Energy systems modelling for 21st century energy challenges

Dr Adam Hawkes CEng MEI
Deputy Director, Sustainable Gas Institute

The SGI will lead research and define innovative technologies that enable natural gas to play a key role in a low carbon world.

SGI Hub and Spoke Integration

PROVIDES INTEGRATING RESEARCH, TRANSLATION
AND EDUCATION ACTIVITIES

SGI Spoke:
Gas Innovations

SGI Spoke:
Energy Efficiency

SGI Spoke:
Carbon Capture,
Storage and Use

New SGI Spoke:
???

50%

SGI HUB RESEARCH THEMES

Gas Technology Modelling Environment
Sustainable Gas Technology
Gas and the Environment
Gas in Future Energy Systems

35%

SGI HUB KNOWLEDGE TRANSFER (TRANSLATION)

15%

SGI HUB EDUCATION

Gas Innovations Collaboration

Gas Innovation Theme

Gas Innovation Centre: BG Group / FAPESP / University in Brazil: $10m + $10m

ENGINEERING PROGRAMME

- Compact "low carbon" natural gas power generation
- Natural gas/hydrogen fuels for shipping
- Associated developments to optimise use of natural gas in shipping
- Techniques to measure, evaluate and reduce methane loss from gas systems

PHYSICAL CHEMISTRY PROGRAMME

- Advanced cleaner natural gas combustion
- Fuel Cell developments
- Conversion of natural gas to chemicals e.g. H_2, CO & NH_3

POLICY AND ECONOMICS PROGRAMME

- Policies for the development of gas in energy systems
- Development a supply chain for natural gas for remote areas

Systems & infrastructure

New applications

Gas-fuelled transport

Power generation

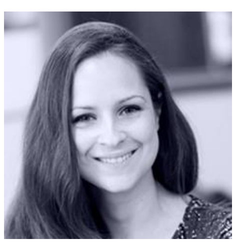
Gas Innovation Fellowship Programme: BG Group / Imperial / Univ. of Sao Paulo
20 PhD students + 5 x 4 year Post-docs

The SGI team

Directors

Nigel Brandon– Director

Adam Hawkes – Deputy Director



Victoria Platt – Ops Director

Research

Sara G – Modelling Lead

Kris – Tech. Lead

Daniel - Modelling

Daniel - Tech

?

PDRA - Demand

Sara B- Tech

PhD

Jonny- UK

?

PhD – Cecilia

?

PhD – Cheng-Ta

Contents

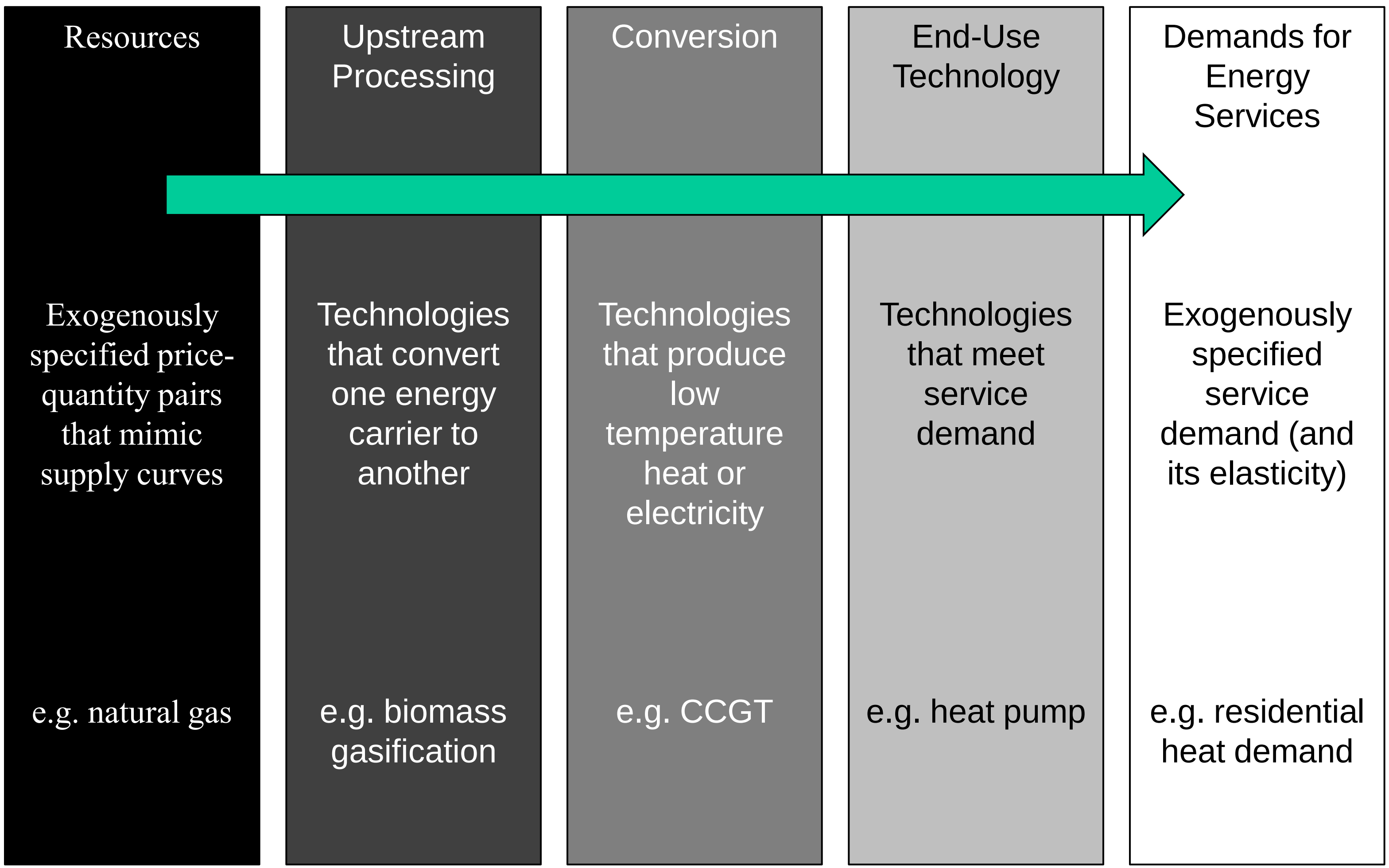
- What is energy systems modelling? Why do we care about it?
- A taxonomy
- Fit for purpose?
- Activity at Imperial College
  - MUSE
  - TIAM-Grantham
- New challenges

What is energy systems modelling?

Remember that all models are wrong; the practical question is how wrong do they have to be to not be useful.

George Box

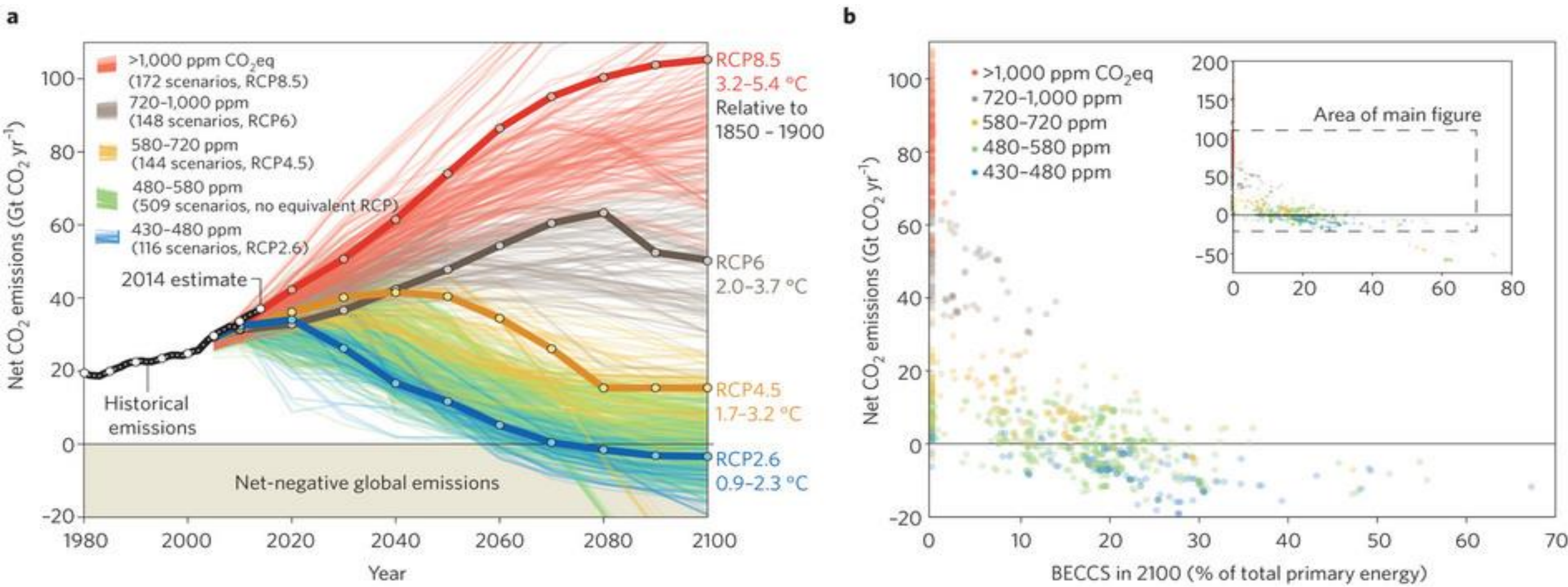
Reference Energy System



What is energy systems modelling?

IPCC 5th Assessment Report

- 1184 scenarios were produced from 31 whole system models
- Quantitative basis for working group 3 conclusions (mitigation)

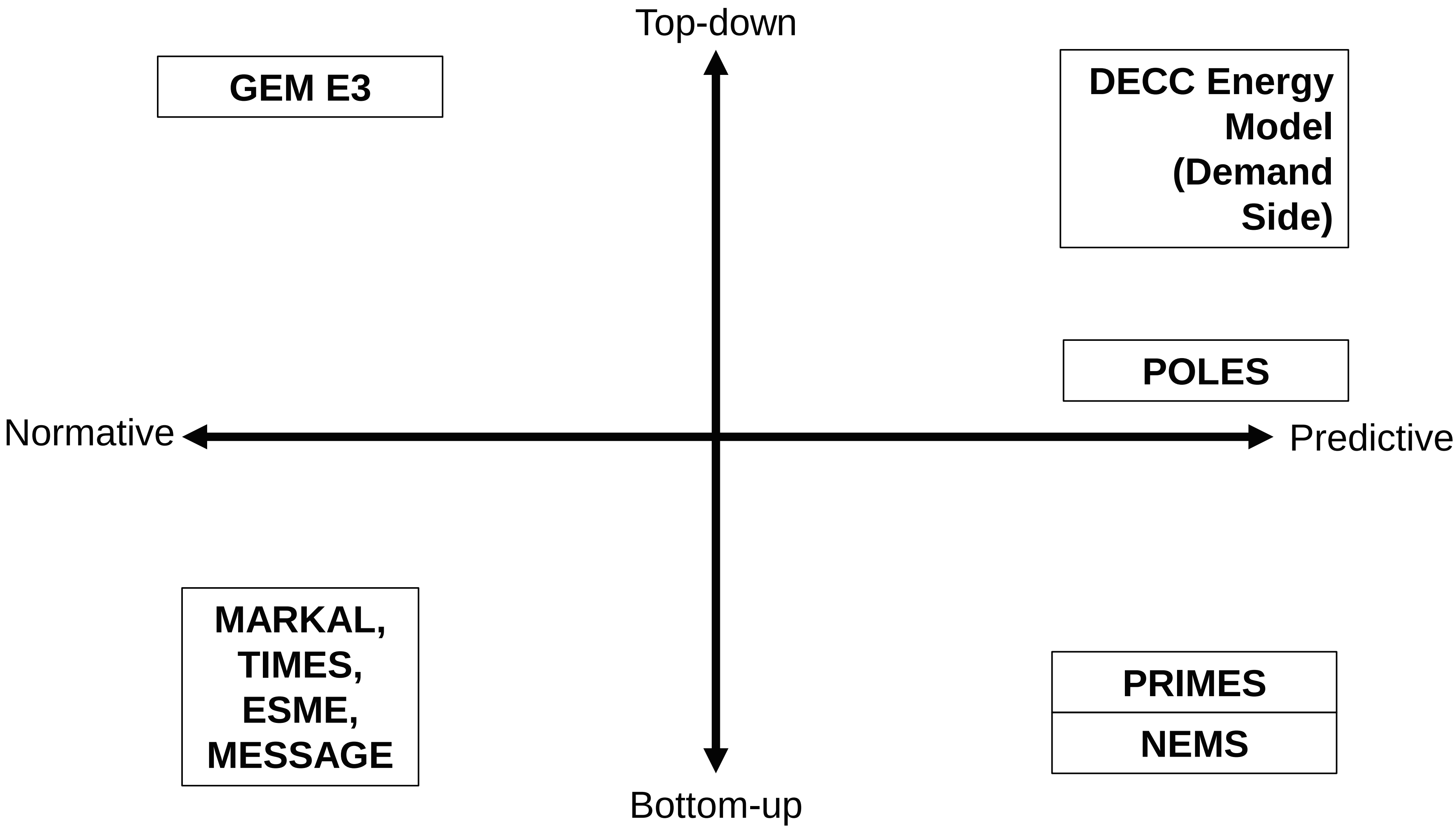


Source: Fuss et al (2014) Betting on negative emissions. Nature Climate Change 4, 850–853

A taxonomy

Normative	–	Predictive
General equilibrium	–	Partial equilibrium
Top-down	–	Bottom-up
Myopic	–	Perfect foresight
Central planner	–	Multiple agents
Deterministic	–	Stochastic
Supply-side focus	–	Demand-side focus

One energy modelling axis

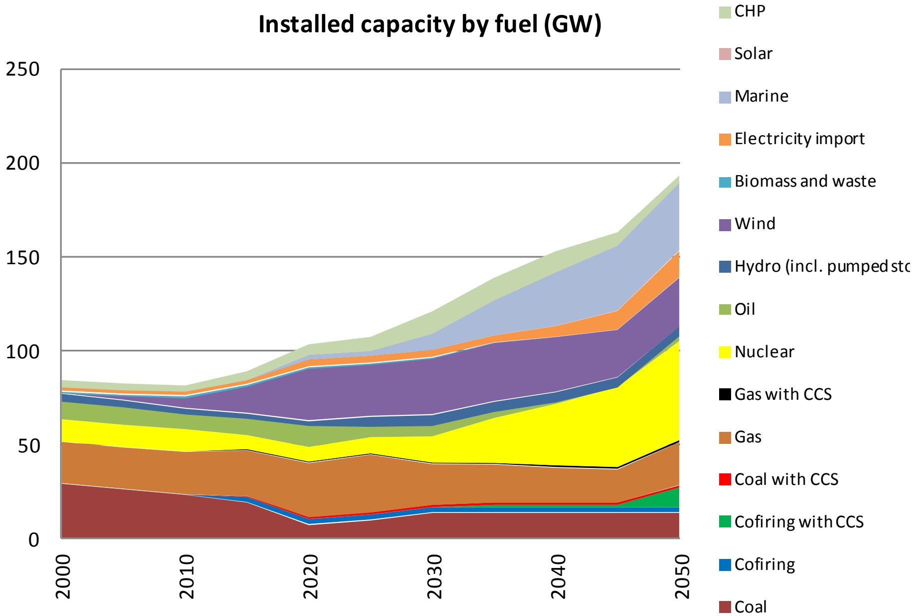


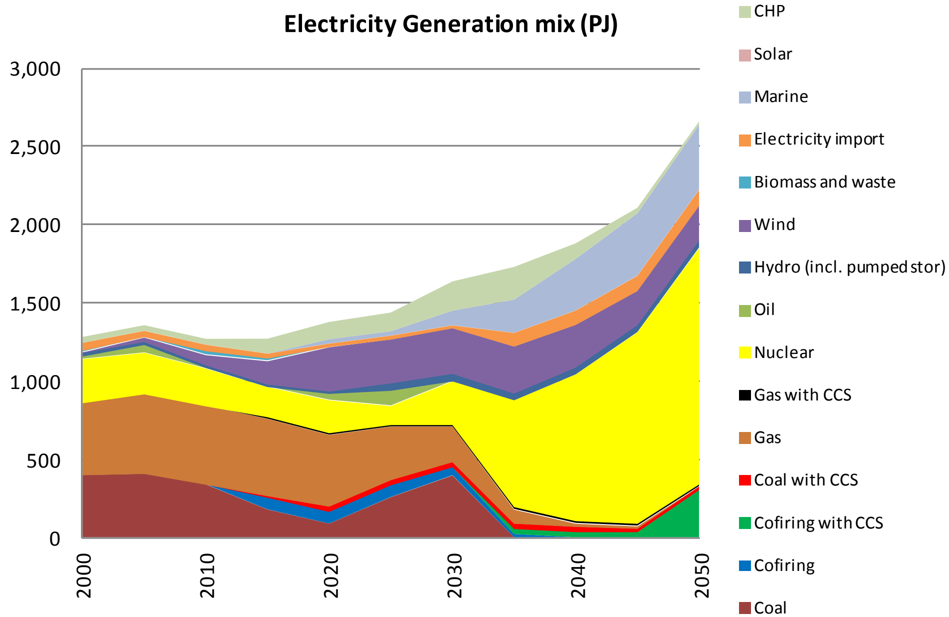
Fit for purpose? Recent criticisms

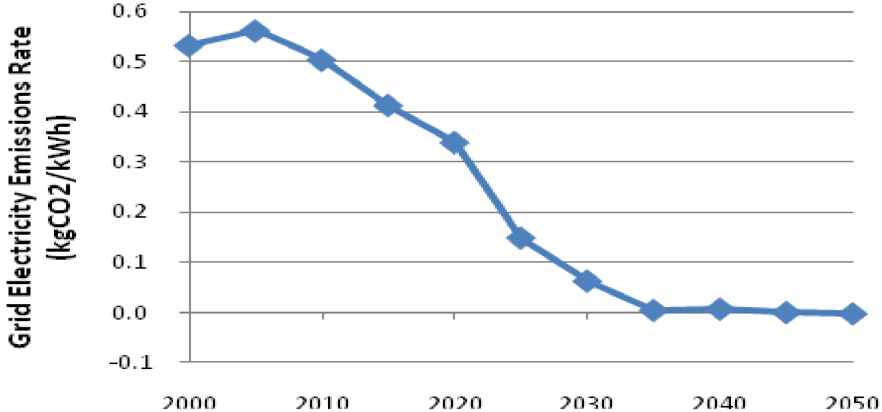
- Richard A. Rosen, Critical review of: “Making or breaking climate targets — the AMPERE study on staged accession scenarios for climate policy”, Technological Forecasting and Social Change, Volume 96, July 2015, Pages 322-326
  - Differences between models not treated in a systematic and credible way
  - Fundamental impossibility of forecasting

- Robert S. Pindyck, The Use and Misuse of Models for Climate Policy. NBER Working Paper No. 21097. Issued in April 2015
  - Perception of knowledge and precision that is illusory
  - Can fool policy-makers into thinking that the forecasts the models generate have some kind of scientific legitimacy
  - Monte Carlo buys us nothing

Fit for purpose? e.g. Power Generation







- *Key role for nuclear power towards 2050*
- *Supported by co-firing (coal + biomass) with carbon capture and storage*

Lies my MACC told me (1) – technology optimism

- Nuclear Fusion, Energy Efficient Lighting, Loft Insulation

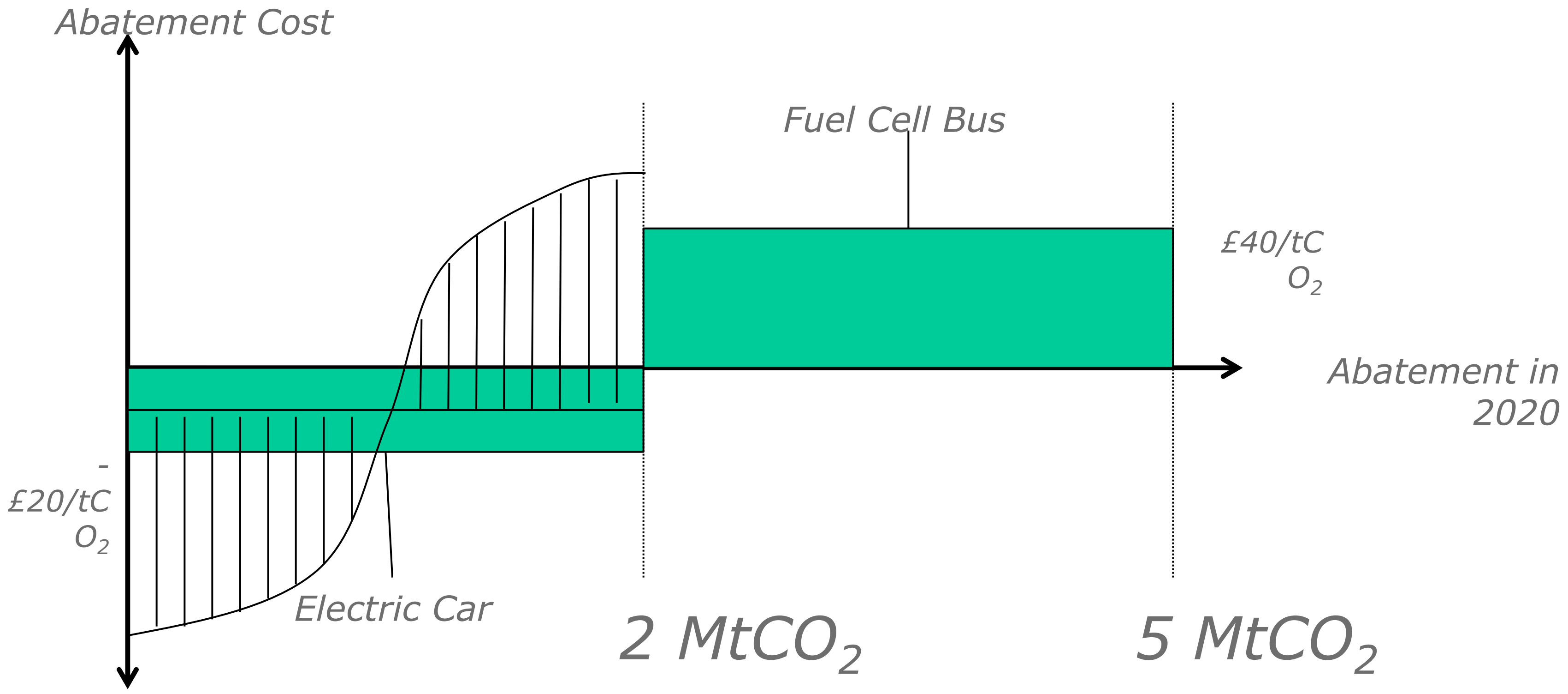
- Assumptions: Snapshot year = 2100. Discount rate = 8%

Measure	Capital Cost	Annual Savings	Year Available	CO_2 savings 2100	Abatement Cost
Fusion	£20 billion	1.4 Mt	2050	72.3 Mt	-£12/tCO2
Lighting	£4	0.0292 t	2010	0.1168 t	£18/tCO2
Insulation	£400	0.378 t	2010	9.82 t	£13/tCO2

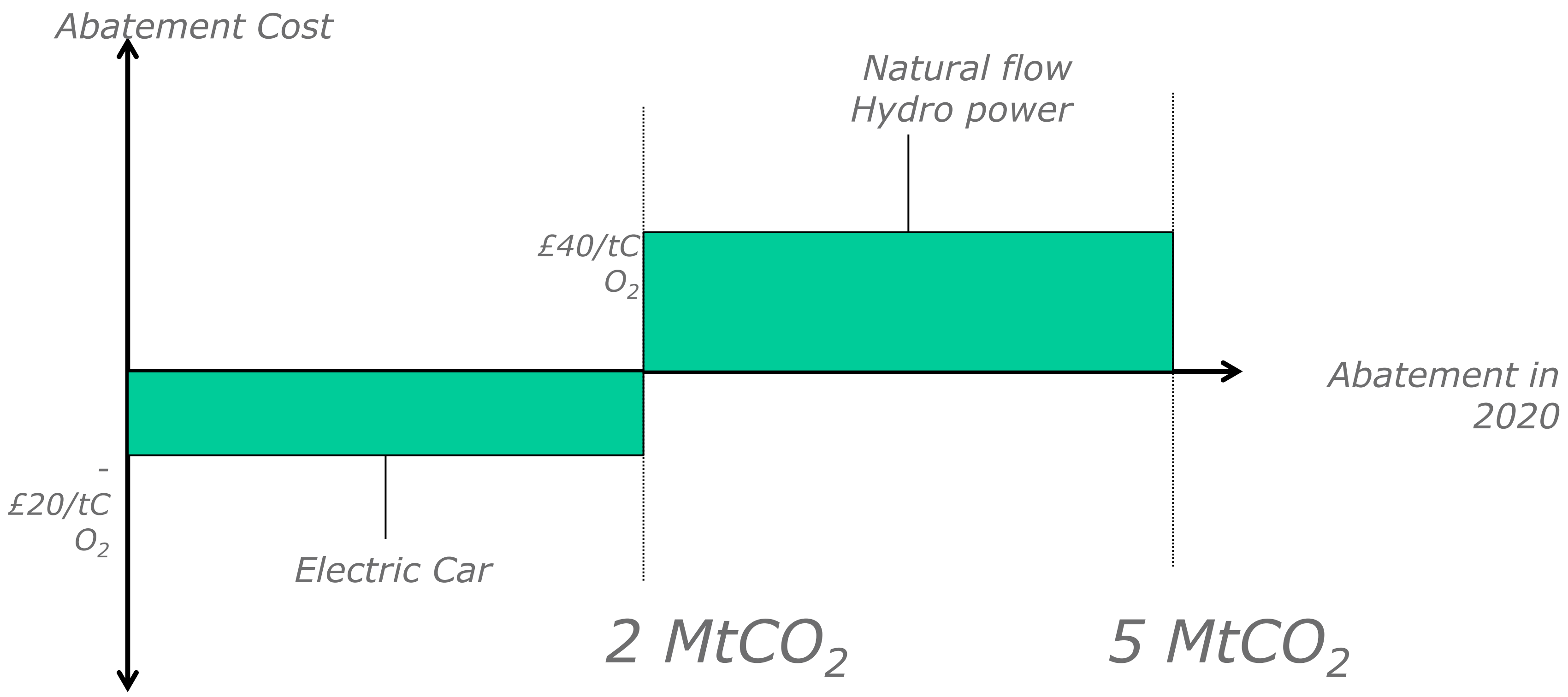
⇒ Adopt nuclear fusion in 2050.

No acknowledgment of technical risk, or aggregate CO_2 reductions

Lies my MACC told me (2) - uncertainty



Lies my MACC told me (3) – path dependency

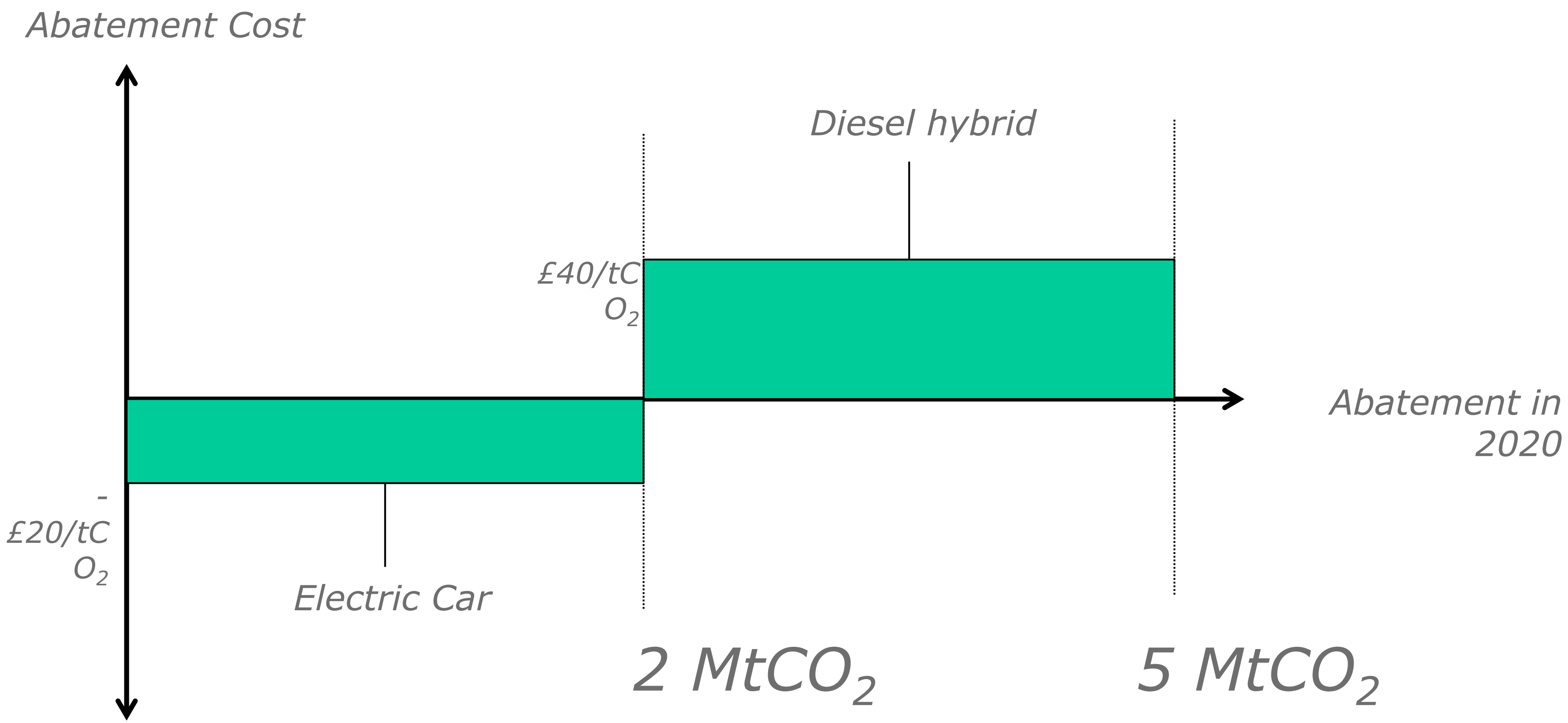


Abatement Target = 2MtCO2 in 2020

Adopt electric car only....But in order for the electric car to deliver CO_2 reduction, decarbonisation of the power sector is required => Natural flow hydro is required

Are emissions reductions properly distributed between interacting measures?

Lies my MACC told me (4) - exclusivity



Abatement Target = 5MtCO2 in 2020

Adopt both electric car and Diesel hybrid....But only one of these can happen – there isn't enough demand for vehicles for both to be necessary

=> Interactions should be incorporated on MACCS, and no exclusive measures can be included

Activity at Imperial College

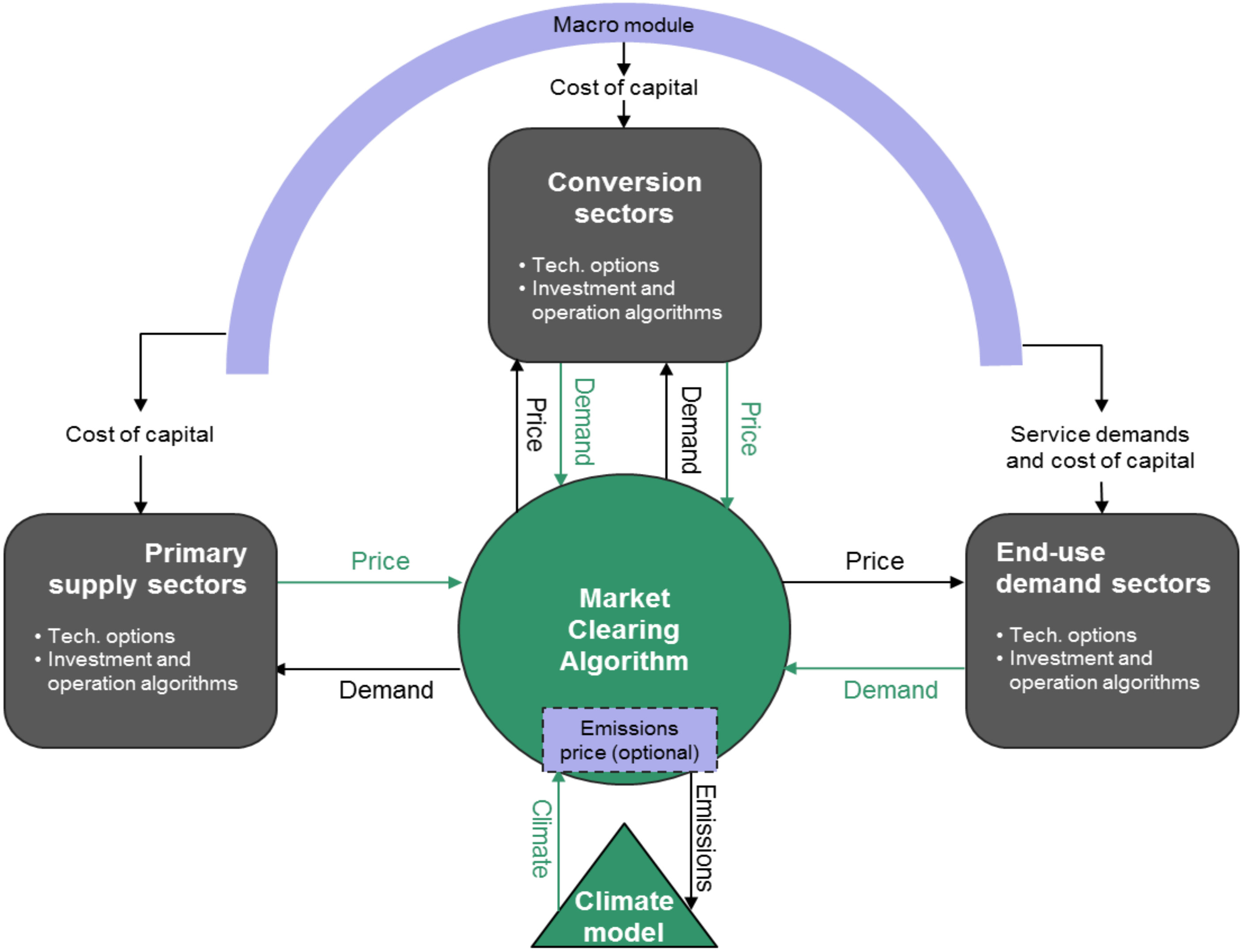
SGI modelling - headline questions

- What is the role of gas in future low carbon energy systems?

- What conditions may lead to stranded assets – why, where, when?

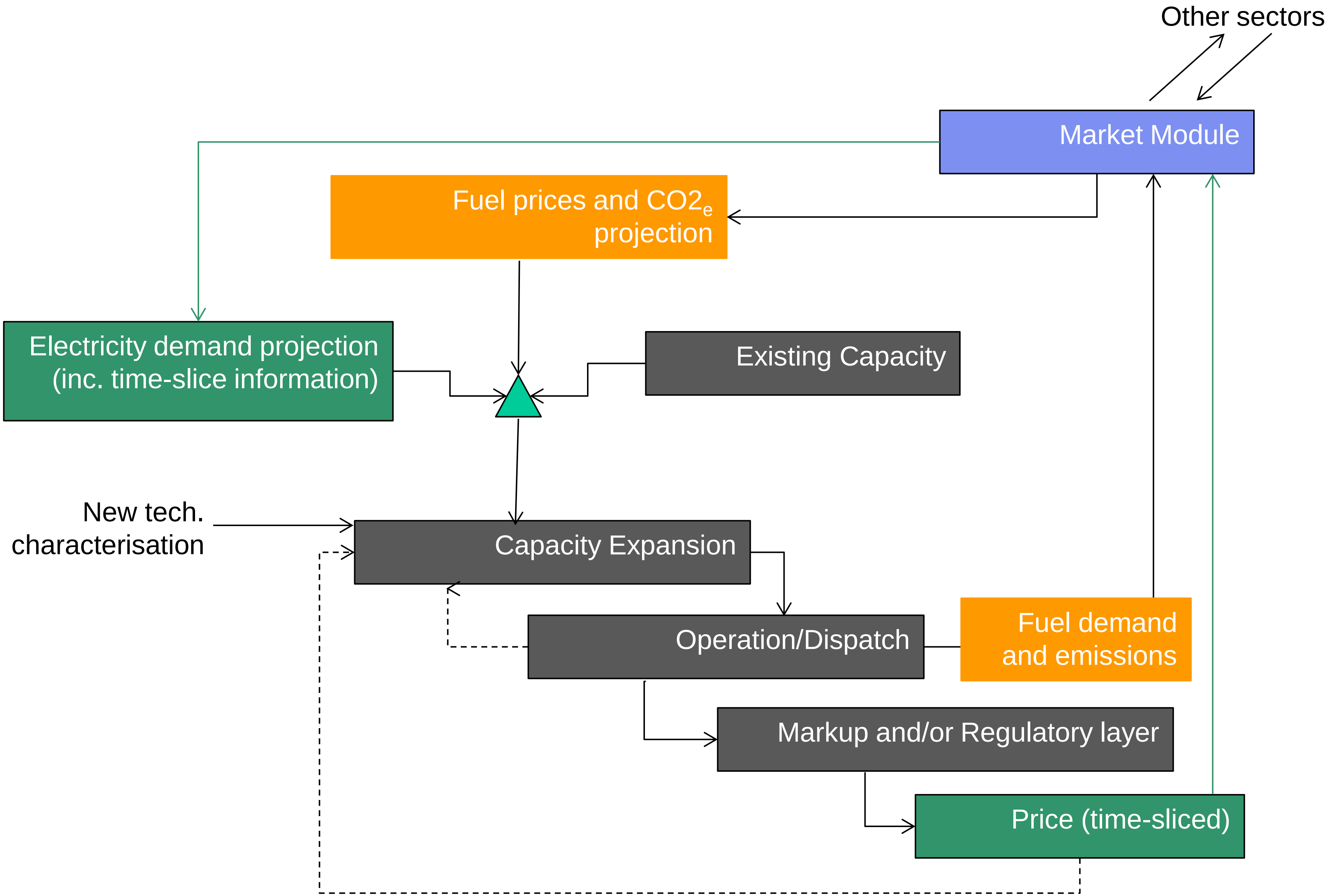
- What technology R&D should we invest in?

ModUlar energy system Simulation Environment (MUSE)

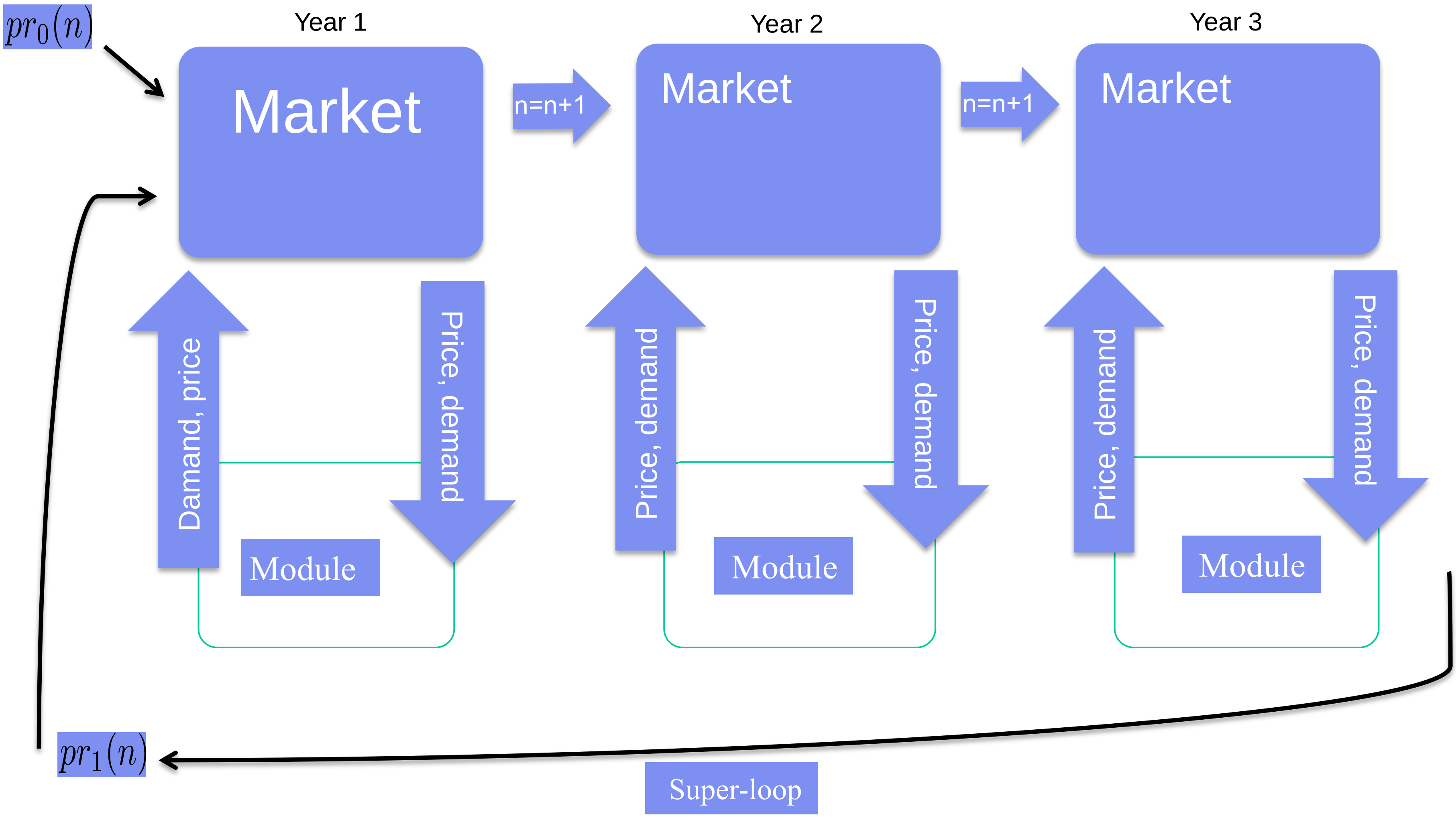


- Partial equilibrium on the energy system (models supply and demand)
- Engineering-led and technology-rich
- Modular: Each sector is modelled in a way that is appropriate for that sector
- Microeconomic foundations: all sectors agree on price and quantity for each energy commodity
- Limited foresight decision makers
- Policy instruments explicitly modelled
- Simple macro feedbacks

MUSE module high-level detail – Power sector

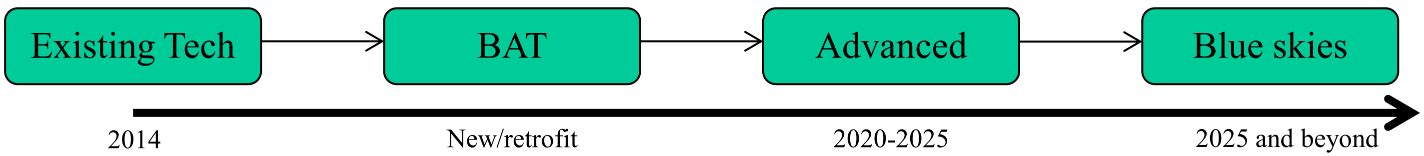


MUSE solve structure - foresight



Application 1: Technology road-mapping

What a technology roadmap could look like

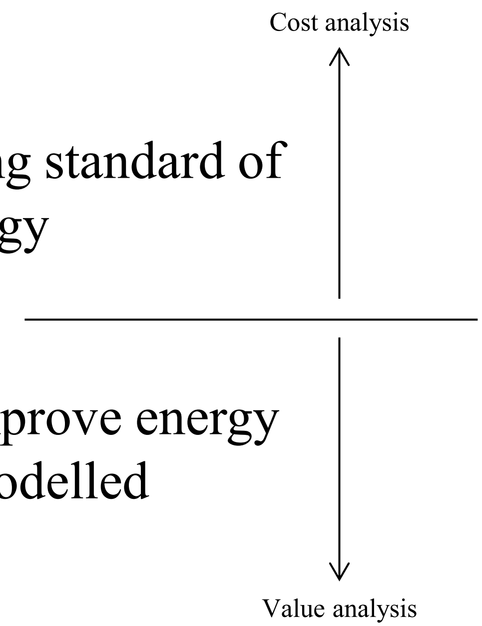


- Existing technology; provides a starting point. Known costs and technology performance. TRL 9.

- Best Available Technology (BAT); defines industry-leading standard of proven systems already in use. Known costs and technology performance. TRL 7-8.

- Advanced concepts; known design concepts that could improve energy efficiency, yet to be implemented. Estimated costs and modelled technology performance. TRL 5-7.

- Speculative research; "what if" scenarios. Unknown costs with research required to estimate performance. TRL 1-4.



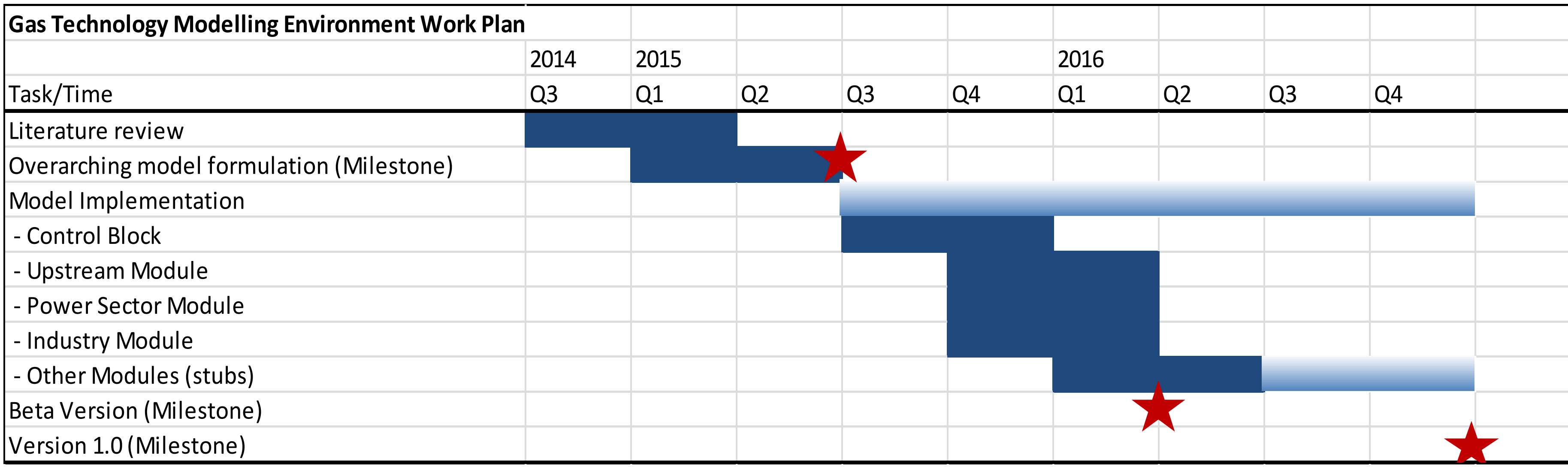
Application 2: R&D prioritisation

- Prioritization of technology R&D investment for higher TRLs (industry-led)
  - Tier 1 (buy): Technologies that always appear in model solutions across ranges of analyses.
  - Tier 2 (hedge): Technologies that exhibit dependencies on the assumptions in sensitivity analyses, but offer significant value where they materialise. University partnership can be helpful.
- Cutting edge blue sky technology research for lower TRLs (university-led)
  - Tier 3 (high risk, high return): "What if" scenario assessment to test hypotheses on the importance of more radical technological change.

Selection of approaches

Model	Solve characteristics				Tech. detail	Foresight	Geo scope (no. of regions)	Open model	Open modelling
	Overall solution aim	Temporal	Equilibrium	Top-down or bottom-up					
AIM/Enduse	Minimise system cost	Inter-temporal	Partial	Bottom-up	High	Perfect	Global (32)	✓	✓
GCAM	Market sharing based on LEC	Recursive dynamic	Partial	Bottom-up	High	Myopic	Global (14)	✓	✓
IMACLIM	Simulate economic growth	Recursive dynamic	General	Top-down	Low	Myopic	Global (12)	×	×
IMAGE-TIMER	Market simulation	Recursive dynamic	Partial	Bottom-up	Int.	Myopic	Global (26)	×	×
MERGE	Maximise profit/utility	Inter-temporal	General	Top-down	Low	Perfect	Global (12)	✓	✓
MUSE	Simulate market equilibrium	Recursive dynamic	Partial	Bottom-up	High	Imperfect	Global (~30)	✓	✓
REMIND	Maximise welfare	Inter-temporal	General	Top-down	Low	Perfect	Global (11)	×	×
ETSAP-TIAM	Maximise surplus	Inter-temporal	Partial	Bottom-up	High	Perfect	Global (15)	×	✓
WITCH	Simulate economic growth	Inter-temporal	General	Top-down	Int.	Perfect	Global (12)	×	×

SGI modelling work plan



Grantham Institute Energy Modelling Team

Programme Lead

Adam Hawkes

Research Lead

Ajay Gambhir

Research Team

Flo Steiner

Tamaryn Napp

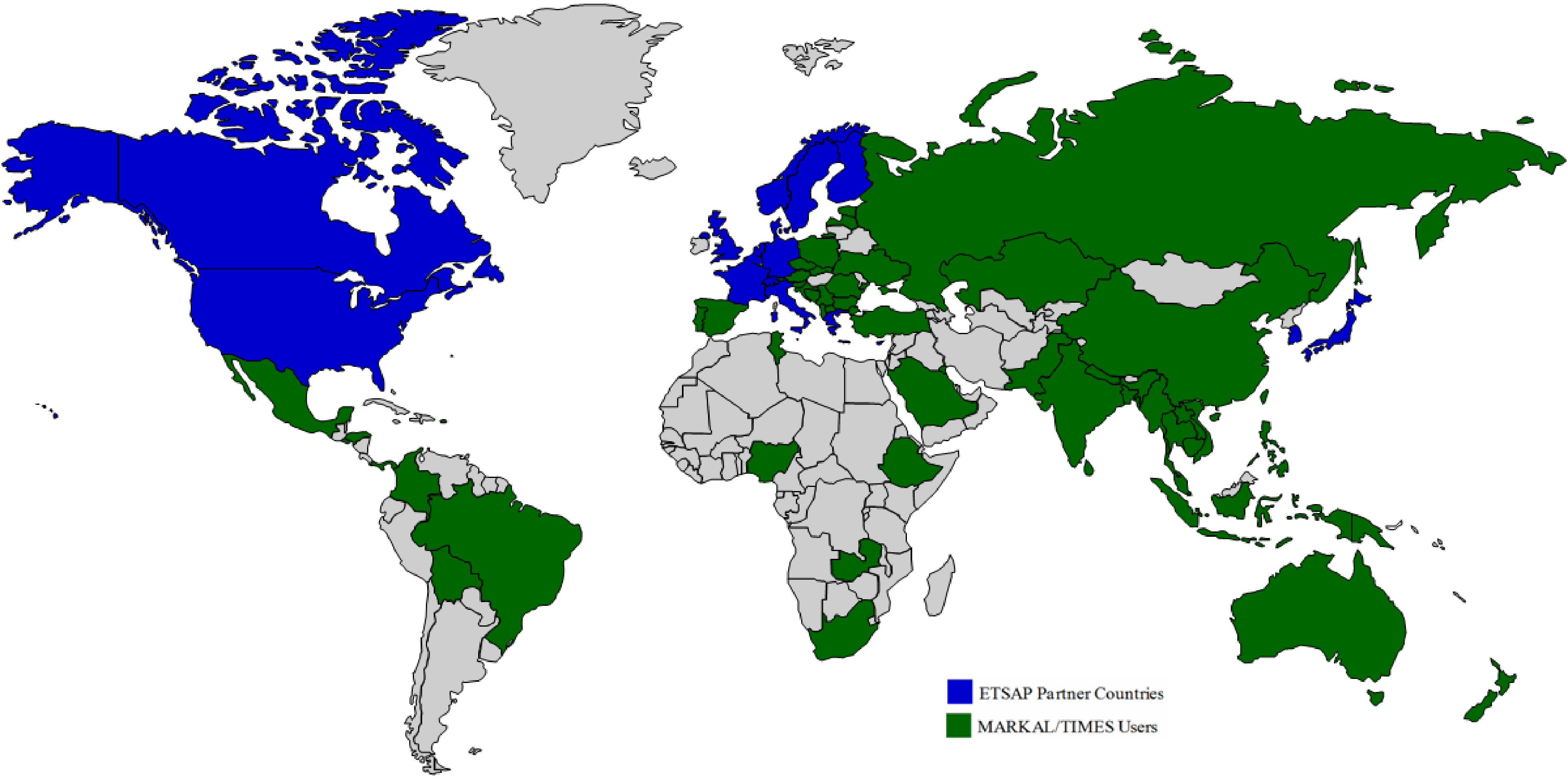
Sheridan Few

PhD Students

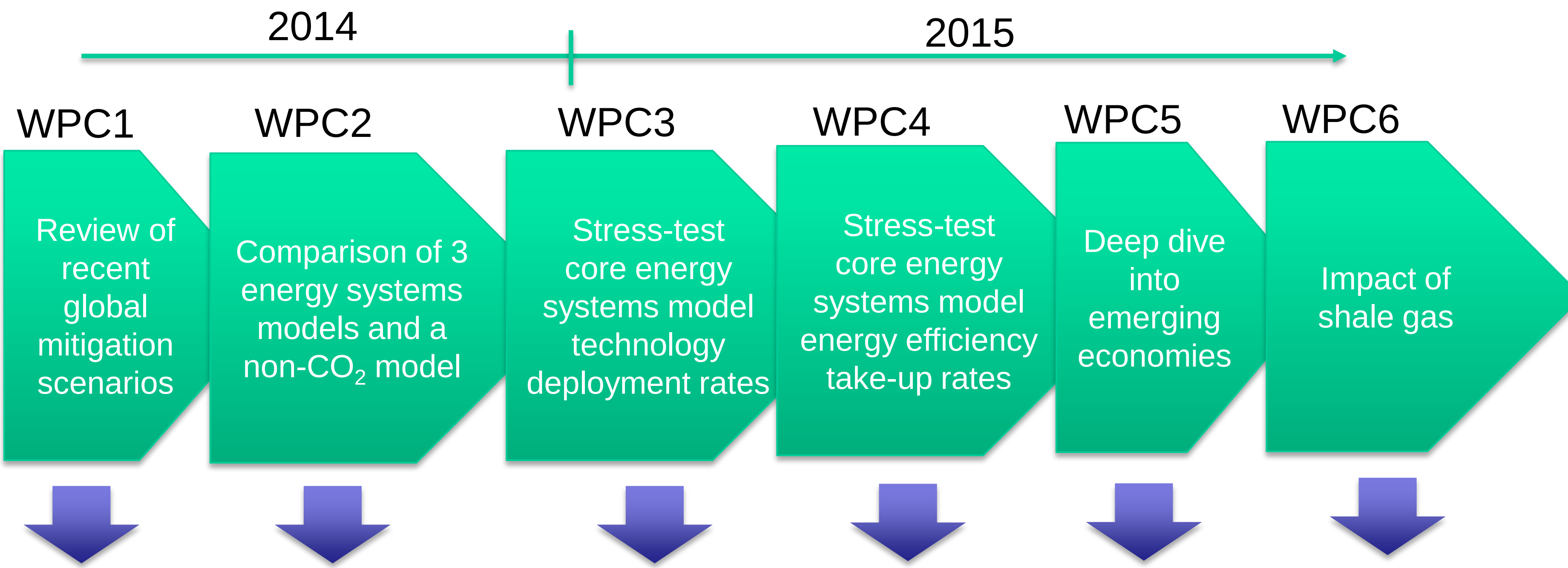
?

Oliver Schmidt

TIMES Modelling (IEA-ETSAP)



AVOID 2 – mitigation modelling work programme



WPC1
Socio-economic assumptions
Targets explored
Key technologies & measures
Costs of mitigation

WPC2
2, 2.5, 3, 4 ^{O}C targets
Delayed mitigation action (to 2020 and 2030)
Delayed and constrained technologies
Analysis of scenario feasibility, technologies and measures
Mitigation costs and other impacts

WPC3
How fast can technologies be deployed?
What does this mean for scenario feasibility?
What does this mean for mitigation costs?

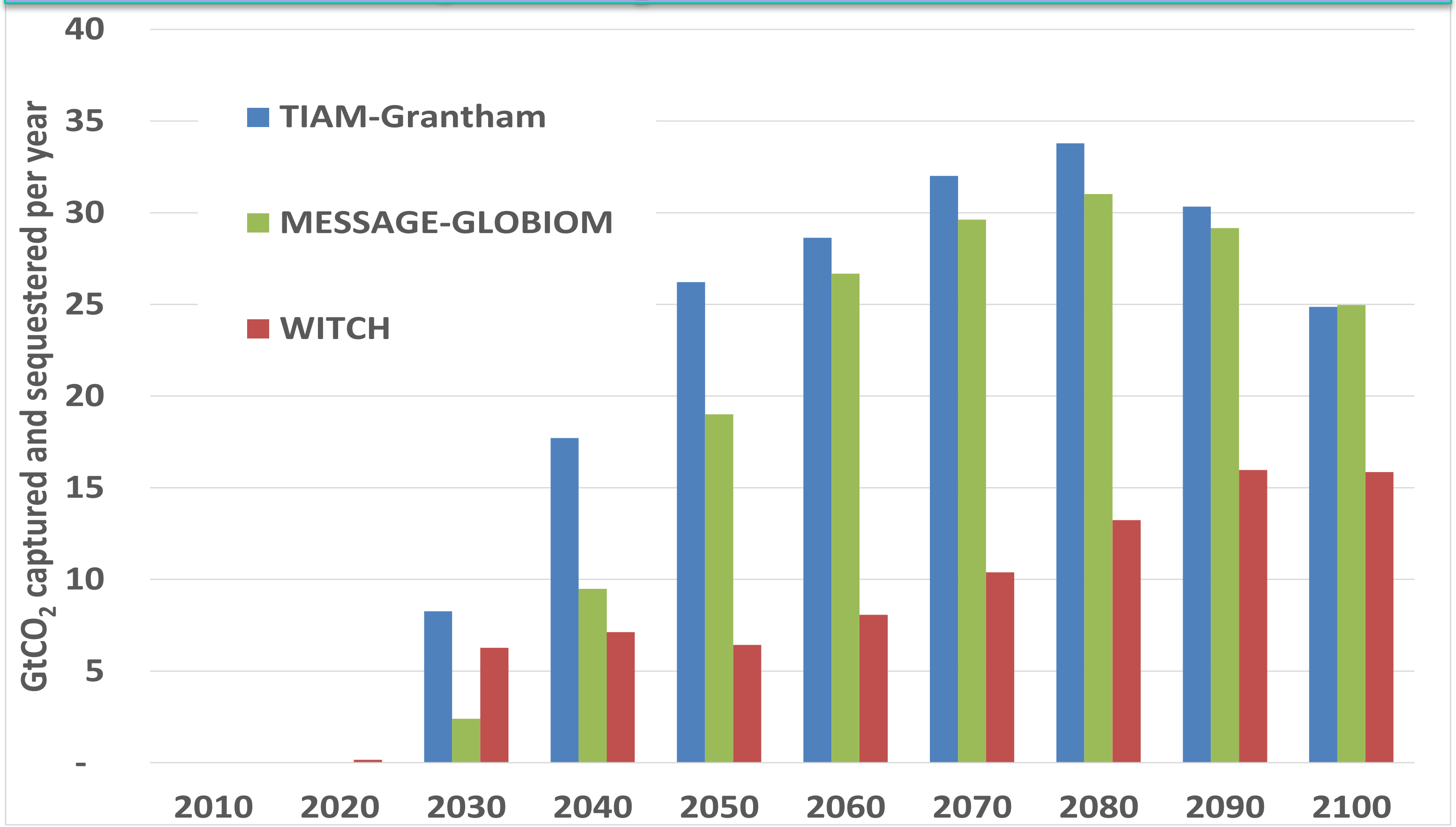
WPC4
How fast can energy efficiency improve?
Which policies are most effective?
How does this impact mitigation costs?

WPC5
What are the drivers and barriers to achieving low-carbon transitions in China, India, other emerging economies?

WPC6
On baseline emissions
On mitigation costs
On investment in low-carbon energy

Reliance on novel technologies (CCS)

In 2C scenario with global action delayed to 2020, TIAM-Grantham and MESSAGE see 30 $GtCO_2$/year captured by 2070 – the level of global CO_2 emissions in 2008



New challenges

- Spatial and temporal scales
- The human dimension
- Complexity science
- Uncertainty
- Communication and Transparency

Stefan Pfenninger, Adam Hawkes, James Keirstead, Energy systems modeling for twenty-first century energy challenges, Renewable and Sustainable Energy Reviews, Volume 33, May 2014, Pages 74-86

Thank you

a.hawkes@imperial.ac.uk