ARC Centre for Complex Systems, Australia

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Vehicle-To-Grid: Plug-In Hybrids will save the electricity system and the climate-system

Complex ‘07
Gold Coast, July 2007

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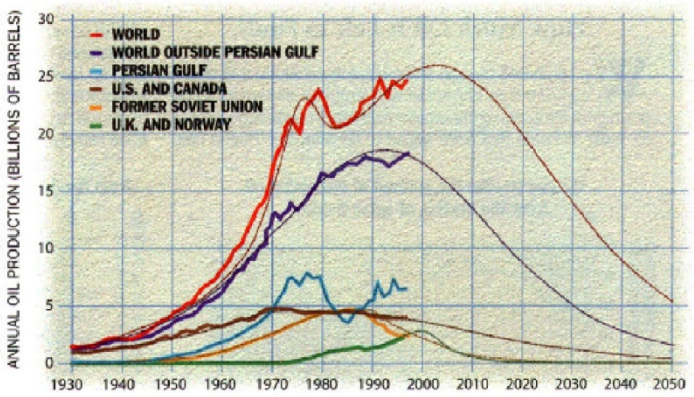
The End of Cheap Oil And Global Warming. V2G and ABM to the rescue!



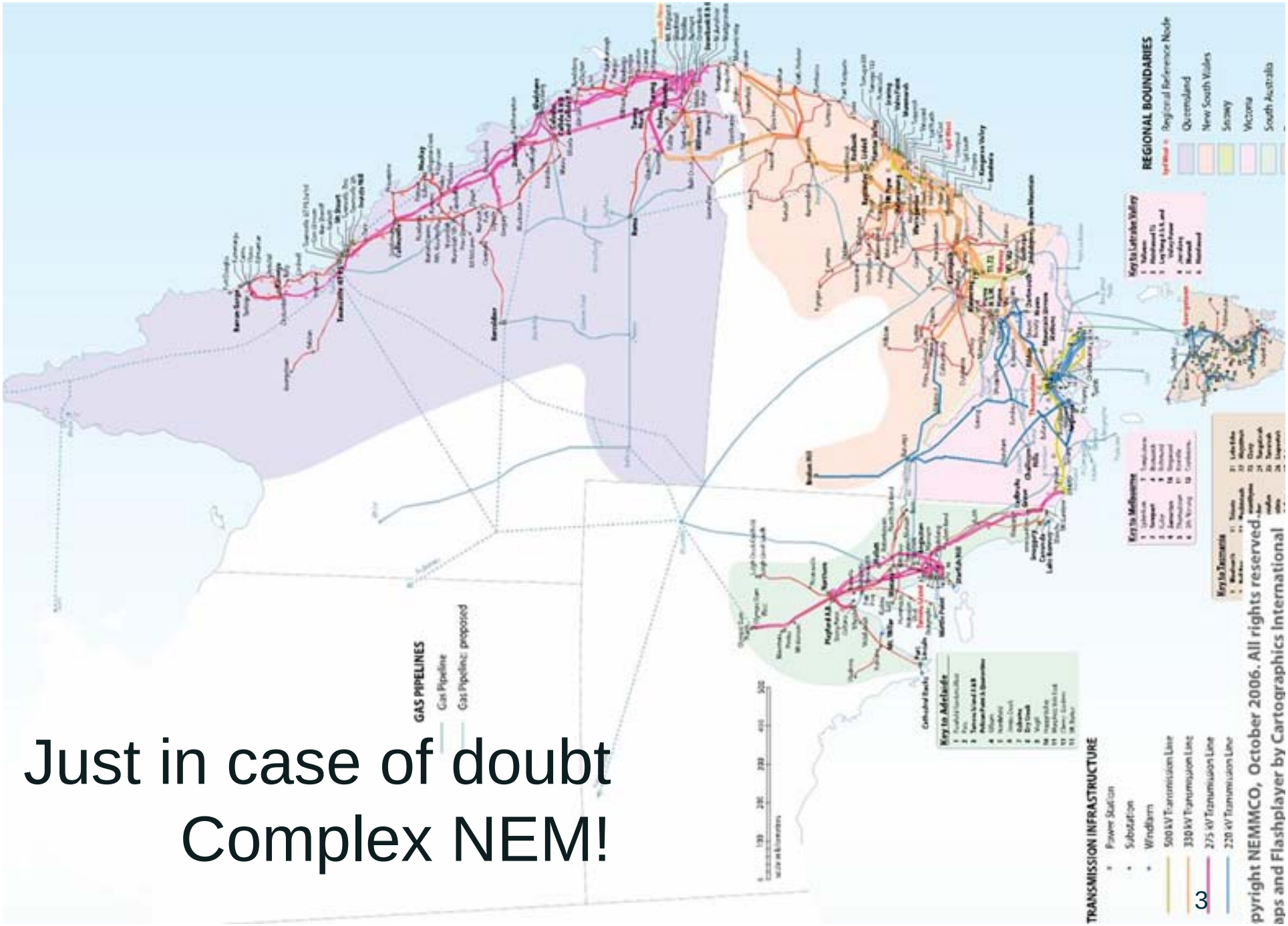
Why Vehicle-to-Grid (V2G) / Plug-in-Hybrids?

- Current electricity grids under stress (Transmission and distribution) due to high-tech driven demand growth.
- Energy economy under stress due to rising oil prices and electricity market deregulation.
- Last, but not least, Climate Change.
- A potential Enabling technology for large scale deployment of intermittent renewable generation

Gerald L. Kulcinski
College of Engineering
University of Wisconsin-Madison, 2005

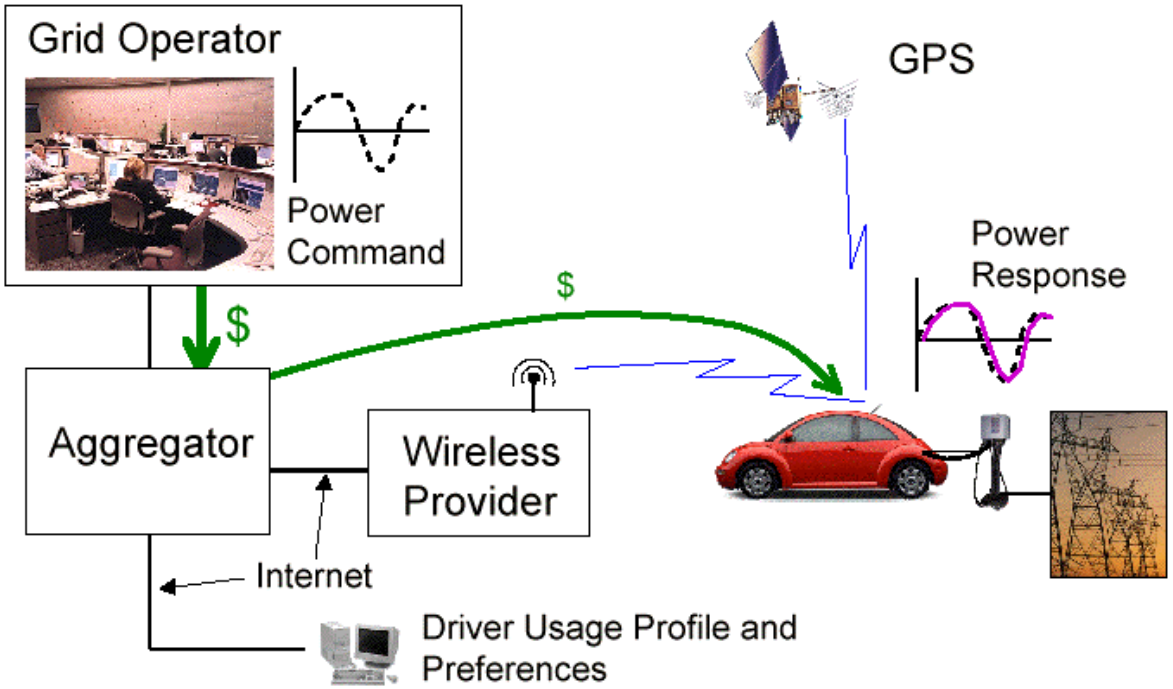
Only possible recently:

- Due to broadband communication and evolving multi-agent based system technology
- This talk describes the methodology for the analysis required to make an economic case for V2G.
- Pumped storage representation of V2G



Just in case of doubt
Complex NEM!

The V2G system: a future complex system



- Each car has is its own automated economic agent responding to market signals provided by the Aggregator.
- This response is parameterised by a commercial contract between the owner and the Aggregator. E.g.
  - Value of approaching empty charge
  - Value of excessive charge-discharge cycles
- Aggregator has a virtual pumped-storage power station whose response parameters are emergent

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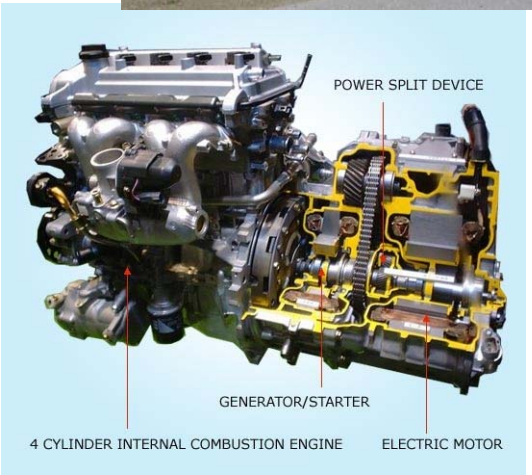
Toyota Prius case study

'06 Prius, $37,000 RRP

- 4.4 L/100km
- 10.9 sec 0-100kph

- 1.5 litre petrol ICE, 56kW
  - Atkinson cycle (vs. Otto)
  - 34% efficient at 13.5 hp
- Two permanent magnet motors
- Power electronics: 3ph inverters matched to motors
  - 50kW total at 500V
- NimH battery pack:
  - nominal 274V, 6.5 Ah (1.8 kWh)
  - 20kW rating at 50% SOC

Breaking News!
Totyota Annouced:
All Hybrids by 2020!



EnergyCS

- Original Prius NimH pack replaced with
- 127kg Lithium-ion Batt pack
- 35-40Ah, 9kWhr
- Uses off-the-shelf Valence Technology Saphion U Li-ion batteries.

Sources: http://www.calcars.org/priusplus.html

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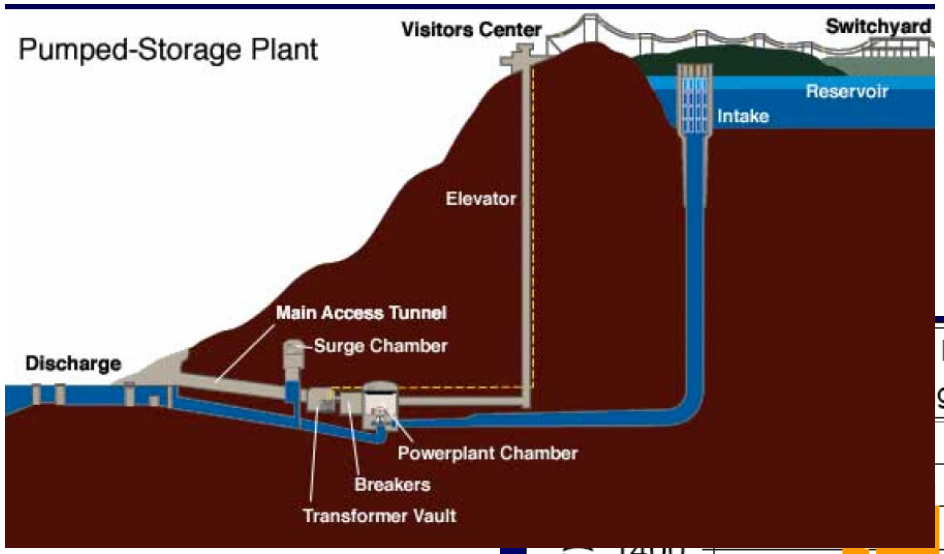
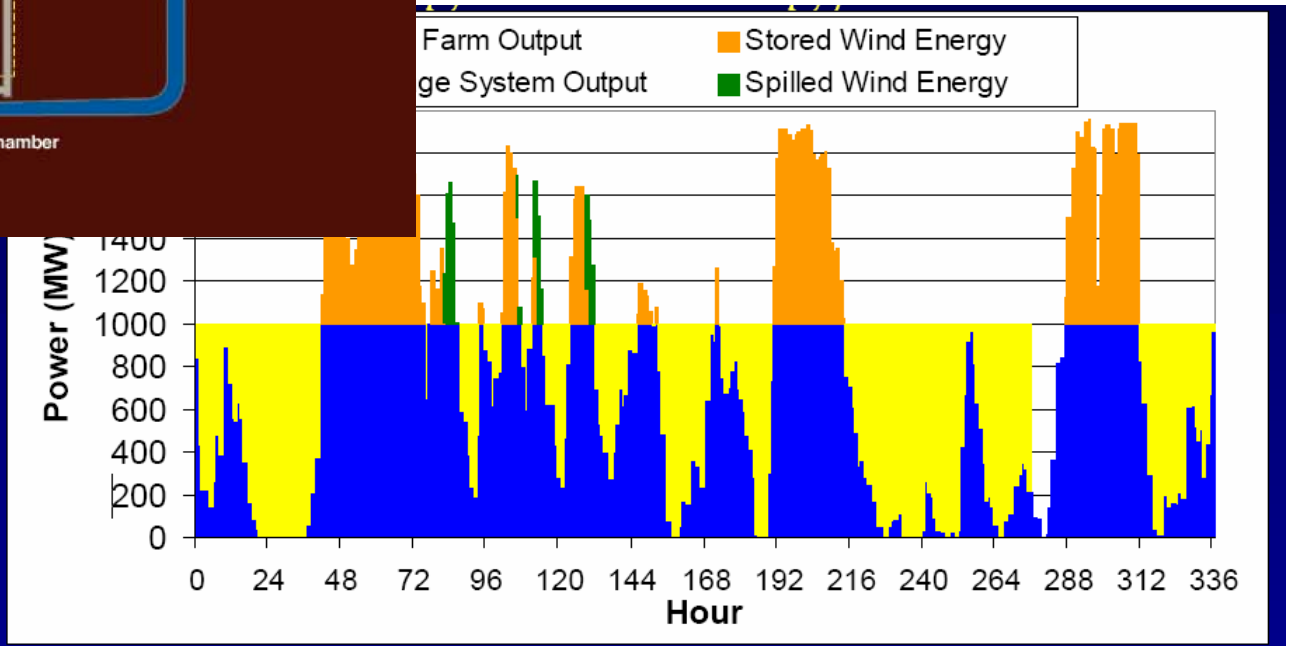
Pumped Storage and Renewables





Model demonstrating performance of a 1000 MW wind power plant, capable of providing 11% of Wisconsin's 2002 demand.

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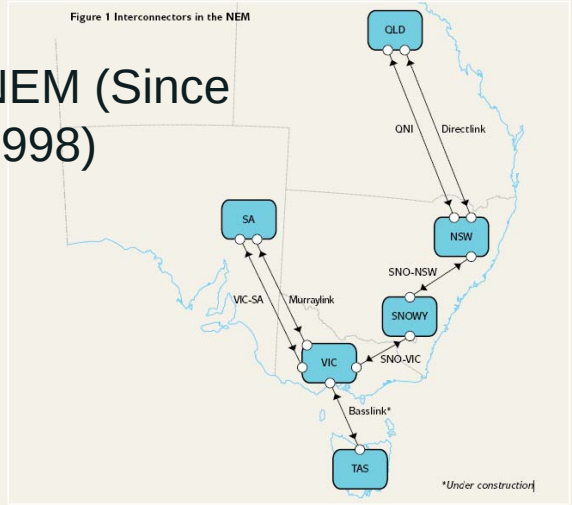
An early case study: The NEM with V2G
Using Plexos' Pumped Storage Hydro optimisation mode

NEM (Since 1998)



- We used Energy Exemplar's Plexos Market simulation software (http://www.energyexemplar.com)
  - Mixed Integer Programming production scheduling model
  - National Electricity Market database kindly provided by Glenn Drayton
  - Models Pumped Storage Hydro as a dynamic program
  - Nash-Cournot Market equilibrium (uniform agent rules)

Year	*Hybrids*	*Cumulative Hybrids*	*kWh / car*	*kW / car*	*Cummulative Total MWh*	*Cummulative Total MW*
2003	300	300	1.3	20	0.39	6
2004	1000	1300	1.3	20	1.69	26
2005	1000	2300	1.3	20	2.99	46
2006	3000	5300	1.3	20	6.89	106
2007	3000	8300	1.3	20	10.79	166
2008	10000	18300	9	20	100.79	366
2009	10000	28300	9	20	190.79	566
2010	30000	58300	9	20	460.79	1166
2011	30000	88300	9	20	730.79	1766
2012	120000	208300	9	20	1810.79	4166
2013	120000	328300	9	20	2890.79	6566
2014	200000	528300	9	20	4690.79	10566
2015	200000	728300	9	20	6490.79	14566

Preliminary Results: 9kWh Plugin Hybrid

Average peak and off-peak yearly prices

Base Case	Property	Timeslice	NSW1	QLD1	SA1	SNOWY1	TAS1	VIC1
	Price $/MWh	NEM Off-Peak	19.93	17.81	30.01	20.29	28.58	19.65
	Price $/MWh	NEM Peak	27.51	26.02	40.46	28.22	31.00	29.61

Scenario	Property	Timeslice	NSW1	QLD1	SA1	SNOWY1	TAS1	VIC1
	Price $/MWh	NEM Off-Peak	18.47	16.31	29.86	18.84	27.98	18.36
	Price $/MWh	NEM Peak	26.23	24.85	41.09	26.85	29.85	28.19

System property differences (Scenario - Base)

Property	Units	NSW1	QLD1	SA1	SNOWY1	TAS1	VIC1	**Total**
Energy	GWh	98	1	1	29	0	-1	**128**
Peak Load	MW	0	0	0	0	0	0	**0**
Price	$/MWh	-1.38	-1.36	0.20	-1.41	-0.84	-1.35	**-1.02**
Load-weighted Price	$/MWh	-1.29	-1.18	0.26	0.00	-0.83	-1.23	**-0.85**
Generator Net Profit	$000	-94,101	-75,734	4,220	0	-1	-68,469	**-234,085**
Transmission Rental	$000	13,088	-1,546,492	-54,609	7,400	15,111	-288	**-1,565,790**

System level changes emerging

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Conclusion

- Early results indicate a promising future!
- Where are the complex system effects? Required for next stage of modelling:
  - Performance of Aggregator's Virtual Generator depends on collective behaviour of Battery Management Systems (BMS) with DIFFERENT performance parameters
  - Interaction between Grid Stability and 100,000's to 1,000,000's of Plug-in-Vehicles traded into a market by 10's of aggregators
  - Requires enhanced market simulation tools which can model individual car BMS's when parameters
- Include intermittent renwables
- Thanks:
  - Peter Lindsay
  - Glenn Drayton, Energy Exemplar, Creator of Plexos
  - Rizah Memisevic, ACCS / Powerlink, Joe Dong, Tapan Saha
  - Australian Research Council