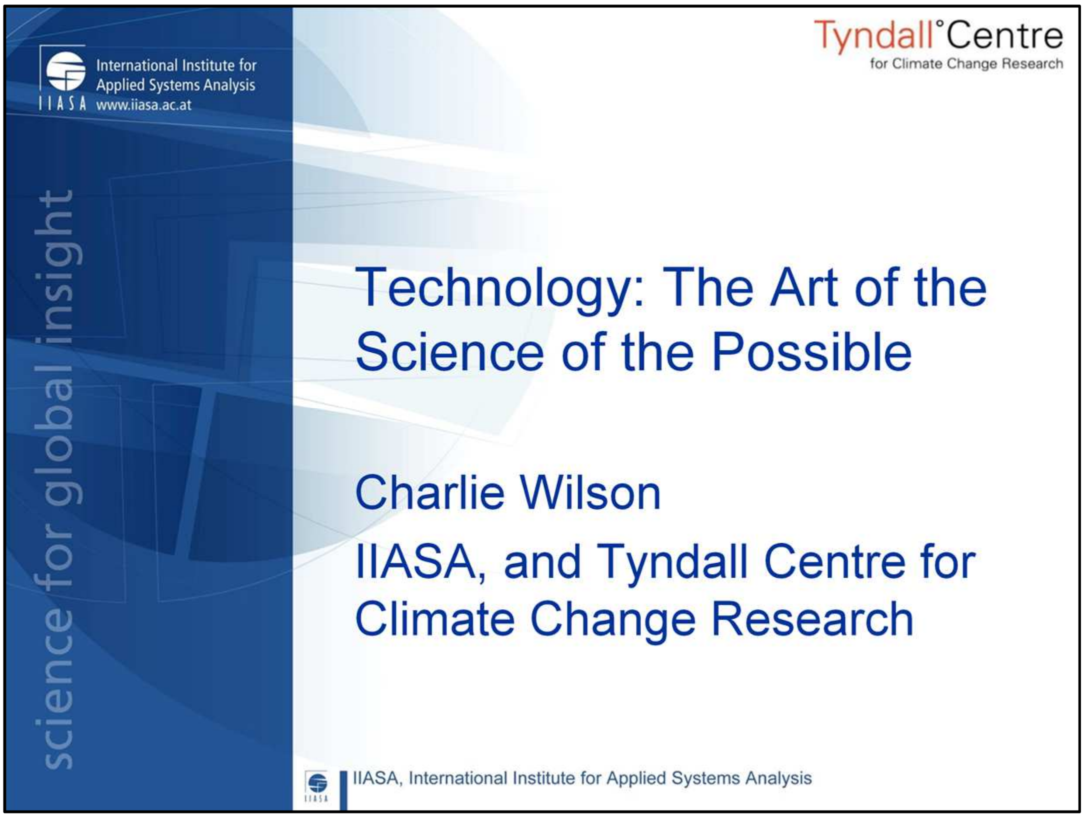
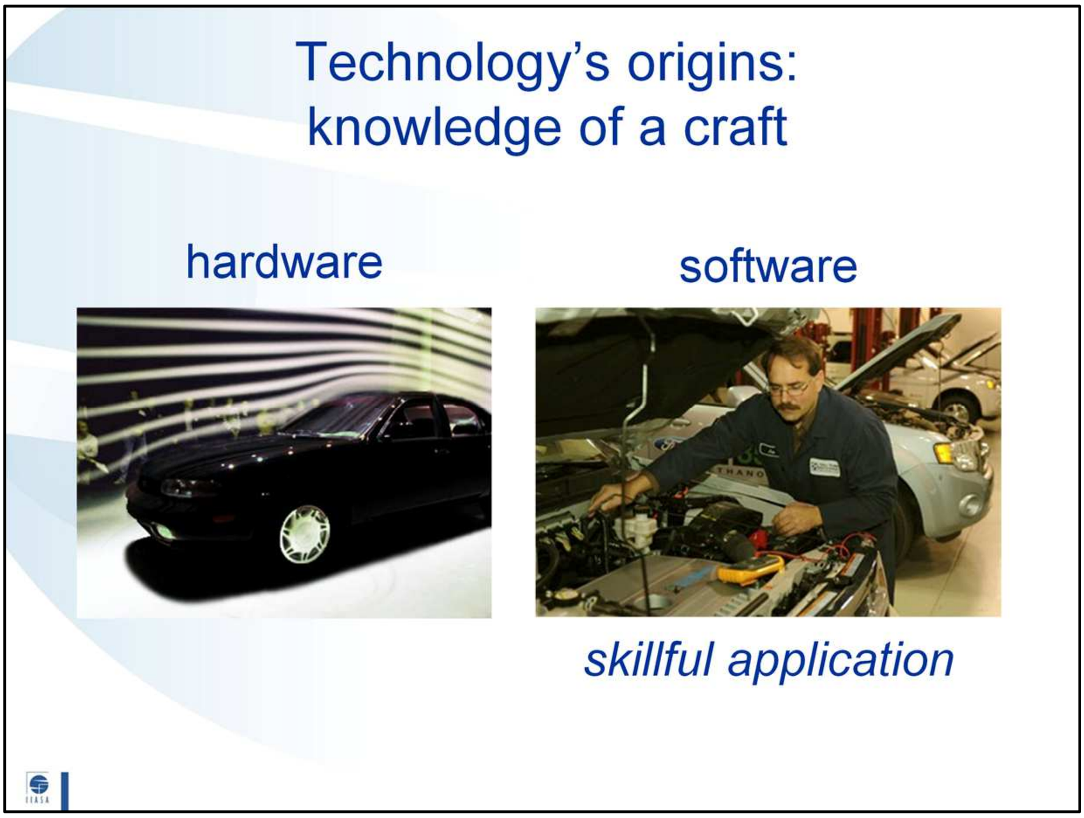


Good afternoon.

Technological change is central to economic growth, to societal development more generally, and is both cause and cure for the environmental impacts of growing populations and affluence.

In this talk, I want to add a particular view of technology as both *art* and *science,* and how both these views help understand technology's role in shaping *possible* futures.



Technology is most immediately thought of as *hardware*, devices, machines.

Technology is also *software*: the know-how and know-why embodied in *people* with skills or experience.

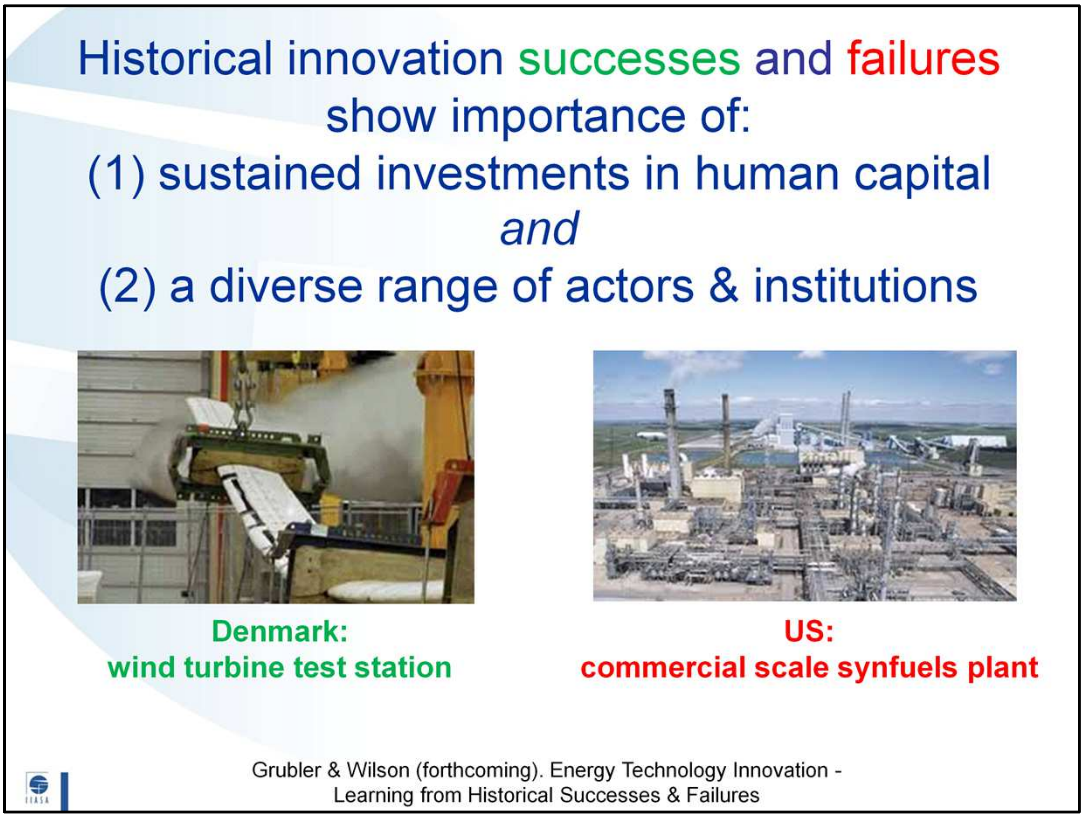
Thinking of technology as *skillful application* underlines the importance of human capital as noted by the previous speaker.

It also points back to the origins of technology in the Greek words:
logos = reason or knowledge
techne = art or craft

Technology appears sometimes *literally* as art. Hundertwasser's cladding of Vienna's waste incinerator will be well known to the locals among you.

More broadly, the *artisanal* characteristics of technology - or "knowledge of a craft" - reminds us that like other forms of knowledge, technological knowledge can be generated and learnt ...

... but also *forgotten* through obsolescence, depreciation, and turnover in human capital.



As part of the Global Energy Assessment, Arnulf Grubler at IIASA led a comparative assessment of energy innovation historically. One aim was to distill out the essential ingredients of innovation success.

Sustained investments in the human capital which underwrites technological knowledge was one such ingredient.

The 20 historical case studies we analysed, to be published soon in a new book, covered both relative innovation successes and failures.

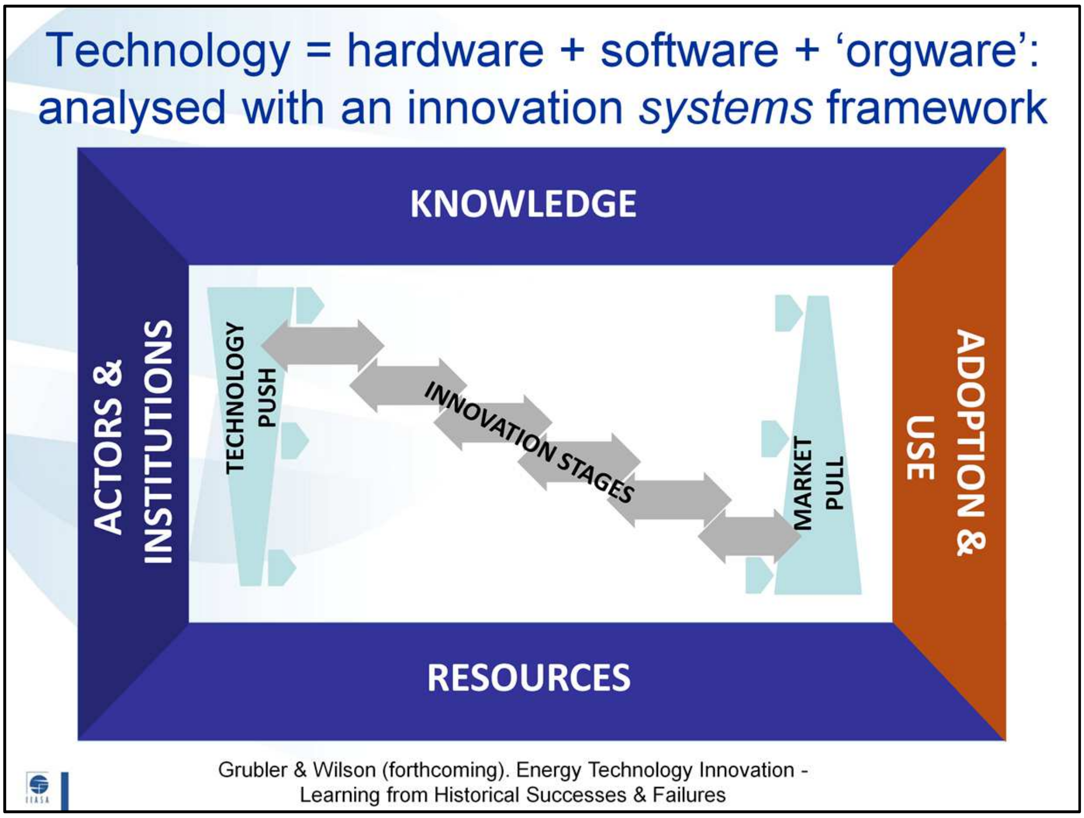
The Danish wind turbine industry is a good example of success.

The US programme to develop synthetic liquid fuels in the 1980s is an example of relative failure, as measured by its own goal of reducing US dependence on imported oil.

A second essential ingredient of innovation success, which links to the importance of human capital, was that effectively functioning innovation systems involve a diverse range of actors and instittions, well beyond the usual suspects of R&D labs and commercial markets.

The Danish case study is illustrated here not with a stirring picture of turbines sweeping the land or seascape, but with a picture of a blade being tested at a turbine test station.

This was one of the public institutions involved in generating and exchanging knowledge during the successful development of a world leading industry.



Knowledge, human capital, actors and institutions, are all integral elements of innovation *systems.*

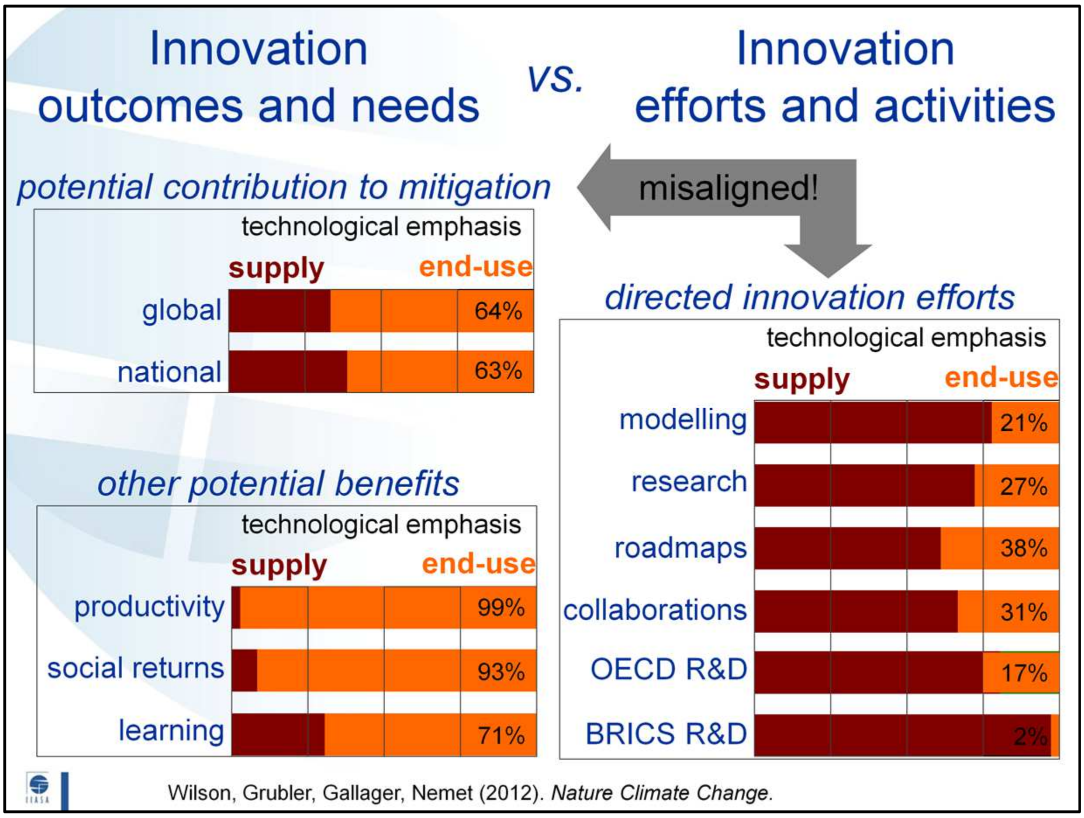
The hardware and software of technology are created and used in particular contexts: institutional, infrastructural, or organisational, giving rise to the term 'orgware' as coined orginally by IIASA scholars.

We captured these contextual characteristics of technological change in a framework comprising
innovation stages - from research and development through to commercial deployment,
innovation drivers - both technology-push and market-pull,
and *innovation processes* which link and contextualise these stages and drivers:

These processes are many and varied, relating
to *knowledge*, and its generation and use,
to *actors and institutions*, with their risk appetites and expectations,
to the *mobilisation of resources*, both financial capital and human capital,
and to the *adoption and use* of technologies.

This innovation systems framework not only allowed us clearer insights into why some innovations had succeeded historically where others had failed.

It also gave us a comprehensive and transparent way to analyse *current* innovation activities.



We looked first at the *respective contributions* to climate change mitigation of *energy supply technologies* - like power plants and refineries - and *efficient end-use technologies* - like vehicles and appliances.

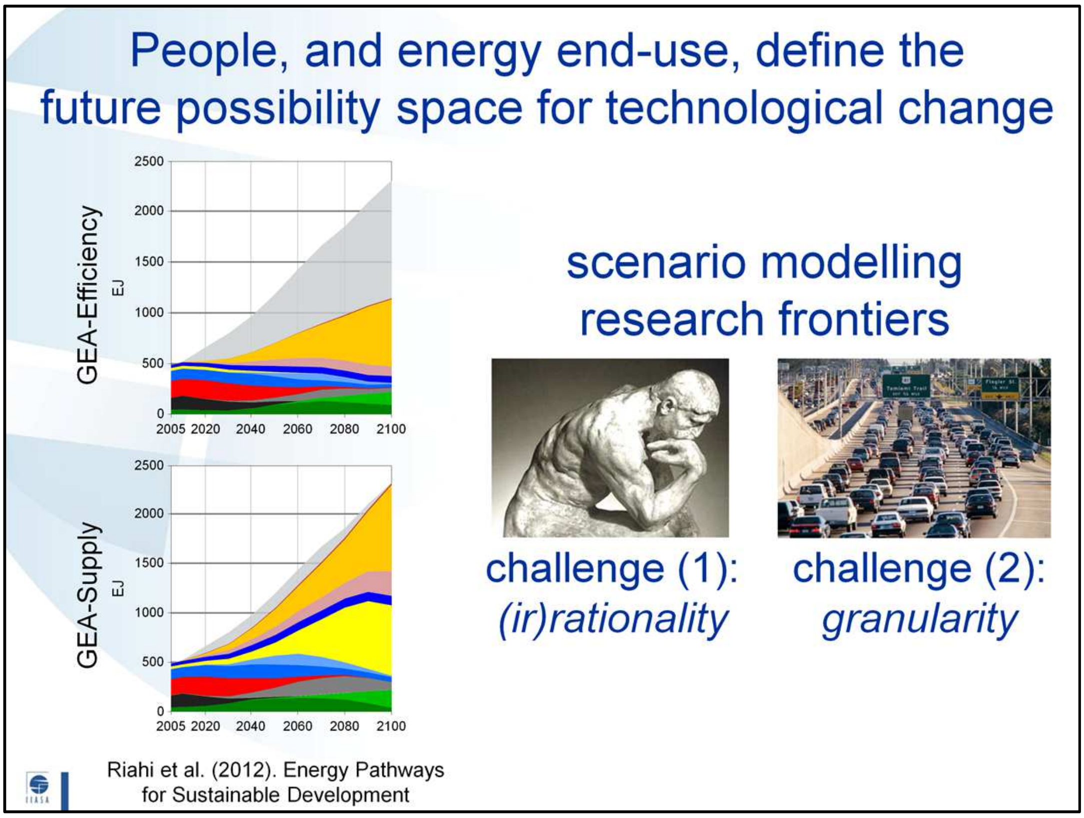
Global and national modelling studies show changes in energy end-use may contribute over half of the required reductions in greenhouse gas emissions.

Efficient end-use technologies also out-perform their energy supply counterparts in terms of:
their impact on economic productivity,
their broader environmental, social, and energy security benefits,
their potential for learning to improve cost and performance, and hence market appeal.

We then asked: how well *aligned* are current innovation efforts being directed by public institutions, policies and resources with these clear potentials for efficient end-use technologies?

We sampled a wide range of data describing all the elements of our innovation systems framework. A few of these are shown here.
we looked at knowledge including modelling and research,
we looked at institutions including technology roadmaps which enshrine shared expectations, and also international technology collaborations, both bilateral and multilateral,
and we also looked at resources including financial investments in both developed OECD countries as well as in the major developing or BRICS countries.

As can be seen, this systemic analysis reveals a striking misalignment between innovation *outcomes and needs* - which emphasise energy end-use technologies - and the *efforts and activities directed to meet those needs* - which emphasise energy supply technologies.



This is important because *current* innovation efforts circumscribe the *future* possibility space for technological change.

Modelling and scenario analysis work at IIASA as part of the Global Energy Assessment has found efforts to improve end-use efficiency dramatically increase the options available for the energy supply, and so insure against possible innovation failures.

The GEA-Efficiency pathways with potential energy savings - represented by the grey block - allow flexibility in *which* and *how much* energy resources are used - represented in the coloured blocks.

The GEA-Supply pathways which lack these large and sustained energy savings have no such flexbility.

Innovations in energy end-use thus insure us against potential innovation failures in any of the silver bullet energy supply technologies.

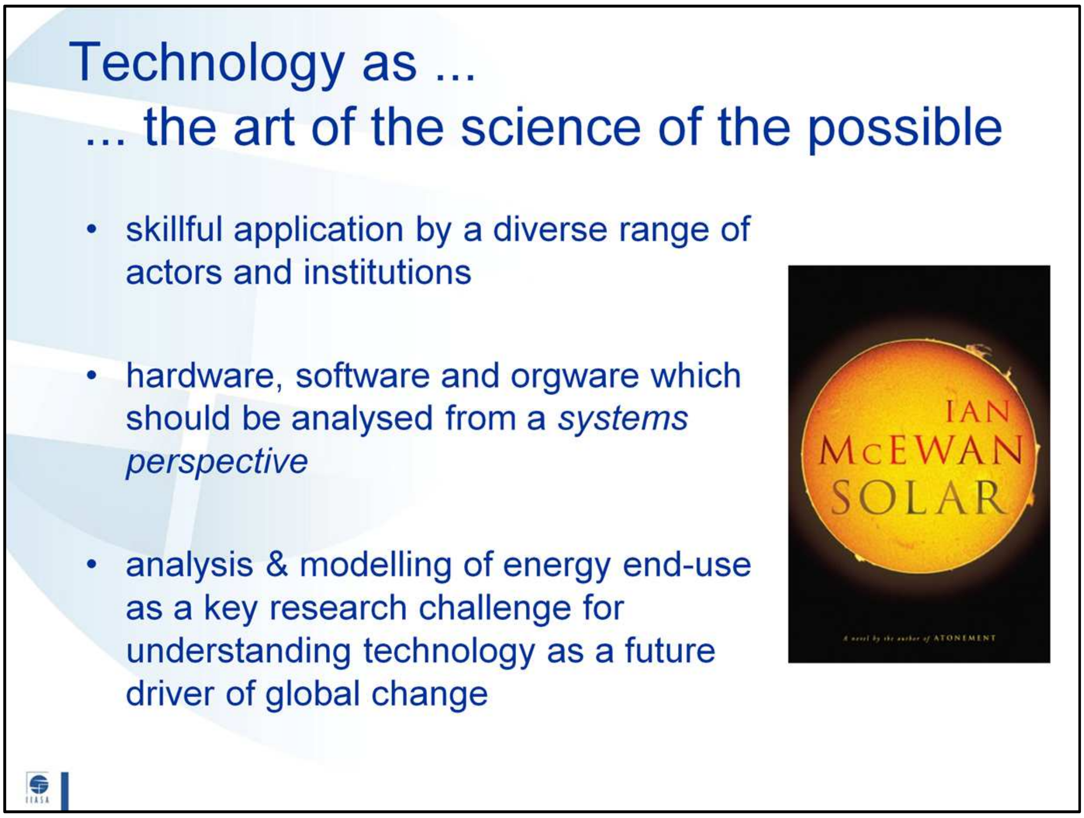
Two of the research frontiers for improving our analysis of energy end-use relate to how we understand, represent, and model *people* ...

... with all their delightful irregularities, or more soberly, their irrationalities.

These are particularly relevant given the *granularity* of end-use technologies: they are small-scale, large in number, dispersed, and highly heterogeneous.

Work just beginning at IIASA led by Keywan Riahi aims to develop the next generation of models by progressing on both these frontiers ...

... and in so doing, help resolve more clearly the future possibility space described by technological change.



In conclusion, I have argued for a view of technology ...

as artisanal, skillful application, both learnt but also forgotten without sustaining investments in human capital,

as hardware, software and orgware which can be analysed and directed ... or potentially, mis-directed as suggested by our analysis of current innovation systems for climate protection.

and technology also as the possible ... because the way technology and people interact will shape the unfolding future of a warming planet.

This is the central theme of the English writer Ian McEwan’s novel “Solar”, another treatment of technology through the lens of art.

The book is woven around a breakthrough solar technology heralded as a silver bullet solution for climate change.

But its protagonist, the solar power entrepreneur, has a personal life of *insatiable appetites* and gluttony.

He thus serves as a darkly comic allegory for our collective conflicted capacity to rein in the consumption *enabled by technology* ... when the signs are all warning to do just that.

The book thus sheds an awkward light on the co-dependencies of people and technology.

Thank you.