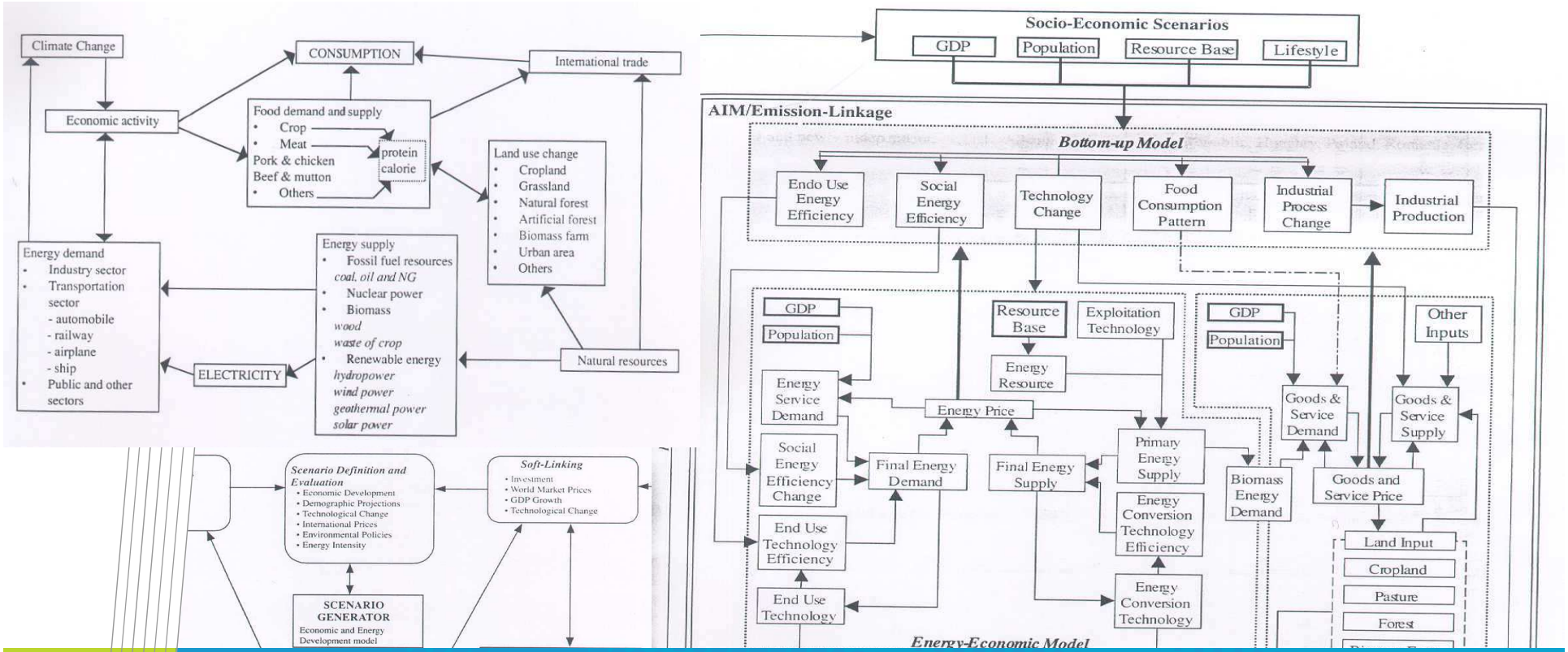


www.csiro.au

The Energy Sector Model (ESM)

Luke Reedman

ANL-CSIRO workshop

31 January, 2012

CSIRO

Outline

- Background
- Overview of coverage of the model
- Programming problem
- Main use
- Development over time
- Where to from here

Some history…

- Began construction of partial equilibrium modelling of the electricity and transport sectors in 2000
- Stand-alone electricity and transport models
- Increasing need to have an energy sector model that had coverage of the whole energy sector
  - Competition for primary energy sources
  - Potential for local energy solutions
  - Electrification of transport

Energy Sector Model (ESM)

- ESM is a partial equilibrium model of the energy sector (electricity generation and transport) solved as a LP
- ESM is solved as a linear program where the objective function to be maximised is net welfare, defined as the discounted sum of consumer and producer surpluses over time.
- The maximisation is subject to constraints that represent the physical limitations of fuel resources, the stock of electricity plant and vehicles, and various market and technology specific constraints such as the need to maintain a minimum number of peaking plants to meet rapid changes in the electricity load.
- Objective function can be cast as minimise total cost

CSIRO

Energy Sector Model (ESM)

- Coverage of all Australian states and territories and New Zealand.
- 9 road transport modes: small, medium and large passenger cars; small, medium and large commercial vehicles; rigid trucks; articulated trucks and buses.
- 5 engine types: internal combustion; hybrid electric/internal combustion; hybrid plug-in electric/internal combustion; fully electric and fuel cell.

Energy Sector Model (ESM)

- Thirteen road transport fuels: petrol; diesel; liquefied petroleum gas (LPG); natural gas (compressed (CNG) or liquefied (LNG)); petrol with 10 per-cent ethanol blend; diesel with 20 per-cent bio-diesel blend; ethanol and bio-diesel at high concentrations; biomass to liquids diesel; gas to liquids diesel; coal to liquids diesel with upstream CO_2 capture; hydrogen (from renewables) and electricity.

- 3 air transport fuels: jet fuel (kerosene) from fossil oil; bio-synthetic paraffinic kerosene (bio-SPK) and Fischer-Tropsch synthetic paraffinic kerosene (FT-SPK).

- Much less detailed fuel substitution possibilities in the rail and shipping sectors.

CSIRO

Energy Sector Model (ESM)

- 16 centralised generation (CG) electricity plant types: black coal pulverised fuel; black coal integrated gasification combined cycle (IGCC); black coal with CO_2 capture and sequestration (CCS); brown coal pulverised fuel; brown coal IGCC; brown coal with CCS; natural gas combined cycle; natural gas peaking plant; natural gas with CCS; biomass; hydro; wind; solar thermal; hot fractured rocks (geothermal), wave, and ocean current.
- 17 distributed generation (DG) electricity plant types: internal combustion diesel; internal combustion gas; gas turbine; gas micro turbine; gas combined heat and power (CHP); gas micro turbine CHP; gas micro turbine with combined cooling, heat and power (CCHP); gas reciprocating engine CCHP; gas reciprocating engine CHP; solar photovoltaic; biomass CHP; biomass steam; biogas reciprocating engine; wind; natural gas fuel cell and hydrogen fuel cell.

CSIRO

Energy Sector Model (ESM)

- Trade in electricity between National Electricity Market regions.
- Assignment of a vintage in annual increments for all vehicles and centralised electricity generation plant, based on when they were first purchased or installed.
- Four electricity end use sectors: industrial; commercial & services; rural and residential.
- Representation of time in annual frequency (2006, 2007, …, 2050).

Key decision variables, constraints, prices

- Key decision variables:
  - Quantity (electricity, transport services, fuel)
  - Capital stock (plant, vehicles)
  - Investment (plant, vehicles)
  - Prices (electricity, transport services, fuel)
- Constraints:
  - Market balance
  - Capacity
  - Capital stock
  - Commodity balance
  - Policy
- Shadow prices:
  - Wholesale and ‘retail’ electricity prices
  - Cost of transport services
  - GHG abatement cost
  - Cost of other policies (e.g., RET, QLD gas target)

CSIRO

Scenario analysis tool – GHG emission reduction

- Main use of ESM is to model technology uptake in a carbon constrained economy

- Can be done in 2 ways:

1. Impose a constraint on the model (energy sector must meet a pre-determined emission trajectory)

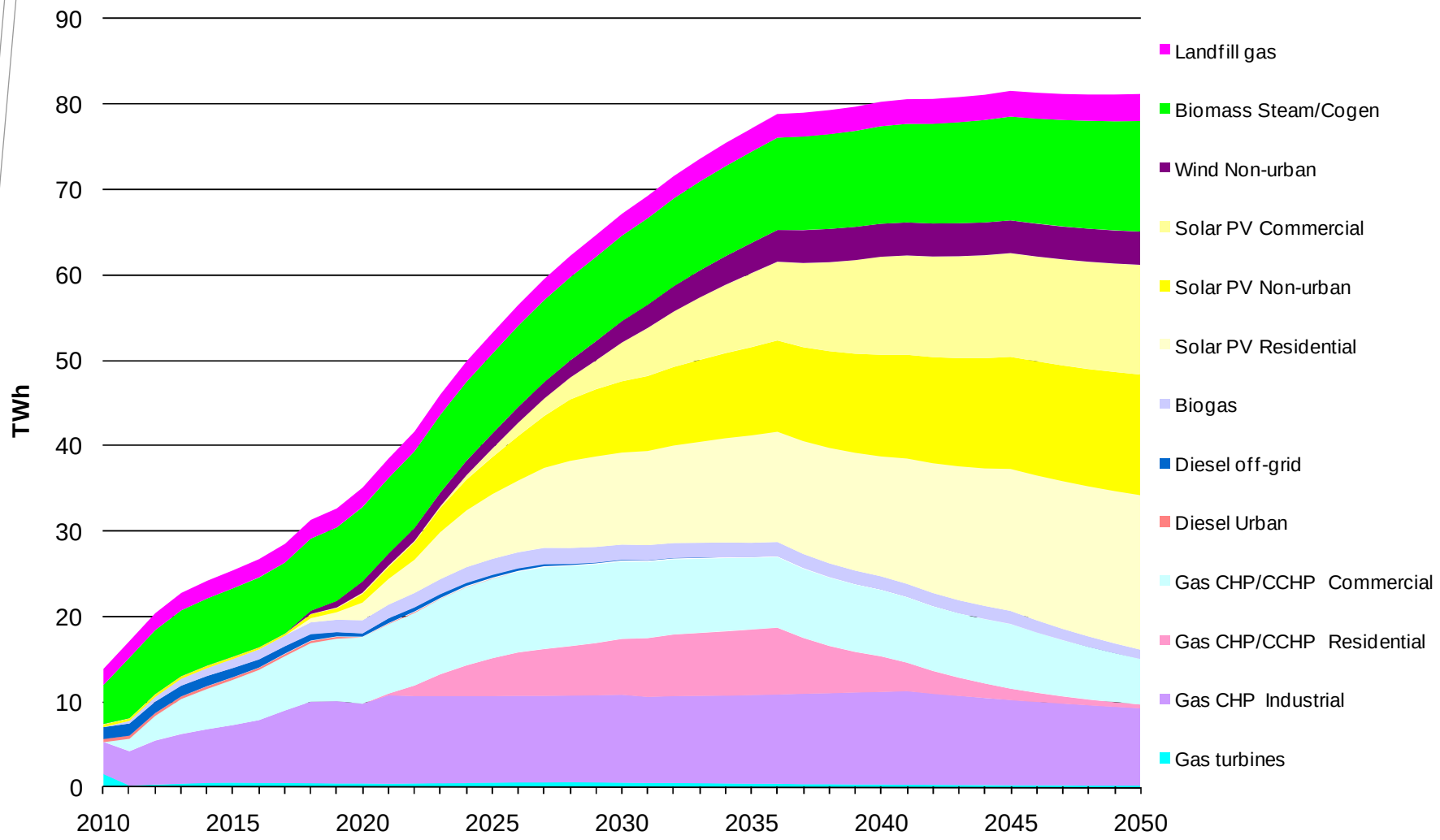
2. Impose a carbon price forward curve (additional cost element in objective function)

Intelligent Grid

- Major study conducted over 3 yrs
- Evaluate the economic, environmental and social benefits of distributed energy for Australia
- Significant development of ESM
- Increased number of technologies
- New constraints
- Linking with other modelling frameworks

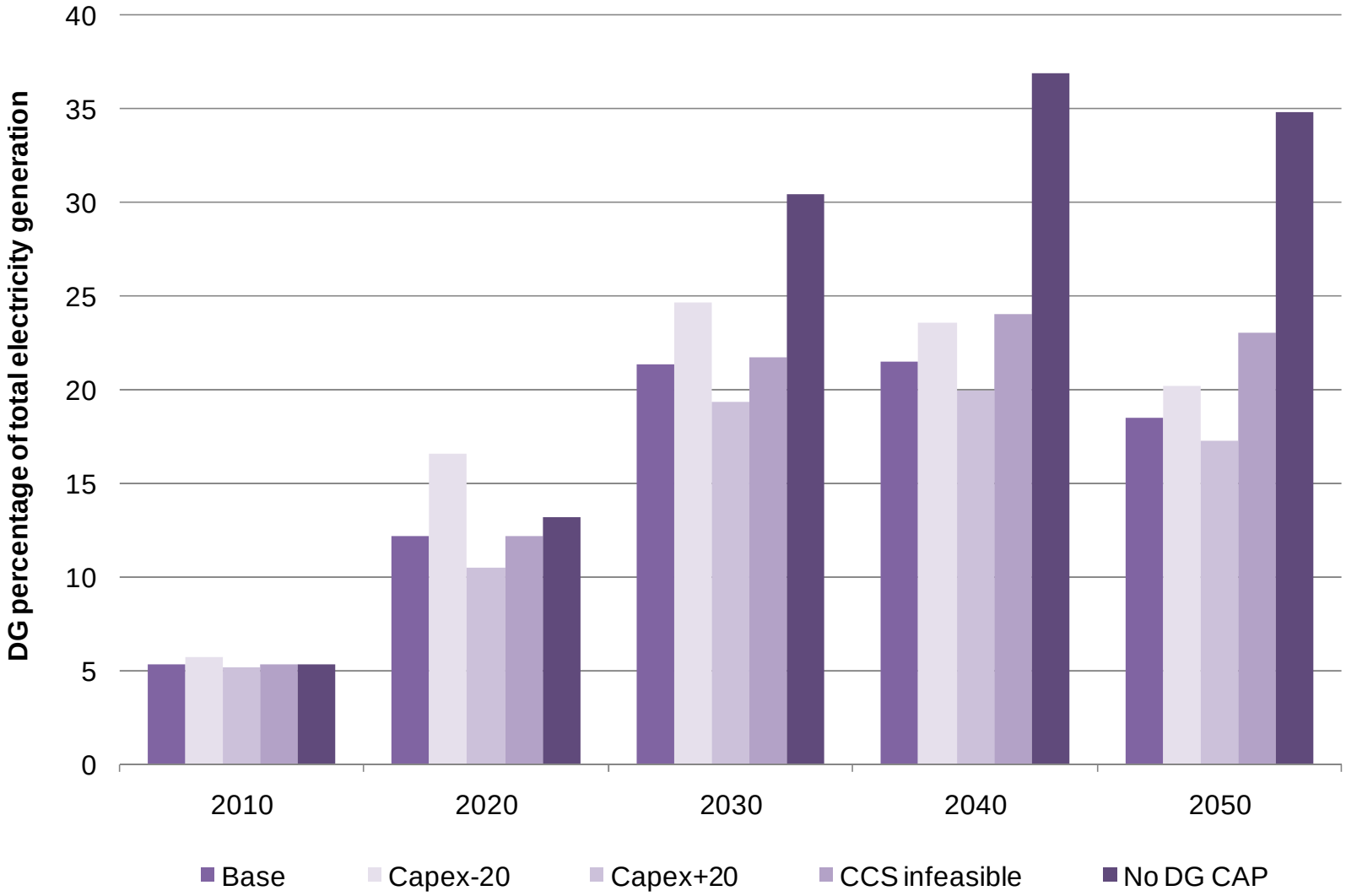
CSIRO

Intelligent Grid – example DG uptake profile

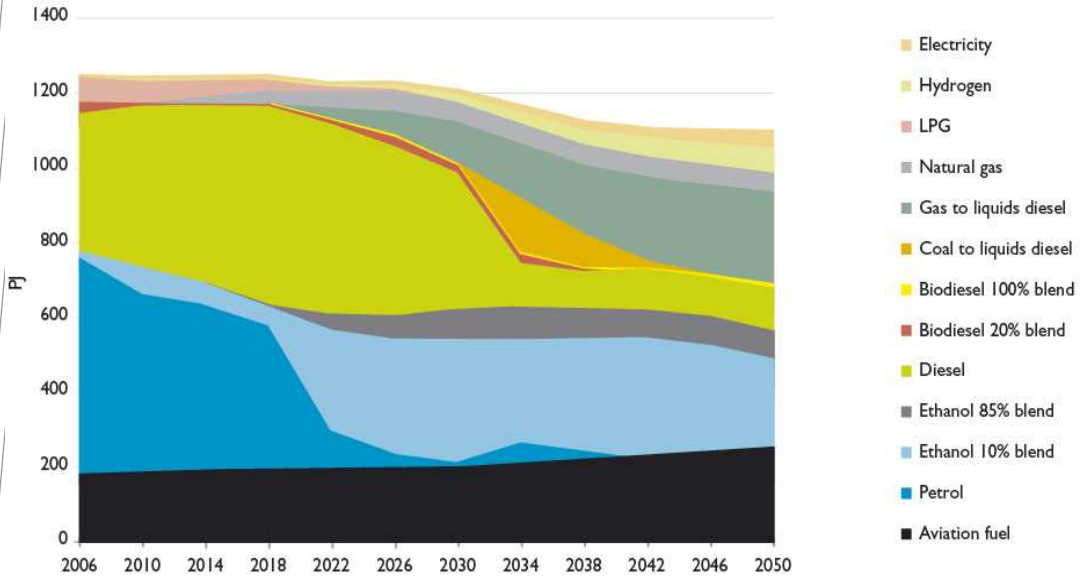


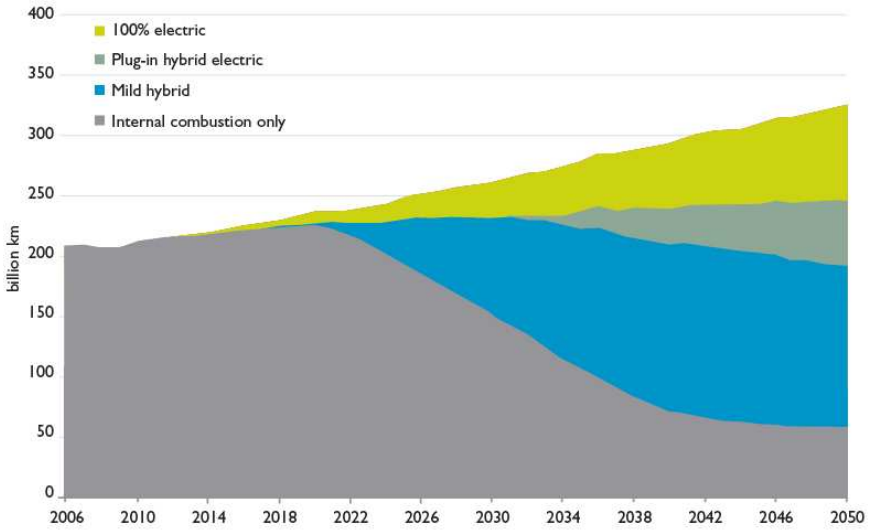
CSIRO

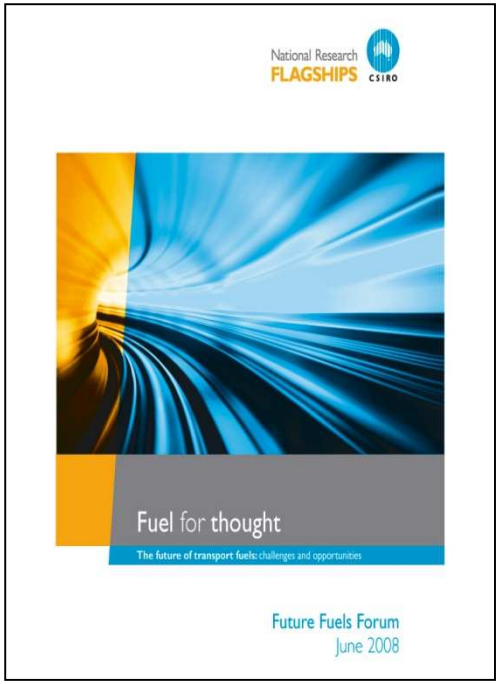
Intelligent Grid – sensitivity analysis



Future Fuels Forum







Key challenge was to model electricity and transport sectors simultaneously

CSIRO

Got some attention…

Petrol: $8 a litre forecast

Petrol predictions a crushing blow

Tourism would face devastation at $8 a litre

$8 a litre spectre for petrol

Forget fuel predictions, it's hitting us hard now

Farms, tourism big losers in dire forecast

$11,000 for a year's fuel?

Petrol price $10 a litre by 2018 says study

Ban thirsty car engines

NRMA urges Rudd to act

$10 fuel by 2018 warn scientists

NRMA wants fuel consumption limit

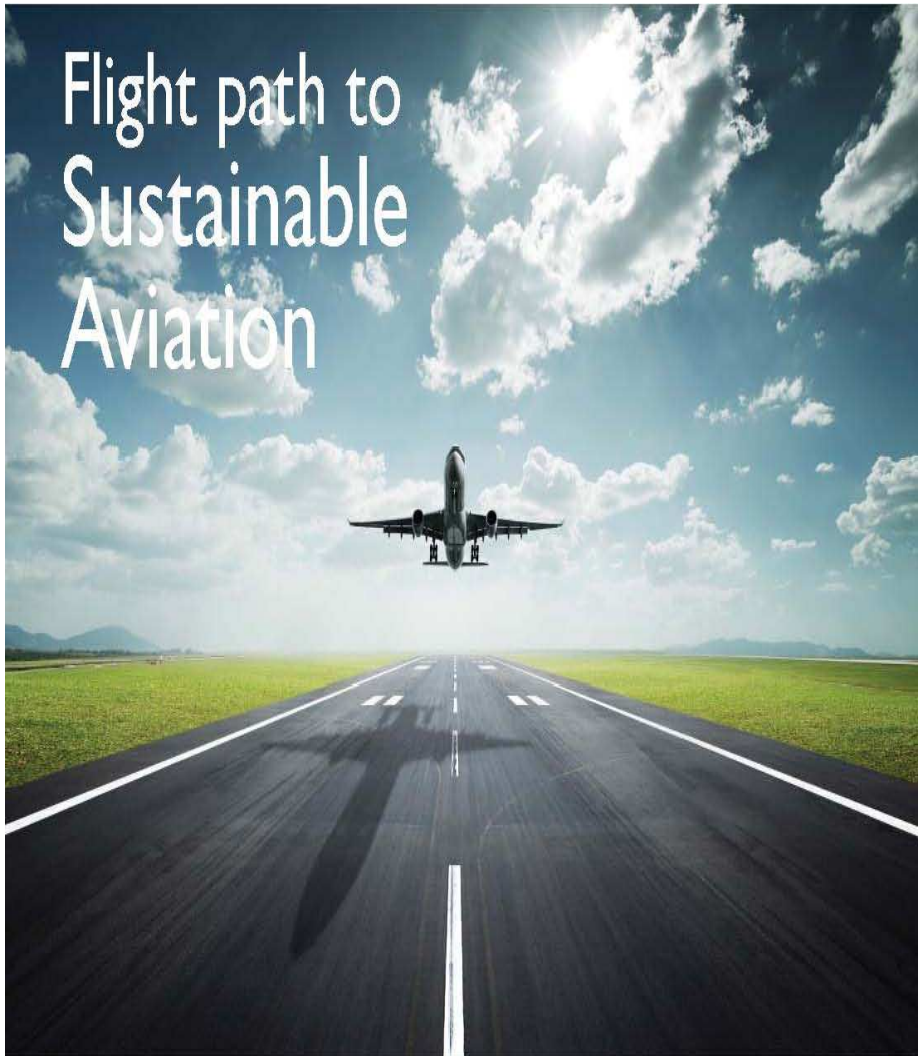
Prices fuel the race for solution

Putting kids on the bus is a start says mayor

CSIRO

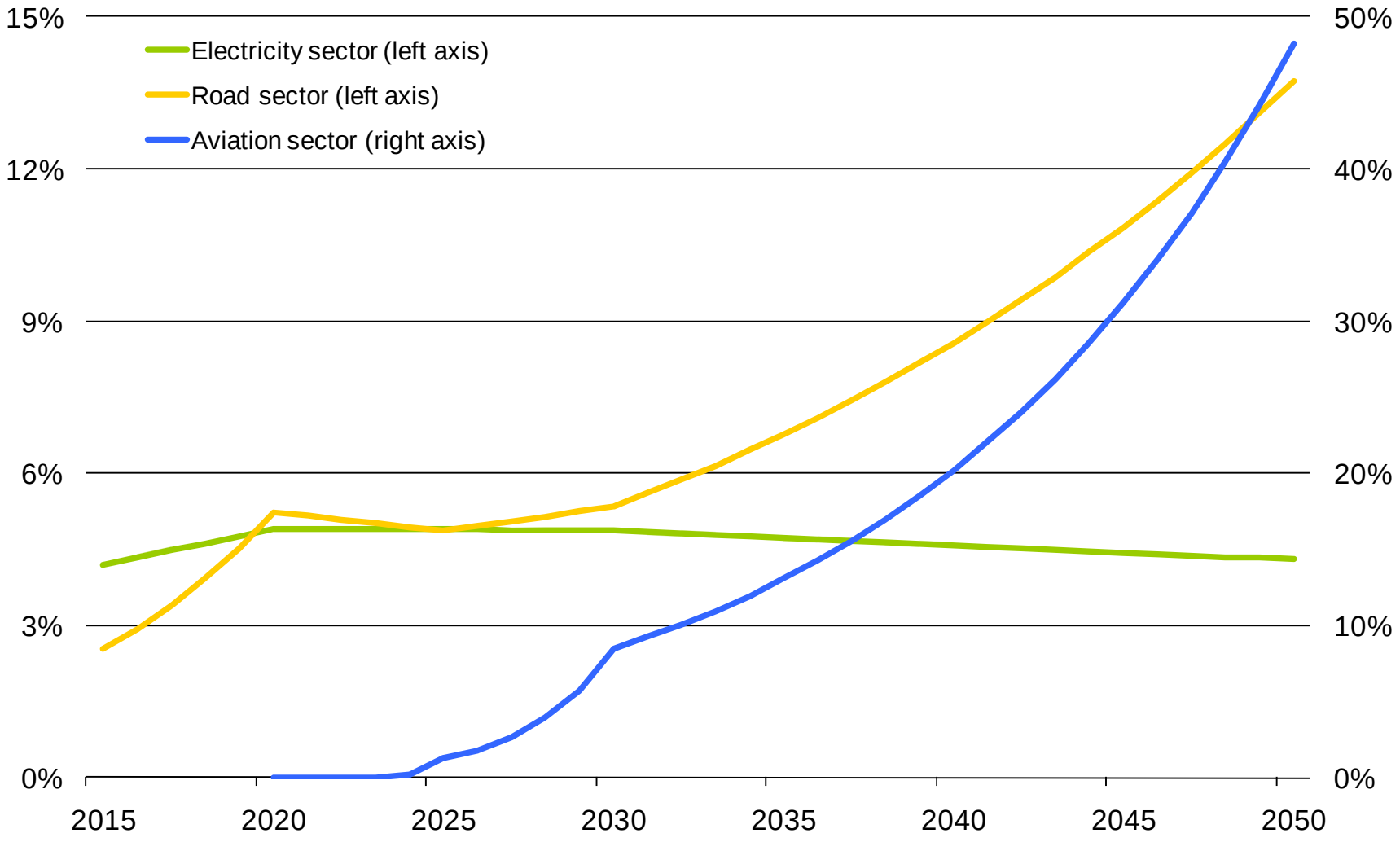
Aviation forum

- Oil prices expected to rise
- Growth 6% p.a.
- Increasingly affordable
- Share of emissions to rise
- Biofuels needed to reduce emissions



CSIRO

Aviation forum – ESM result



Aviation forum

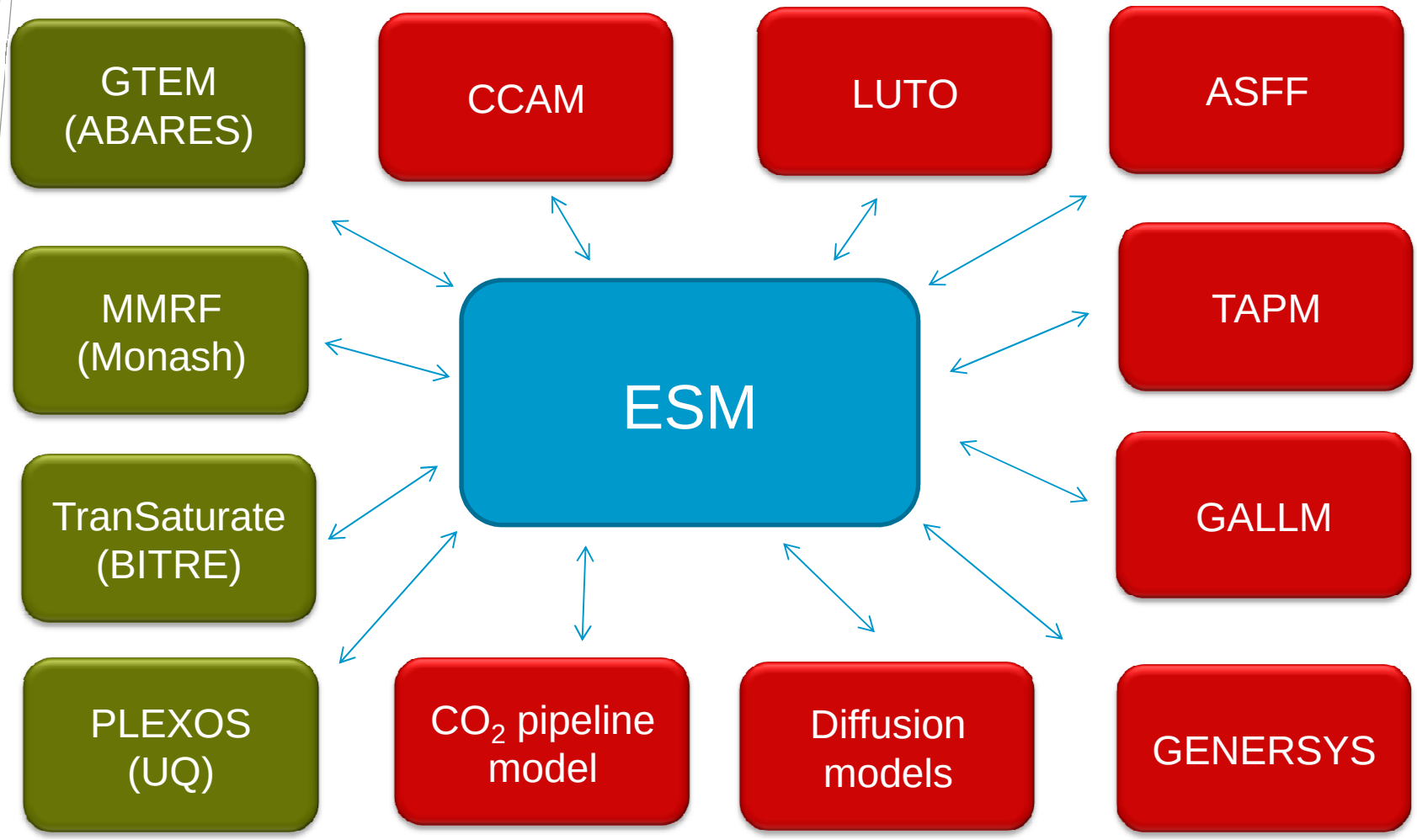
Road map

+ 14 recommendations addressing the main challenges:

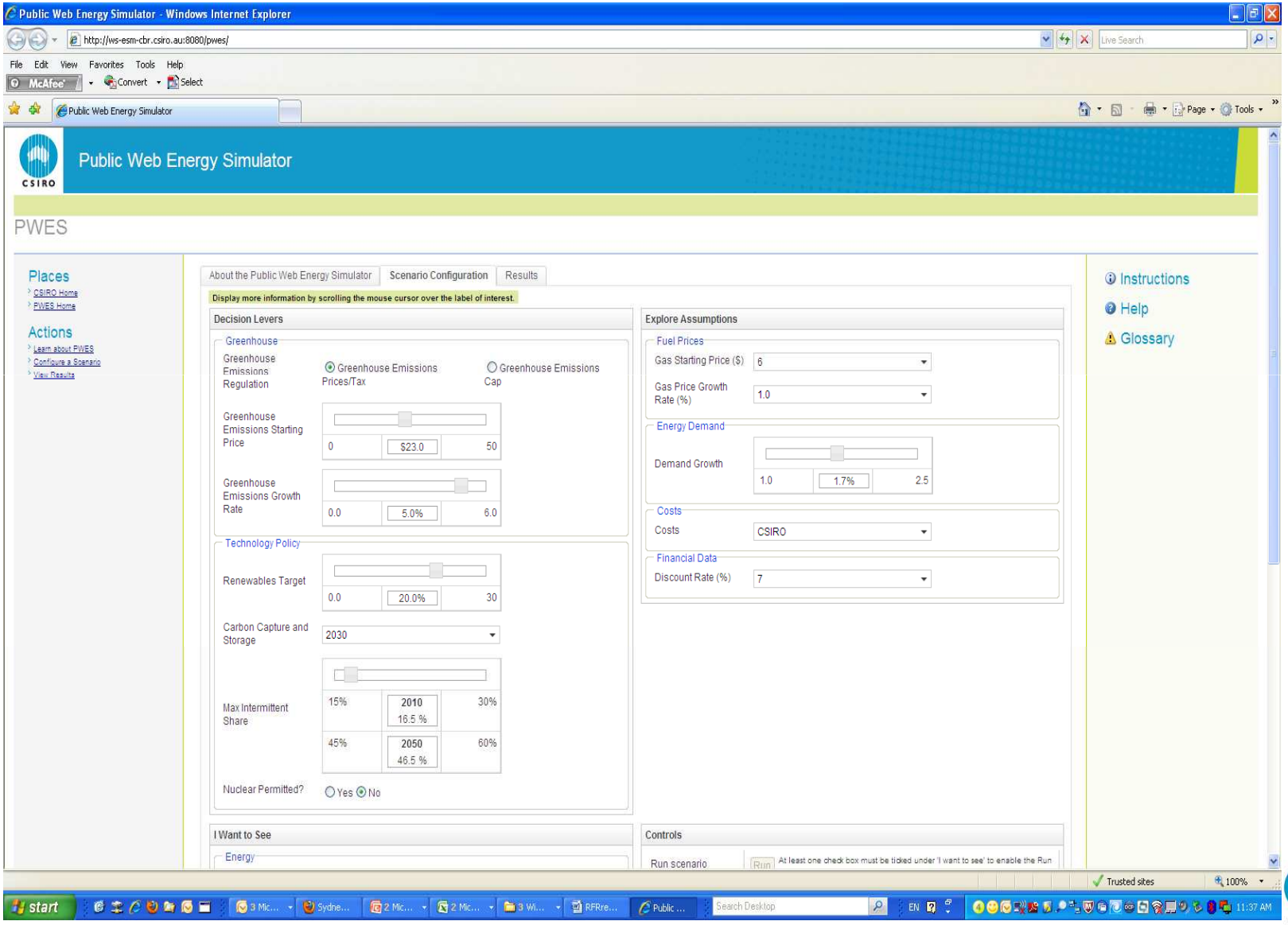
- Some resources still relatively unknown
- Some known but not trialled
- Prospective refining processes not proven
- No sustainability certification process
- Access to distribution infrastructure uncertain

CSIRO

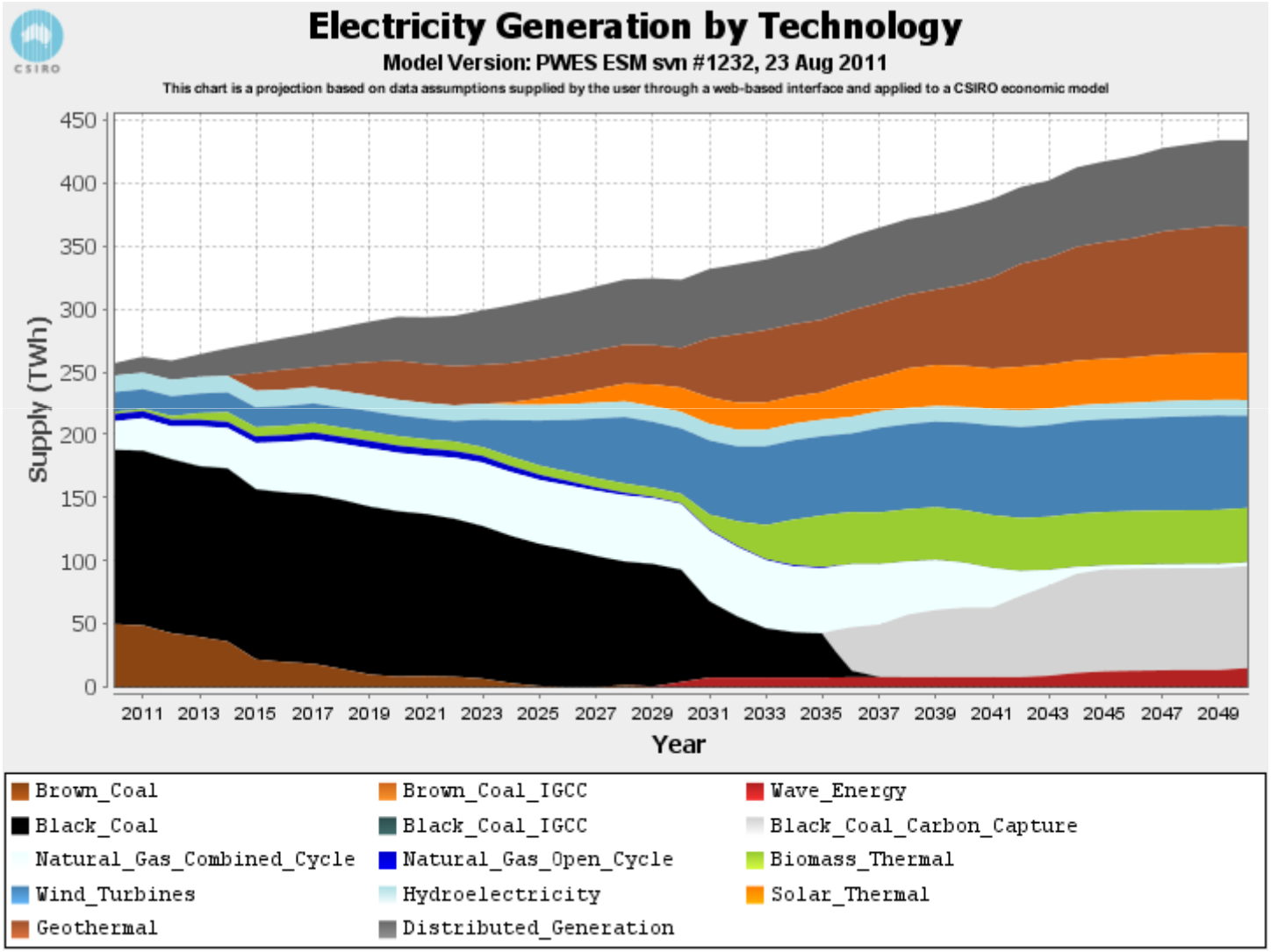
Links to other models



Web version of ESM



Web ESM example output



Conclusions/further work

- Number of achievements
- Model development is on-going
- Improve demand-side of the model
- Increasing need for sensitivity analysis
- Debate on spatial scale
- Web interface
- Linking with other models

Energy Transformed Flagship

Dr Luke Reedman
Research scientist
Email: luke.reedman@csiro.au

www.csiro.au

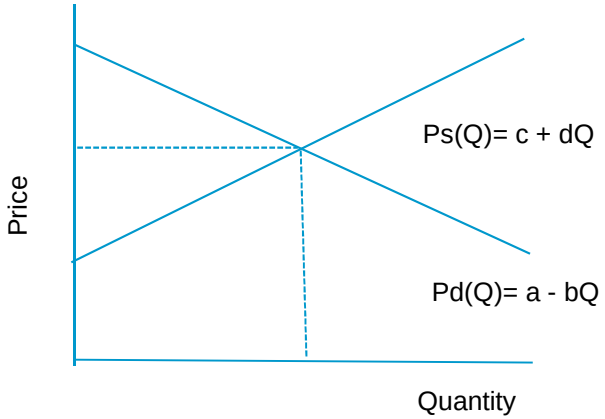
Thank you

Contact Us
Phone: 1300 363 400 or +61 3 9545 2176
Email: enquiries@csiro.au Web: www.csiro.au

CSIRO

Maximise welfare?

Maximisation of the area under the demand function minus the area under the supply function is a way of solving for the point at which demand intersects supply (equilibrium).



$$Max\ NSW = \int (a - bQ)dQ - \int (c + dQ)dQ$$

To find the maximum, take the derivative of the net social welfare function with respect to Q, and set it equal to zero:

$$\frac{dNSW}{dQ} = \frac{d}{dQ}\left[\int (a - bQ)dQ - \int (c + dQ)dQ\right] = 0$$

This solves for the value of Q where the demand function intersects the supply function. The value of P is implied from the solution value of Q.

$$(a - bQ) - (c + dQ) = 0$$

$$\Rightarrow Pd = Ps = P^*$$

“Reaching for renewables” study

- Study for Central Victorian Greenhouse Alliance (CVGA)
- How renewables can contribute to reducing emissions
- Sub-state analysis focus on CVGA LGAs:
  - Subtract from what Vic currently is
  - Trade with each other
  - Trade with Vic
  - Do not trade with other states
  - Have no coal but some gas and renewables
  - Have higher priced retail electricity then Vic
  - Can invest in CG or DG

CSIRO

“Reaching for renewables” study

Method for modelling peak oil

- A fuel supply constraint is imposed. The shadow price represents what we would have been willing to pay to avoid having to adopt alternative fuels

$$\sum_{s,\, foil, g, m} EXFC_{s, g, foil, m, t} \leq L_t$$

- *s* is the states and territories of Australia
- *foil* is the subset of exogenous fuels that are derived from oil such as petrol and diesel and the blended component in biofuels
- *m* is the set of road transport modes
- *g* is the set of engine technologies
- *t* is time in annual increments
- *EXFC* is consumption in petajoules of those fuels that are defined in the model by exogenous parameters
- *L* is the upper limit of the total supply of fuels derived from oil.

CSIRO

Potential range of petrol price outcomes under peak oil

CSIRO