-city. GEI has also transferred its model to other developing countries, such as Sri Lanka and Laos. Nor are such sales between developing countries marginal, but they are likely to dominate the market for low carbon investment in the coming decades.

Finally, Chinese innovations may also succeed through 'reverse' or 'periphery-to-core' innovation, in which disruptive innovations that initially only offer profitability to small companies in developing countries then find unexpected but significant markets in developed ones.[39] Though none of our examples has yet achieved this, it is conceivable that many could and will. Opening up to and shaping the globalisation of innovation is thus an important strategy for Chinese disruptive low carbon innovation, in the process expediting a low carbon shift on a global scale.

2.5 Four principles of low carbon innovation – revisited

In the 2007 *Disrupters* report, Rebecca Willis and her colleagues likewise suggested four principles of low carbon innovation. There is clearly significant overlap between their list and ours and the lessons from that report remain utterly pertinent to the present discussion. But our Chinese examples add to this discussion in two important ways. First, they bring to the fore a number of extra dimensions. These are crucial considerations for low carbon innovation at the necessary global level that also broaden the case for the importance of disruptive innovation, namely: socio-economic development; international collaboration; the diverse and important roles for government, even where hi-tech incubation and 'picking winners' is downplayed; and the singular opportunities for disruptive innovation in China, given current strengths and innovation capacities.

Secondly, in the spirit of the 3Ds, our Chinese case studies translate the lessons from the original report in ways that add inflections and nuances that reflect the particular Chinese context. For instance, while disruptive innovation rightly highlights the importance of looking beyond hi-technology and so keeping it 'in perspective' (Lesson 1), the Chinese debate demands that this also admits the enduring political importance of the goal of creating a hi-tech economy. Similarly, discussions of trends towards 'democratised' user-led innovation (Lesson 2) tend to imagine the technologically literate, on-line and relatively affluent user of developed country markets. In China, and especially rural areas, however, 'users' includes reluctant users, such as farmers, who lack the resources to experiment, with all the risks involved, and are unused to technological change.

'Breaking open closed systems' (Lesson 3) does not necessarily involve a radical shift in economic structures, with SOEs 'opened up' to a 'level playing field' of intense market competition, but includes them as a significant opportunity and source of demand for disruptive innovators. Finally 'unusual connections' (Lesson 4) includes not only the blurring of sectoral boundaries and the combination of innovations, aggregating towards tipping points of systemic change. Connections are also needed across levels of socio-economic development, between different types of institution (government/ SOEs, SMEs, NGOs, users and citizens), and across geographical borders through international collaboration.

Translating these lessons in this way shows the exceptional importance and relevance of disruptive low carbon innovation to a country of 1.3 billion people that is undergoing unprecedented social change – whether in industrialisation, urbanisation or agriculture – and the exceptional challenges and opportunities that come with this.

39. Immelt, J., Govindarajan, V. and Trimble, C. (2009) How GE is disrupting itself. 'Harvard Business Review.' October: 56-65; Ming Zeng, and Williamson, P. (2007) op.cit.; The Economist (2009) 'Healthcare in India: Lessons from a frugal innovator.' The Economist, April 18-24, pp.69-70.

Part 3: Towards disruptive innovation policy

3.1 Lessons for low carbon transition

These case-studies of Chinese disruptive low carbon innovation offer a number of important lessons as China strives to shift to and shape the trajectory of a new sustainable and equitable model of development.

First, they show that there are numerous disruptive or game-changing low carbon innovators in China, many of which have already experienced significant success. While only seven have been profiled here, we did not have to dig deep to find our case studies and there are without doubt many, many more. There is thus significant entrepreneurial effort and imagination in China invested in low carbon ventures; dynamism that, like the UK examples, is "motivated both by a commitment to [environmental issues] and a desire to make a business opportunity out of a necessity".[40] Moreover, these examples illustrate the particular relevance of disruptive low carbon innovation to China, given its needs, concerns and current innovation capabilities.

Secondly, even the seven ventures discussed here could have sizeable impact on GHG emissions (see Table 1). Indeed, some already have, as in the case of Himin Group and Lüyuan. But the potential in all cases is large, not least given the sheer size of China's population and the global impact of China's high and growing total GHG emissions. Total GHG savings in the next five years could equal as much as 66 million tonnes CO_2e (CO_2 equivalent) per year – or the equivalent of 12 million homes in the UK, 25 million homes in China. Growth of these companies and their low carbon effects may be even greater in the medium term, especially where there is successful reverse innovation or South-South sales. And these calculations do not include the potential for emergent effects, as these innovations contingently converge with other innovations into broader systems changes. Indeed, such complementarities are conceivable even between these case studies. For example: GEI's rural cooperatives delivering agricultural residues to a Shengchang pellet factory on a Lüyuan or Pearl Hydrogen electric small truck; or buildings incorporating Himin hot water and ISAW air-conditioning, effecting quantum improvements in energy bills and commensurate strides in widespread adoption of the model; or industrial plants incorporating ZNHK waste-water treatment, ISAW heat recovery and Shengchang biomass heating.

Finally, all our examples have encountered a number of problems that demand new ways to support such low carbon innovation better. Although many have received government support and access to private innovation finance is improving more generally, it remains the case that innovation policy, including for low carbon, is focused on major projects of government-led and high-technology breakthroughs. Conversely, these SMEs are already a significant asset to the Chinese economy and to the development of an innovation-based economy, yet they struggle to achieve the attention of policymakers. As a result, communication regarding the redesign and introduction of specific policies that would support their embryonic ventures is forestalled and growth of the companies is itself restrained, to the cost of the Chinese economy as much as the initiatives themselves. And funding for these low-cost innovations is scarce, while financial support may be necessary in early stages, especially where the disruptive innovation is competing with entrenched and closed systems.

40. Willis *et al.* (2007) p.25.
41. Coal to CO_2e conversions have been done on basis of 2,338 kg CO_2e per tonne of coal. See Carbon Trust at: http://www.carbontrust.co.uk/cut-carbon-reduce-costs/calculate/carbon-footprinting/pages/2-types-carbon-foot-print.aspx
42. Figures from Lüyuan.
43. Figures from Li Junfeng, Deputy Director of the Energy Research Institute, National Development & Reform Commission. Available at: www.greenpeace.org/china/en/campaigns/countdown-to-copenhagen/dezhou-solar-story (Accessed 15/02/10).
44. Wood and woodchip to CO_2e conversions at 121.5 kg CO_2e per tonne. See Carbon Trust at: http://www.carbontrust.co.uk/cut-carbon-reduce-costs/calculate/carbon-footprinting/pages/2-types-carbon-foot-print.aspx
45. Firewood and deforestation savings from An Xin and Chen Zhiping (2008) Solving the issue of sustainable development in rural China through a three-in-one mode. In: 'China Insight: Rural Financing, Energy Conservation & Forest Resources.' Beijing: Global Environment Institute. Methane calculation based on 1.5m^3 per day, methane density of 1.82kg/m^3. Savings from avoiding deforestation and reduced inorganic fertilizer use are not included in this calculation, though they too could be significant.
46. Figures from ISAW.
47. Figures from Pearl Hydrogen.
48. Figures from Shengchang.
49. Figures from ZNHK.

Table 1: Estimated GHG reduction potential of the Chinese Game-Changers

Game-Changer	Estimated Impact	Savings t CO_2e per year[41]	Potential for scaling up (approx. 5 yrs)	Total potential savings each year t CO_2e
Lüyuan	Total e-bike market of 120 million bikes, replacing cars running about 10,000km/year, with savings of at least 1 t CO_2e per vehicle[42]	120 million t	Growth is uncertain due to regulation, but conservative estimate of 10 per cent growth in 5 years	130,000,000 (Total market)
Himin Group	1 x 2m^2 solar tank saves 300kg coal per year[43]	0.7t per year per tank	Total solar thermal market of 200 million families	140,000,000 (Total market)
Sub-total for Established Companies				**270,000,000**
GEI Biogas Project	Saves 4.2t per household,[44] release of 1t of methane and deforestation of 8 *mu*[45]	22t per year per household (mostly through savings of methane emissions)	Grow model to 10,000 households	220,000
ISAW[46]	Energy recovery for 1 cigarette factory	1,000t	Currently 5 cigarette factories fitted. Fitting of energy recovery units in all (≈100) cigarette factories	100,000
	1 t steam cooling & heating (= 50m^2 floor space) for a year	2t per 50m^2	5 per cent of Chinese air-conditioning market (conservative estimate of 15 billion m^2 total national air-conditioned floor area)	30,000,000
	1 solar desalination plant at daily capacity of 100,000 litres water per day	1,500,000t	Five plants	7,500,000
Pearl Hydrogen[47]	One 1kW fuel cells, average operating time is about 300 hrs per year, can save about 40kg standard coal	94kg per 1kW	Sales projected of up to 30MW in 5 years	2,800
Shengchang Biomass[48]	400 boilers at Zhangziying Greenhouse Project vs. coal-fired boilers	7,000t	Sales of 10,000 boilers	175,000
	Cooking stoves use 1kg per meal, approx. 2kg per day vs. 1.5kg coal	1.2t per stove	Production capacity of 10,000 stoves per day hence total sales of 3.6m per year Total aggregate sales of 22m in 5 years	26,400,000
	Industrial boilers estimated savings from one 18,000 sq meter building (Economic Times)	265t per heating season	Fitted in 1,000 buildings	265,000
ZNHK (Sinen En-tech)	Saves 8,400t coal per year for 1 petrochemical plant of typical 100t/h steam[49]	22,000t per plant	Fitted in total of 60 plants	1,320,000
Sub-total for new ventures				**65,982,800**
Total				**335,982,800**

For instance, the definition of 'hi-tech business' needed to be changed before ZNHK could take advantage of the crucial financial supports available for such companies. ZNHK, Shengchang and Lüyuan all explicitly mentioned the importance of national standards, while others, such as ISAW and Himin, would also no doubt benefit from them. Pearl Hydrogen, ISAW and GEI have struggled to get government assistance, while Shengchang, Pearl and GEI are all tackling closed systems that do enjoy considerable government support, in the form of coal, cars and construction respectively.

3.2 Iterative innovation and institutional learning

How, then, can government better support these disruptive innovators in the broader context of optimising their contribution to a transition to an equitable and sustainable low carbon system? It is not our role here to formulate concrete policies, not least given the importance of broad participation and local considerations for governance of low carbon innovation under the 3Ds agenda advocated here. Instead, we suggest five considerations that should be explicitly addressed by policymakers in formulating such policies:

3.2.1 Policy should take account of the crucial opportunities for China regarding disruptive low-carbon innovation

The first consideration addresses the commitment to incorporate disruptive low carbon innovation into policy in the first place. Doing so will undoubtedly involve extra policy work, to understand, devise and implement policies that assist a group of low carbon innovators previously not often considered important. Before proceeding to more concrete concerns, therefore, we must first ascertain why such extra work is worthwhile, indeed necessary. To recap, there are numerous reasons, both in general and for China in particular.

First, to bring about a low carbon systems transition, focusing on a 'Plan A' of hi-tech improvements, while itself crucial, will not be enough. This is not only because it is extremely unlikely to be able to produce the kind of reduction in GHG emissions required and in the exceptionally tight time constraints, but also because such systems innovation will require incubation of the wild cards and 'small beginnings' from which profound socio-technical change is likely to emerge. This is thus not so much a 'Plan B' as a 'Plan A+B'. Disruptive innovation, producing a social redefinition of technologies, also offers an important route to maximise the impact of existing low carbon technologies that will have primary responsibility for the vast majority of emissions reductions by a 2050 deadline. Engendering these small disruptive innovations will also add diversity and hence resilience to the emerging low carbon socio-technical regime – a crucial consideration in the face of the extreme complexity, openness and uncertainty of this social and political transition process.

Secondly, global climate change demands that low carbon innovation will remain an utter priority for socio-economic activity for the foreseeable future. Global leadership in low carbon innovation will thus be a major determinant of the overall competitive strength of various national and regional innovation systems in the 21st century. Given that no country yet has a low carbon society, the firms that will dominate the low carbon global economy in many domains are probably not yet household names – even while it is existing low carbon technologies that will be most important in the low carbon transition. Most currently dominant firms have innovation capabilities and managerial capacities that make them a success in their current high-carbon context. Conversely, disruptive low carbon innovators are likely to feature prominently in this regard, as their very strength is the ability to exploit market opportunities that break away from established innovation trajectories and would be unprofitable and/or organisationally difficult for large and established firms.

Disruptive low carbon innovation is thus important for all national economies. But, following the latter point in particular, it is also likely to be especially important for a rapidly developing country such as China. Indeed, a major element of low carbon innovation policy in China is anxiety regarding whether or not some of the dominant firms of the low carbon economy will (or can) be Chinese. Such concerns are particularly intense given the continued domination of existing hi-tech low carbon technologies by OECD-based companies, set alongside the highly proprietary global economic regulatory architecture for innovation that privileges just such intellectual property ownership of high technologies.[50]

50. Lee, B. *et al.* (2009) op.cit.

China's innovation capabilities are improving rapidly, but it remains the case that the singular strength of the current innovation system is the development of low-cost solutions addressing the needs of previously excluded customers. Far from being a comparative weakness, however, this may well be a much more effective and faster route to strong hi-tech capabilities and globally leading firms than targeting these goals directly. This is even more the case given the characteristics of the demand for low carbon innovations, with approximately 70 per cent of future low carbon investment coming from similarly developing countries that will have low-cost requirements that much more closely match those of the domestic Chinese context than those of the relatively wealthy customers of OECD-based companies.

Drawing public attention to the opportunities for disruptive low carbon innovation, which would be profitable from the outset and focused on low-cost solutions, would also help to allay widespread apprehension that serious low carbon measures are expensive, beyond the capabilities and financial resources of most Chinese firms (and customers) and hence 'anti-growth'. Such a public campaign would also thereby target the widespread apathy to innovation *per se* amongst many Chinese businesses, who continue to be profitable largely on the basis of cheap labour costs and export sales. Thirdly, and perhaps most importantly, highlighting the exceptional opportunities for Chinese disruptive low carbon innovation would help engender a movement towards the broader public recognition of the potential for China to *shape*, and not merely *follow*, the low carbon trajectory. This would be a profound change of mindset for many and one that could catalyse an entirely different dynamic for low carbon innovation and on a global scale.

Finally, as a Plan A+B, there is no reason that China's support for development of its hi-tech innovation capabilities cannot continue while space is created to incubate its game-changing low carbon innovators. Rather, these could be seen as complementary, with the growing capacities and technological sophistication of the game-changing innovators (as well as their customers, stakeholders and regulators) embedding the broader cultures of innovation and commercialisation experience that are crucial for hi-tech innovation itself.

In short, the extra policy work needed for an explicit disruptive low carbon policy is worthwhile because of the exceptional opportunities for China in incubating such innovations. The substance of such a policy raises a number of further questions, to which we now turn.

3.2.2 Policy should create spaces for these types of innovation

Disruptive innovation, in principle, should involve a new product or service that offers immediate opportunities for profit, at least to small and flexible firms. Our Chinese Game-Changers illustrate this perfectly, yet they also indicate that having a potentially profitable offering by no means guarantees success. Rather, even disruptive innovations can be forestalled by closed sociotechnical systems that lock in incumbents and lock out new players. These considerations are relevant both regarding encouragement of start-ups and their subsequent embedding and hence policy cannot be 'neutral' regarding the players it chooses to support, in whatever capacity.

A Plan A+B, therefore, needs concerted efforts both: (1) to forge the institutional space, or niches, in which the novel connections that characterise disruptive low carbon innovations can be explored and developed, so that they are relatively robust organisations before taking the further step of expansion and broader societal impact; and (2) to consider and shape the extent to which there is room for non-incumbents to play a significant role in the low carbon transformation of particular sectors. Furthermore, as many such innovations will fail to take hold in this second stage, multiple niches and experiments are needed. Creating such spaces would then allow these innovators to lead indigenous and endogenous processes of low carbon change.

Such a policy of experiments clearly would fit well with the pragmatic approach adopted by the central government to the whole process of economic reforms of the past three decades. It was as an experiment in Anhui that the household responsibility system of agricultural reform began, breaking up collective farms. Similarly, the success of the SEZs (special economic zones) such as Shenzhen catalysed the expansion of the model to other cities. The sheer size and diversity of China and its government structures, with relatively devolved powers to the provinces and municipalities and local GDP per capita levels ranging from the relative wealth of Shanghai to the poverty of Guizhou, could also be exploited as a significant strength, providing the opportunity for a huge variety of low carbon experiments, with successful projects acting as templates for national, and indeed international, learning (see below).

Furthermore, these low carbon niches could take the form of 'low carbon zones' that offer fiscal benefits and regulatory support. By pulling low carbon innovators together, including disruptive ones with boundary-crossing innovations, these zones could also stimulate exploration of the potentially synergistic interaction of innovations and systems integrations that could drive major changes towards a low carbon shift. Such a policy is already under exploration, and in collaboration with international partners. For instance, UK think-tanks E3G and Chatham House together with the Chinese Academy of Social Sciences and NDRC's Energy Research Institute are leading an EU-China project for low carbon zones with a demonstration project in Jilin.[51]

To exploit these important developments fully, however, efforts must be made to ensure that they do not focus only on hi-tech innovation by SOEs or foreign JVs, or the commercialisation of hi-tech projects from universities and CAS institutes. Policymakers should question the extent to which such incumbents and familiar models of heavy industrial development can (alone) achieve the kind of low carbon transition they are seeking to seed and demonstrate in these zones. Rather, the zones should explicitly invite low carbon innovators that make use of established technologies but in innovative and low-cost ways that target previously ignored customers. Similarly, and more generally, all national and provincial ministries tasked with the detail of low carbon innovation policy should set aside at least a small, but high-level, team to ensure the needs of disruptive low carbon innovators are included in the formulation of such policies.

3.2.3 Policy should (seek to) provide the right kind of governance support

For disruptive innovation to flourish, then, it needs support from government, but this must be of an appropriate kind. In particular – and as argued in the 2007 report – the role of government must shift from one of controller or sponsor to one of enabler. In other words, the role of government is not to establish a 'policy-driven' market, which creates unhelpful dependencies, let alone to lead top-down change. Rather it is to establish platforms and frameworks that help minimise risks and so enable innovators, users and citizens themselves to change. Unlocking the dynamism of the population at large in this way – 'inviting innovation', rather than simply delegating it – builds in the diversity and resilience needed for the expedited low carbon transition. It also, therefore, raises the inescapable decision of the extent to which innovation policy focuses only on incumbent firms (whether local, national, regional or global) for delivering a low carbon transition. This is just as true in the case of China as it is for the UK.

Current Chinese policy, both regarding low carbon innovation and more broadly, has much merit in this respect. For instance, on the one hand, many private companies that have proven significant successes (for example, Himin, BYD, Suntech, Chery or Geely) also now receive considerable policy support, at various levels of government. On the other hand, as a central pillar of the Chinese economy, SOEs must play a major role in any low carbon transition. Yet continuing support for SOEs is not *per se* contrary to such an enabling form of governance, both as regards the considerable management autonomy that many SOEs now enjoy and the competition they face and as a major early source of demand for low carbon innovation, as we have seen with ZNHK and Pearl Hydrogen.

However, much more could be done by policy to assist China's game-changers and at the appropriate level of government. For instance, the national level needs to provide the overall framework to support environmental and low carbon innovation. This would not only include general pressures towards energy efficiency and awareness building, but also creation of national standards on low carbon products and services and constant vigilance over who is covered, and who excluded, from policies of national support for 'innovative' companies. In particular, a refocusing of fiscal and other supports from 'hi-tech' to 'innovative' companies, more broadly defined, could significantly help many innovative companies that are excluded under current definitions. National platforms to allow low carbon innovators to find partners with compatible innovations or investment opportunities could also be useful to aggregate learning (see below).

It is at provincial and local levels, however, that most of the actual work of introducing an innovation will take place initially. Opportunities for direct contact with local policymakers, building the relationships needed for ongoing learning about the developing needs of these small businesses, are thus

51. Chatham House, Chinese Academy of Social Sciences, Energy Research Institute, Jilin University and E3G (2010) 'Low Carbon Development Roadmap for Jilin City.' London: Royal Institute of International Affairs.

crucial. This could be achieved to some extent through policies associated with low carbon zones that give businesses and other initiatives included in the zone a regular right of audience with the local policymakers, regardless of the size of their business or their existing *guanxi*.

3.2.4 Policy could exploit the opportunities of low carbon innovation policy to improve governance (not just economic growth and innovation capacities)

As a socio-technical process, innovation inevitably places demands not just on the growth of innovation capacities but also on the forms and institutions of governance. Regarding developments in both innovation *per se* and ecological sustainability – hence low carbon innovation especially – there is a widespread consensus in the literature that these present considerable challenges to traditional top-down modes of governance. These challenges are relevant in all countries, but given the political structure, they are particularly germane in China.

The parallel development of innovation and governance, however, allows us to look at the challenge from both perspectives and as an opportunity as much as a test. In short, just as low carbon innovation needs different governance, so conversely new governance is supported by different (patterns of) innovation. By shifting towards support for the existing Chinese strength of disruptive low carbon innovation, therefore, China can take important steps towards meeting the challenge of establishing forms of governance that would parallel emergence of a low carbon society.

It is perhaps in this regard that current policy must change the most in order to capitalise upon the opportunities presented by China's game-changers. In many respects, the current goal of innovation policy is to replicate the currently dominant American model of hi-tech, IPR-intensive and institutionally concentrated innovation, beating the US (and other countries) at its own game, but with SOEs instead of large private multinational corporations as the primary agents. Yet this model necessarily limits the broad civic engagement in innovation required for a sustainable low carbon transition and hence engenders forms of governance that are ill-suited to this challenge. Furthermore, it privileges firms with innovation and management capacities of which there are currently comparatively few in China. There is thus little reason for China to seek to emulate this model in its ongoing project of constructing a robust national innovation system.

Conversely, acknowledgement and increased engagement with disruptive innovators in the ways just discussed would be a significant improvement, involving SMEs in local and even national innovation policy in a way that remains uncommon. As policymakers and SMEs alike become more used to and adept at communication, governance structures would emerge that provide the former with the necessary information to support innovation and sustainability, while involving the latter in policy formation in ways that disperse governance as is needed to meet these challenges.

But such broader engagement would also need to include users and citizens, including via NGOs, to pay full attention to the 3Ds of direction, distribution and diversity. This engagement could take the form of opportunities for these groups to be directly involved in concrete examples of disruptive low carbon innovation, as in the case of GEI's work in Lijiang, rather than focusing directly on political processes. By building up the capacities for engaged low carbon innovation, this could start a positive cycle of socio-economic change and governance improvement developing in mutually reinforcing parallel.

Once again, an enabling mode of government would be needed to facilitate these developments, with platforms for active involvement of these various parties sponsored by government. To succeed, however, these platforms would need to be established with the explicit aim of deepening learning, including by government itself, of the conditions for low carbon innovation and the needs of those that it will service and affect.

3.2.5 Policy should maximise the opportunities for intra-national and international learning

From our experience of conversations both in China and in the UK, it is clear that it cannot be stated too often that *no* country yet has a low carbon society, nor does any single country have the innovation capacity to effect a low carbon transition alone. Rather, in striving towards an expedited low carbon systems transition we are faced with considerable uncertainties, ignorance and knowledge asymmetries and the great importance of unpredictable synergies, connections and combinations.

There are thus huge opportunities for mutually beneficial international collaborations and the global dissemination of the learning – both the 'first-order' learning regarding technological or institutional innovations and the 'second-order' learning about processes of innovation and international collaboration themselves – that comes with them. International collaborations will be crucial to optimise the impact of disruptive low carbon innovations by maximising connections and associated opportunities for broader social embedding. It also follows from our third consideration above, regarding niches, that a policy for low carbon innovation must prioritise the ability to monitor and build on these experiments, both nationally and internationally. While the first and fourth considerations thus primarily address Chinese policymakers, this final one thus concerns policymakers from all countries, including the UK.

The current system of international collaboration, both in China and elsewhere, tends to focus on publicly-funded academic scientific work, on the one hand, and openness to FDI, on the other, regarding 'science' and 'innovation' respectively. Notwithstanding the need for improvement of these kinds of international collaboration themselves, it is clear that international collaboration between SMEs and other non-incumbents in low carbon innovation has received little attention and support. To be sure, such international collaboration may prove more difficult for smaller enterprises and initiatives, which may understandably be focusing on their domestic situation in the first instance. But as our case studies illustrate, this is by no means always the case and there are also considerable opportunities for international collaboration and learning between disruptive low carbon innovators.

Such learning will spread via, and arise from, both formal and informal interactions. But both of these will need the construction of new platforms, whether to fund the events and outputs of the former or to facilitate the new bottom-up connections of the latter. In both cases, these platforms would provide the necessary conditions both to forge new long-term relations, building the trust and stability that are such crucial elements of encouraging the innovation and behavioural changes that will coalesce into systems transition, and to establish the structures for the *ongoing* public negotiation of socio-technical change that is the essence of sustainability.

Formal platforms could take the form of an annual international conference and ongoing research programme exploring disruptive low carbon innovation. This could build on existing major arenas for innovation policy discussion, such as Shanghai's annual Pujiang Innovation Forum. This platform would involve not just policymakers and scholars of innovation, but also the innovators themselves and other stakeholders. Sponsorship for disruptive innovators to participate in these events would encourage them to come forward themselves, solving to some extent the problem of the ongoing hunt for interesting and important examples. A high-profile set of awards (like the UK's Ashden Awards) associated with the conference could provide further incentive. And lending government support and sponsorship to such a programme would also deepen the engagement of policymakers in these learning processes and help publicise and valorise the importance of the opportunities for disruptive low carbon innovation more broadly.

Regarding informal interaction, national and international platforms for match-making innovators could be pursued, again with official government support. Active mediators may also be needed, including the work of NGOs such as GEI, especially where these interactions depend upon opening of networks to parties who have no prior connections, as will often be the case in projects focused on socio-economic development. Sponsorship of such mediation is thus another important target for policy support.

Who should pay for these initiatives at the international level? Significant contributions should undoubtedly be from developed countries, including the UK, given their moral responsibility for leading efforts to respond to climate change. Matched funding from all parties (or approximations thereof), however, does provide the best basis for productive collaborations based on mutual benefit. As is often already the case, however, this could well take the form of in-kind contributions rather than actual financial assistance, so that simply hosting these events in China would be a major step towards such parity. Both developed country sponsorship and Chinese 'matching' are thus possible.

Low carbon innovation in China is a singularly important issue for China and the world as a whole, at the heart of the key global challenges for the 21st century of sustainable and equitable development. By explicitly addressing these five considerations in the formulation of policy and hence supporting its existing strengths in 'game-changing' disruptive low carbon innovation, including via mutually beneficial international collaboration, China could lead the global low carbon transition that we need in the next 40 years.

Appendix: The Chinese low carbon game-changers

GEI (Global Environment Institute)

Name	GEI (Global Environment Institute) – Snow Mountain Organic Vegetable Corporation.
Location	Beijing and Lijiang, Yunnan Province, China.
Sector	Renewable energy and organic agriculture.
Employees	36 farmers are involved in the project.
Date started	GEI's rural biogas project in Lijiang began in 2004.
Funding	Initial funding from overseas aid funds, together with funding from Lijiang government for biogas digesters and Beijing government for technical support.
Business model	GEI is a Chinese NGO committed to setting up "market-based solutions to environmental problems to achieve sustainable development". Snow Mountain is part of a full system transition toward sustainable low carbon agriculture incorporating biogas digesters and organic vegetable farming.
Potential impact	Savings of 4.2t per year of firewood and combustion of 550m^3 of methane that would otherwise be released leads to savings of about 22 t CO_2e per household. Increasing the model to include 10,000 households would generate annual savings of about 220,000 t CO_2e. Impacts from avoided deforestation increase this figure further, as do reductions in use of mineral fertiliser regarding its production, transport and release of N_2O, which is nearly 300 times as potent a GHG as CO_2. As a result, 70 per cent of agricultural emissions come from nitrogen fertiliser.
The concept	GEI's work encourages farmers to shift over to low carbon forms of agriculture and heating, while also attending to their paramount concern of stable and higher earnings.
Brief description	Snow Mountain is a private limited company that sells organic vegetables from Lijiang farmers to markets in large Chinese cities on the coast. The farmers are aggregated into cooperatives to improve economies of scale and to increase access to finance. Stable sales of lucrative organic vegetables have increased farmers' incomes and add to the economic viability of the biogas digesters provided by GEI, which produces the organic fertiliser or slurry. The digesters also produce enough methane to service cooking requirements. This reduces demand for wood (4.2t per household per year), and so deforestation (about 8 mu or 1.3 acres or 0.5 hectares of forest per year), while also burning methane – a much more potent GHG than CO_2 – that would otherwise simply be released into the atmosphere.
Process to date	**2004-2006:** GEI begins work in Lijiang with the introduction of biogas digesters, bought from a company in Hunan and tailored by GEI to local circumstances and users' demands. Half of funding for building materials is provided by Lijiang government, the other half being demanded of the farmers. Further efforts are thus needed to make the gains from the biogas digester economically attractive. GEI accordingly sets to introduce lucrative organic vegetable farming to the farmers.

GEI (Global Environment Institute) cont.

Process to date cont.	**2006-2008:** It also establishes a number of rural credit cooperatives, involving 6 or more farmers in each case. These RCCs can access bank loans, but also can aggregate sales of their organic produce, introducing economies of scale. Organic vegetable cultivation grows to sixty mu (9.9 acres, 4 hectares), producing 80t vegetables per year. Finally, a share-holding company, Snow Mountain, is established to match sales from Lijiang with demand from Beijing, Shanghai and the Pearl River Delta. Investment in Snow Mountain includes two Chinese shareholders, three from the US and GEI itself. Snow Mountain also funds consultation and advice from Yunnan Agricultural University for training the farmers in organic agriculture. **2009:** The funding for GEI ended in December 2008. Farmers' incomes are raised by the project (some 12.5 times) and Snow Mountain continues to trade successfully. Urbanisation, however, threatens some of the land occupied by farmers with biogas digesters.
Barriers encountered	Coordinating all of the various elements of the full system transition involved was in itself a significant barrier. Such a comprehensive solution was necessary to get the farmers to engage with and commit to the changes, and hence make the most efficient low carbon use of their biogas digesters. Establishing the cooperatives was also problematic. Encouraging the farmers to participate was difficult given previous experiences of collective agriculture, and legal status for these cooperatives was only achieved after July 2007, when the central government enacted the Law on Specialised Cooperatives. Lack of funding for the project and shortage of investment remained a problem and continues to do so regarding rolling out to other locations. Poor transport infrastructure is one main consideration regarding investment – trains are usually too slow for the perishable organic vegetables, while planes will not transport cargo, only people, during winter months. Low carbon forms of transport for organic vegetables have yet to be developed, while markets for organic produce are weak or non-existent outside the largest Chinese cities, even in large provincial cities such as Kunming.
Future plans	GEI is exporting its model to other developing countries, including Sri Lanka and Laos. The success in Sri Lanka has been such that the Sri Lankan government has been concerned that all farmers will start to demand biogas digesters. Funding for these overseas ventures is available from the Chinese central government, but investment in expanding the model within China is not. GEI instead continues to look for investors, including from overseas, to pursue this opportunity.
Website	www.geichina.org

Himin Group

Name	Himin Group.
Location	Dezhou, Shandong province, China.
Sector	Solar thermal energy.
Employees	4,000+ staff in Dezhou, 50,000+ nationwide.
Date started	1992, officially incorporated 1995.
Funding	Originally established with self-funding.
Business model	Himin builds solar thermal equipment, focusing on high reliability and low cost as well as combination with other technologies to produce a range of products and solutions.
Potential impact	An average 2 sq m water tank serving a family's daily hot water needs saves 300kg coal, or 700 kg CO_2e, per year. In a population of 1.3 billion, 200 million water tanks could save 140 Mt CO_2e per year in China alone. Further emissions savings are possible from bigger boilers for public buildings and alternative applications, such as central heating, high temperature solar thermal electricity generation and industrial applications.
The concept	Solar thermal energy uses concentrated sunlight to heat a medium, usually water. As a low-cost and low carbon technology, it is an attractive option for many Chinese customers, with capital expenditure recouped within five years and free hot water or energy thereafter.
Brief description	Founder and CEO Huang Ming is not merely a green entrepreneur but a national, indeed international, celebrity. Himin Group is now the largest solar thermal company not only in China but in the world; a sector that is internationally dominated by Chinese companies. The business strategy has been to produce low-cost solutions to energy and heating that directly attract customers and so do not depend upon government subsidy. Based in Dezhou, Shandong province, the success of Himin has increasingly attracted the attention of local, provincial and national government, but the company remains self-sustaining. Competition in the industry is deemed essential and welcome.
Process to date	**1982-1992:** Huang Ming is working as a research fellow within the state-owned petroleum sector under the Ministry of Mineral Resources studying the future of mineral resources. Confronted by the size and imminence of the associated environmental problems and deeming that "commercialisation of renewable energy is the only way out", he determines to set up a company working within renewable energy. He founds a small company in the name of his research institute. **1992-2000s:** Deciding that solar thermal energy offers considerable opportunities, he starts out making solar thermal water heaters, initially by hand. As there is no government support for his ventures, he has to rely on building demand based on the attractiveness of his products and services to potential customers. Virtue is made of necessity, focusing on the strategy of negotiation and learning between producers and customers in the creation of attractive products. Significant learning experience and R&D improves the efficiency, reliability and longevity of the boilers, reduces the price and adds important services, such as installation. Himin is formally established in 1995, changing its name from Xinxing Hi-tech Co. Ltd. **2000s-present:** Himin continues to grow, with revenues rising to RMB 2 billion by 2007 and the solar thermal industry as a whole in home town of Dezhou reaching 800,000 or 30 per cent of the workforce. Government support also grows, including for R&D projects, including four projects under the national 863 programme. Himin now owns in excess of 200 patents. **2008-present:** Work begins on the Sun-Moon Mansion, a conference centre heated and powered entirely by solar thermal and solar PV energy. It is due to be completed in 2010. In recognition of the international significance of the company, Goldman Sachs invests nearly US$100 million in Himin.

Himin Group cont.

Process to date cont.	Himin also invests over RMB 1 billion in construction of two demonstration projects: 'International Environmental-friendly Energy Conservation Demonstration Zone' and 'Chinese Solar Energy Demonstration Town'. Himin also establishes a number of training centres, including: a school for professional engineers within the solar thermal industry, a second for academic engineers and a third for business managers within the industry; and a university sited on a 200,000 sq m campus, due to open mid-2010.
Barriers encountered	Lack of investment and government support from the outset posed considerable hurdles, though the low-cost and customer-focused disruptive strategy of Himin has responded to these challenges. Standards for quality control of boilers, as well as lack of governmental support for capacity building, education and training of (future) staff and R&D have also been significant issues. More recently, growth of the market has been such that the main problem is having sufficient production capacity to meet demand. As the applications for solar thermal grow, increasing demand, and sales have been concentrated to date in Shandong and surrounding provinces, problems of capacity are expected to persist.
Future plans	Himin will focus in the short- to medium-term on building market strength in other areas of China, growing capacity and developing new products in combination with solar thermal technologies. Solar buildings are considered a particular opportunity, focusing on the opportunities to use solar thermal and solar PV building materials as ways to make low carbon buildings attractive and fashionable.
Website	www.himin.com

Hangzhou ISAW Technology Corporation

Name	Hangzhou ISAW Technology Corporation.
Location	Hangzhou, Zhejiang Province, China.
Sector	Environment equipment, energy.
Employees	20.
Date started	2007.
Funding	CEO and founder Yuan Yijun funded the company himself. The national government has also provided some funds for research.
Business model	Provide core technology, equipment and service to exploit psychrometric principles for low carbon processes, including air-conditioning, energy recovery and solar desalination.
Potential impact	For energy recovery, if all the cigarette factories in China were to use this system, 100,000 t CO_2e per year could be saved. The system, however, can also be used in other industries, such as coal-fired power plants. Reduced emissions for a 1,000MW power plant would be about 40,000 tonnes of coal or 100,000 t CO_2e. For air-conditioning, a 5 per cent market share in China would save 30 Mt CO_2e. For solar desalination, one solar desalination plant with capacity 100,000 t water per day would save 1.5 Mt CO_2e per year.
The concept	Hangzhou ISAW Technology Corporation is devoted to commercialisation – including products, engineering and services – and R&D of different core technologies related to psychrometric energy (integrating solar, air and water).
Brief description	Psychrometric energy has three main applications namely, energy recovery, air-conditioning and desalination. Energy recovery includes macro and micro heat and mass cycle, the former involving a pump to drive the water that realises heat and mass transfer between the heat sink and heat source (i.e. energy recovery) while the latter relies only on the cycling of water through temperature and concentration differences. The green air-conditioning process is driven by thermal energy, such as solar or waste heat, which concentrates salt water via water evaporation. This concentrated salt water then absorbs moisture from the air and reduces the enthalpy of the air, producing a cooling effect. The process occurs under ambient pressure, without compressors or vacuums, and only water (pure and salt) is used, not other potentially polluting chemicals such as CFCs. The desalination process is also a thermal driven process, again using solar or waste heat to evaporate salty water and condense the vapour as pure water. The condensation process also releases heat, which energy is reused, hence very little thermal energy is required for the process.
Process to date	**2007:** Following an unsuccessful cooperation with a company for air-conditioning in 2006, Yuan Yijun decides to set up his own company, motivated by a vision of a large future market in green air-conditioning and energy recovery. He sets up Hangzhou ISAW in Hangzhou in order to commercialise his technologies based on psychrometric energy. Joint research with Nottingham University testing ISAW air-conditioning products begins. **2008:** ISAW air-conditioning is used in a new housing development in Shenzhen by Vanke Corporation, one of the largest real estate companies in China. **2009:** Many projects on energy recovery are carried out in cigarette factories. A solar desiccant cooling system is also contracted for the Shanghai 2010 International Expo and an India research institute. A solar desalination system is also introduced at American Beirut University.

Hangzhou ISAW Technology Corporation cont.

Process to date cont.	The cooling system produced by ISAW is introduced in a report of the World Society of Sustainable Energy Technology regarding the Masdar eco-city project in Abu Dhabi. Negotiations also begin regarding an international cooperation on solar desalination.
Barriers encountered	The Hangzhou ISAW has found attracting investment and support from government or venture capital difficult for several reasons. First, the company is too small to attract government attention and to be approved as a 'hi-tech' innovative company not sited in a special hi-tech zone. Secondly, as a small start-up, ISAW has no formal R&D centre or separate group of R&D personnel and so cannot easily apply for government R&D funding. Thirdly, the low carbon incentive policies focus on the large companies who are users of the technologies, such as cigarette factories or construction companies, not the company who is providing and innovating such technologies. Finally, ISAW's CEO is a scientist by training who is still learning how to present a business plan that will attract financial investment.
Future plans	Future plans include increasing strategic investment from venture capital and other sources, such as Earth Power Group, as well as working with other partners to improve the development of the company and diffusion of technologies. ISAW is also considering a cooperation to set up a new company in order to enlarge the market for low carbon building that includes its air-conditioning technologies. Regarding desalination, ISAW is looking for some industrial companies with which to commercialise and diffuse the technology. Regarding energy recovery, ISAW will develop its cooperation with Shanghai Chengxin Group.
Website	www.i-isaw.com

Lüyuan Electric Vehicle Co., Ltd

Name	Lüyuan Electric Vehicle Co., Ltd.
Location	Jinhua, Zhejiang Province, China.
Sector	Transportation products.
Employees	More than 2,000 in 2009.
Date started	1996.
Funding	Originally supported by Jinxin Technological Venture Capital Co.
Business model	Design, R&D, production and service of e-bikes.
Potential impact	The CO_2 emissions of an electric bicycle over 10,000km (e.g. an annual commute of 20km both ways) is around 96kg, around 5 per cent of the emissions of a car running the same distance. This gives a conservative estimate of savings of at least 1 tonne per year per vehicle.
The concept	To provide an environmentally-friendly vehicle to ordinary people in order to meet the energy challenges of China's rapidly growing economy.
Brief description	Lüyuan in Chinese means 'green power', referring to the greater (potential for) sustainability of electricity vs. petroleum. The bicycle is a popular form of transportation in China but it needs physical effort, especially uphill, and takes a long time to travel long distances. Most Chinese people cannot afford a car, but they need cheap and convenient transportation. The electric bicycle offers a solution to all these requirements. Lüyuan is not only a successful pioneer in the e-bike industry but also a leader in championing the e-bike cause in China, recognising the importance of changing existing concepts and aspirations about ways of life and helping people accept new things. Lüyuan is also a key member of the national committee for formulation of national standards on e-bikes and main components, including lead batteries.
Process to date	**1996:** After visiting a research institute in Beijing working on an electric vehicle, Ni Jie, founder and CEO of Lüyuan, decides to invest in the electric bicycles. With the support of Jin Xin Technological Venture Capital Co., after three months research and development, Ni successfully develops the first e-bike in China. **1997:** Commercialisation begins and Lüyuan Electric Vehicle Co., Ltd. is formally incorporated in Jinhua. Lüyuan e-bikes are also permitted on roads, the same as bikes, in Jinhua. **1998:** Starts to sell in Hangzhou, the capital of Zhejiang Province. Zhejiang government issues a local regulation to manage the development of the e-bike and its right to the road. Lüyuan joins the formulation of national standards on e-bikes. The year ends with Lüyuan facing bankruptcy because of the poor quality of its battery. **1999:** Bouncing back, Lüyuan's production base is established in August and it introduces the first e-bike batteries matching national standards. **2001-2005:** Lüyuan breaks into profitability in 2001, with rapid growth in this period. A serious challenge, however, comes from regulations in Beijing, Fuzhou and other cities forbidding e-bikes from roads. In the new traffic law of China issued in October 2003, the e-bike is officially classified as a kind of non-motor vehicle. **2005-2006:** Established as a pioneer of the e-bike industry, Ni Jie is elected as one of the ten best and most famous businessmen in Zhejiang in 2005. Other honours include the award of 'Zhejiang Brand'. **2007:** A new, expanded manufacturing base is opened. Lüyuan is recognised as one of 50 fast-growing companies by the magazine 'Fast Company' alongside Nike, Honda, etc. **2008:** Ni Jie authors two traffic security reports about two-wheel electric vehicles, the first such reports in China. **2009:** The central government plans to launch a new e-bike regulation to restrict the specification of e-bikes on 1st January 2010. According to this new regulation, a

Lüyuan Electric Vehicle Co., Ltd cont.

Process to date cont.	large percentage of e-bikes produced by Lüyuan (and others) will be classified as an e-motorcycle, which people cannot ride without a driving licence. The regulation would pose the most serious crisis in the Chinese e-bike industry. At the last minute, the new regulation is postponed. When it will be introduced remains undecided.
Barriers encountered	Since they are widely accepted by consumers, being inexpensive and convenient, e-bikes were approved in most of Chinese cities by 2004. The most serious barrier faced by the Lüyuan, however, has been local regulations forbidding e-bikes from roads or restricting e-bike specifications. For instance, in 2002, Beijing city government banned them on the basis that e-bike traffic was hard to manage and the batteries caused pollution. Fuzhou city government and a few others followed suit. Such debates often focus on whether the e-bike is a bicycle or a motorcycle; many e-bikes look like a motorcycle and have maximum speeds of e up to 40-50km/h. Some people also overload their e-bikes with heavy and large goods. Because of these problems, the central government formulated a new standard for e-bikes in 2009 following long consultation from 2004. Under the new standard, e-bikes with maximum speed above 20km/h and weight above 20kg are to be classed as electric motorcycles, not electric bicycles. Riding these e-motorcycles requires a driving test, as for a car. Introduction of this new regulation would significantly reduce demand. Lüyuan is responding by developing technology to restrict the maximum speed and to reduce the possibility of illegal reequipping.
Future plans	Despite the regulatory challenges, Lüyuan is continuing to build its R&D programme, including development of three-wheel electric vehicles for the disabled and elderly and design of a cheap and convenient system to reequip a normal car as an electric vehicle.
Website	www.luyuan.cn/ www.luyuan-ebike.com

Pearl Hydrogen

Name	Pearl Hydrogen.
Location	Shanghai.
Sector	Energy, Transport.
Employees	25.
Date started	2006.
Funding	Initially funded by Angel Investment fund. Further venture capital is expected in early 2010.
Business model	Target existing market opportunities for fuel cells, together with significant simplification of the technology, allowing time to develop the technology and new products.
Potential impact	In portable applications and UPS, fuel cells will replace lead-acid batteries with both lead pollution and energy savings, due to the higher efficiency of the recharging process. One 1 kW fuel cell, average operating time about 300 hrs per year, can generate about 200 kWh electricity. The efficiency is twice that of an internal combustion engine, so one 1 kW fuel cells can save about 40 kg standard coal (94kg CO_2e).
The concept	A simplified fuel cell targeted at applications for which there is already an economic case, rather than targeting the familiar goal of electric vehicles from the outset.
Brief description	Fuel cells are usually cooled by a water-based cooling system, which adds considerable complexity to the fuel cell stack as well as weight. Pearl Hydrogen has developed a way to cool the fuel cell using air, thereby using the same channels for the fuel cell reaction and the cooling process. This reduces costs of production and also cuts accessory energy costs. The core technology is a catalyst-coated membrane that allows air-cooling, leading to a fuel cell with higher efficiency. The company has decided to target applications for this technology in the first instance that are immediately profitable, rather than focus on development of a fuel cell vehicle – the usual goal of fuel cell companies. Three applications have been identified and developed to date, namely: stationary 'uninterrupted power supply' (UPS) emergency back-up generators, e.g. for telecommunication base stations; an electric bicycle and other niche transportation equipment; and a portable power source.
Process to date	**2006:** The company is founded by Brian Tian and Dong Hui, following R&D work since 2003 at other Chinese fuel cell companies. A 200W prototype fuel cell is developed. **2007:** The prototype is converted into a 200W product. This is integrated into an electric bicycle in collaboration with Celimo, a Chinese bicycle manufacturer. In 2008, the bicycle makes its debut in European market. Work also continues on integrating fuel cells in more powerful stacks for alternative applications. In 2009, Pearl puts importance in the application of UPS and works with ZTE to draft out Chinese standard for fuel cell powered UPS. In 2010, some samples will be complete by Pearl and its partners. Market research is conducted regarding the most profitable applications for the technology, with UPS as the most obvious candidate. R&D and testing of the fuel cell also continues, improving the technology and demonstrating its high reliability, high efficiency and low cost. **2008:** The electric bicycle Green Angel is displayed at the Zaragoza International Expo. The bikes go on sale in China with a view to targeting markets in Italy and elsewhere in Europe. Fuel cells of 2000W also goes on sale, targeting the UPS market in China and south east Asia. Major contracts are signed with private industrial intermediaries to provide UPS fuel cells to major Chinese telecom SOEs. **2009:** A collaboration with Imperial College, London is established for the development of a racing car powered by Pearl's PhyX-4000 fuel cells for the 'Formula Zero' race.

Pearl Hydrogen cont.

Process to date cont.	Pearl is also approached by an Italian company Acta, listed on the London AIM stock exchange, for collaboration in the development of a full system solution for a hydrogen fuel cell bicycle. Acta produces a high-pressure electrolyser that allows home generation of the hydrogen fuel source for the bicycle's fuel cell from the user's tap water. A further collaboration with Acta Energy develops a portable hand-held power source powered by Pearl's fuel cells with power range between 50W~5kW. **2010:** A 10kW fuel cell is expected to be applied in niche transportation tools.
Barriers encountered	Although commercialisation in niche transportation and the UPS field is considered easier than for the car industry, government and investors put less importance on the two industries.
Future plans	In the near future, Pearl will continue to focus on UPS and the niche transportation industry. Some demonstration of fuel cells-powered UPS will be carried out in 2010 in China. In the next two years, Pearl will work with its partners to develop more applications in niche transportation: small boat, bicycle, golf car, forklift and so on.
Website	www.pearlhydrogen.com

Beijing Shengchang Bioenergy S&T Co. Ltd

Name	Beijing Shengchang Bioenergy S&T Co. Ltd.
Location	Beijing, China.
Sector	Biomass energy.
Employees	160.
Date started	February 2006.
Funding	Self-funding and Government funding for individual projects.
Business model	Production of biomass pellets from agricultural residues and biomass combustion equipment, focusing on local collection of raw materials and distribution of pellets.
Potential impact	Domestic boilers save about 10 t CO_2e per year, the patented cooking stove saves about 1.2 t CO_2e per year and industrial/ building heating boilers save about 265 t CO_2e per heating season, in each case compared to coal combustion.
The concept	Under the slogan "We care and we do biomass" Shengchang aims significantly to reduce carbon footprints from heating and cooking by providing locally sourced biomass pellets to replace coal.
Brief description	Biomass pellets are made from a range of agricultural residues, including wood chips, corn and cotton stalks and peanut shells. These are collected from farmers within a 20km radius of the pellet-making plants, delivered by the farmers themselves in return for RMB 160 per tonne. By turning these residues into efficiently burning feedstocks, inefficient combustion of both coal and the residues themselves on the farm is avoided. Pellets are then delivered by the company to customers, either in 50kg bags or, for industrial users, in a specially adapted truck as bulk. To ensure maximal efficiency of the combustion of the pellets, Shengchang has also developed its own boilers, using technology from Tsinghua University in Beijing that was not otherwise commercialised, and a patented cooking stove. Tests have been done by third parties (including Tsinghua) regarding emissions from these boilers using Shengchang pellets with very favourable results regarding emissions vis-à-vis coal (see above). SO_2 savings are also considerable, at less than 10 per cent of coal combustion. Both the boilers and the fuel are also relatively low-cost and an economical option for both individuals and business customers. The pellets are sold at RMB 550 per tonne (versus RMB 950 per tonne for coal at 2008 prices) and only about 25 per cent more by mass is needed. The boilers are also cost effective, especially with a RMB 300 subsidy for the RMB 400 cost from the Beijing municipality, while the stoves sell at under RMB 200 each.
Process to date	**2006:** Shengchang is founded by CEO Fu Youhong, building on his entrepreneurial experience in the pharmaceutical industry and motivated by environmental concerns in rural areas. He conducts extensive research in China and Europe regarding options for renewable energy. Biomass is chosen from the various possibilities as an industry with potentially significant GHG emissions reductions, this being the priority. Were profit the primary consideration, wind or solar would have been chosen instead. A demonstration plant making 4 t/day biomass pellets from sawdust is set up in Lixian, a rural county of Beijing, with support of the Ministry of Agriculture (MoA). **2007:** Following success of the demonstration project, two further plants are established, also in rural counties of Beijing. Subsidies for pellets are provided by the Beijing government at RMB 147 per tonne. Residues are bought at RMB 160 per tonne and sold at RMB 550 per tonne, with three tonnes of residue making one tonne of pellets to start with (this ratio has since improved to 1.2:1). Over the summer, 200 students, funded by the Beijing municipal government and MoA, conduct a transport feasibility study. The report, in January 2008, concludes that plants must be within 20km of farmers if they are to consider delivering residues worthwhile. R&D continues and an Engineering Technical Centre is established.

Beijing Shengchang Bioenergy S&T Co. Ltd cont.

Process to date cont.	**2008:** A boiler factory is established in Daxing Industrial Development Area in south Beijing, manufacturing domestic and industrial hot-water boilers and a patented cooking stove, which is targeted to replace the inefficient coal-burning stoves that are used everywhere across China. The combustion equipment has been developed by Shengchang. **2008/9:** Big projects include a greenhouse project at Zhangziying, with 400 boilers heating 200 greenhouses; an industrial boiler to heat the Economic Times building (18,000 sq m, 2.1MW); a successful demonstration house in Tongxian district using biomass together with solar power that leads to the 'Double Hundred' project to build 100 biomass-solar public bathrooms for farmers in 100 villages; and an industrial demonstration in Daxing district of Beijing (0.7MW). Sales of both pellets and boilers are solicited from across China (e.g. Hubei, Hunan, Heilongjiang, Guangdong, Tibet), and five sets of negotiations to establish new plants are entered into. To meet this demand, a pelleting-machine factory is established in Haidian district, Beijing. The company is moving steadily towards profitability (regardless of government subsidy).
Barriers encountered	Encouraging farmers to change their routines and habits and shift towards both selling their agricultural residues and using biomass boilers instead of coal has been difficult. Government has provided considerable support, in the form of the transport survey, pellet subsidy, boiler subsidy and funding for some R&D. Experience with the new boilers has also served to encourage other farmers to follow suit, especially due to the reduction in smoke, which improves the living environment. The business model was not immediately viable without government support but is quickly moving into profit. Fu was lucky enough to have good contacts from his former work in the pharmaceutical industry to access such support. However, continuing government support for the coal industry undermines the economic case for shifting to biomass, just as it presented Shengchang with a closed system into which it had to break when starting out. And most government attention in renewable energy is focused on solar PV and wind.
Future plans	Shengchang plans to expand its locally sourced biomass model across China, following on the openings already under negotiation. As people become more aware of the problems – ecological and economic – associated with coal and oil and experience shortages of energy (e.g. during the cold snap at the end of 2009) growing demand for alternative energy sources is expected. Despite some interest from Europe, it is not at this stage deemed strategically worthwhile to pursue opportunities overseas. Long-term plans focus on building strategic partnerships with biomass electricity generating projects.
Website	www.bj-sbst.com

Beijing Sinen En-tech Co. Ltd (ZNHK)

Name	Beijing Sinen En-tech Co. Ltd (ZNHK).
Location	Beijing, China.
Sector	Energy efficiency and water purification.
Employees	The company has five branches and five offices across China, an experimental base, an R&D centre at China University of Petroleum and its Beijing headquarters.
Date started	2004.
Funding	RMB 600,000 from founder CEO Yang Yucheng and partners, followed by further RMB 2 million from a Xinjiang investment company.
Business model	ZNHK is the leading company in China (and worldwide) offering high-temperature filtration and recycling of water from industrial processes that meets new Chinese national standards of water purity.
Potential impact	A typical industrial plant using 100t/hour of steam will save 8400t of coal per year (≈22,000 t CO_2e per year) by reducing the energy demands on heating cold water. Water use is also significantly reduced – another significant impact given existing strains on water usage. Twenty plants have been fitted in five years to 2009, and installation has been improved, reducing the time it takes from three months to one. Accordingly a total of 60 plants could easily be completed by 2015. Total annual GHG emissions reductions would then be 13.2 Mt CO_2e.
The concept	ZNHK reduced emissions from industrial plants by reducing the energy consumed in heating water into steam. Yang's tenet for the company is "resources saving and environmental conservation with benefits".
Brief description	Many industrial processes involve huge volumes of water being converted into steam. This both uses significant amounts of energy and contaminates the water, which must then be treated before legal release. In China, 70 per cent of this water is discarded while 30 per cent is recycled back into the industrial process. However, cleaning this water usually involves cooling the water first in order to be effective. Accordingly, recycling still generally requires wasting the energy of heating the water. ZNHK has developed a patented filtering technology – an ultrafine membrane filter combined with adsorption by microfibres – that allows filtering to take place at elevated temperatures while also filtering the water to exceptionally high standards. As 1 per cent fuel is saved for each 6°C, this has significant impacts on overall emissions from these plants. Cost savings from reduced fuel and water consumption are also considerable, allowing capital expenditure to be recovered within one year.
Process to date	**1980s-2004:** Yang Yucheng works for large petrochemical Sinopec in research on energy saving and conservation, together with colleagues from China University of Petroleum. There he develops the core water treatment membrane technology. **2004:** Yang sets out on his own to commercialise the technology. There is no interest in investing from banks, a fledgling venture capital sector or the government but Yang manages, with partners, to raise RMB 600,000 of their own money. This is followed by a RMB 2 million investment from an investment company in Xinjiang specifically interested in the technology. The company achieves certification as a high-tech enterprise in Beijing's Zhongguancun, following legislative revisions by central government that include environmental technologies under the title of 'hi-tech'. **2005-2007:** Projects begin, with ZNHK targeting Sinopec and other petrochemical SOEs as initial customers, given that directives from central government to deal with energy efficiency creates the necessary demand for their product and services. Learning from these projects improves the technology and the service, while R&D continues separately on associated applications. Profitability is reached in 2006. New and higher water standards are also introduced, with Yang sitting on the committee.

Beijing Sinen En-tech Co. Ltd (ZNHK) cont.

Process to date cont.	**2008:** Business continues to grow, revenues reaching RMB 35 million, and the company is awarded a number of honours including: certification as a national hi-tech company; a cover story in Forbes China; and high rankings in Deloitte's 'high-tech with high-growth' rankings for China and Asia-Pacific. Technologies continue to be improved, for example, an on-line monitoring system developed to shut off and redirect water flow in the event of higher than normal concentrations of pollutants in the filtered water. **2009:** ZNHK grows to four branches and five sales offices across China. Negotiations with overseas companies also begin for introduction of the technology to the US and for establishing a leasing company to increase the financial attractiveness of the service.
Barriers encountered	When founded in 2004, attracting start-up finance was very difficult and, in the end, abandoned. Much has changed in China since then regarding both the overall attractiveness of investment in energy efficiency and growth of the venture capital sector. However, investment remains by no means straightforward. Accessing the financial and fiscal benefits of 'hi-tech' status was also crucial to the company, especially in its early stages. This was only possible, however, following a redefinition by central government in late 2004. The strategy of using SOEs, primarily from the petrochemical industry, as initial customers has been successful, but is entirely dependent upon central government policy setting energy efficiency as a priority. Accessing the broader market of smaller and/or private companies in which government directives have less sway has proven more of a challenge, but improving their service and product through accumulated experience is crucial in this regard.
Future plans	ZNHK is developing its sales across China and moving beyond petrochemical companies to increase sales in other industries that use steam boilers. As 95 per cent of production boilers in China use steam, 70 per cent of the market would amount to RMB 25.2 billion.
Website	www.znhk.com

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Names

Chinese names are presented throughout the report in standard Chinese order of 'surname-first name', unless the person has an English first name.

NESTA Making Innovation Flourish

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