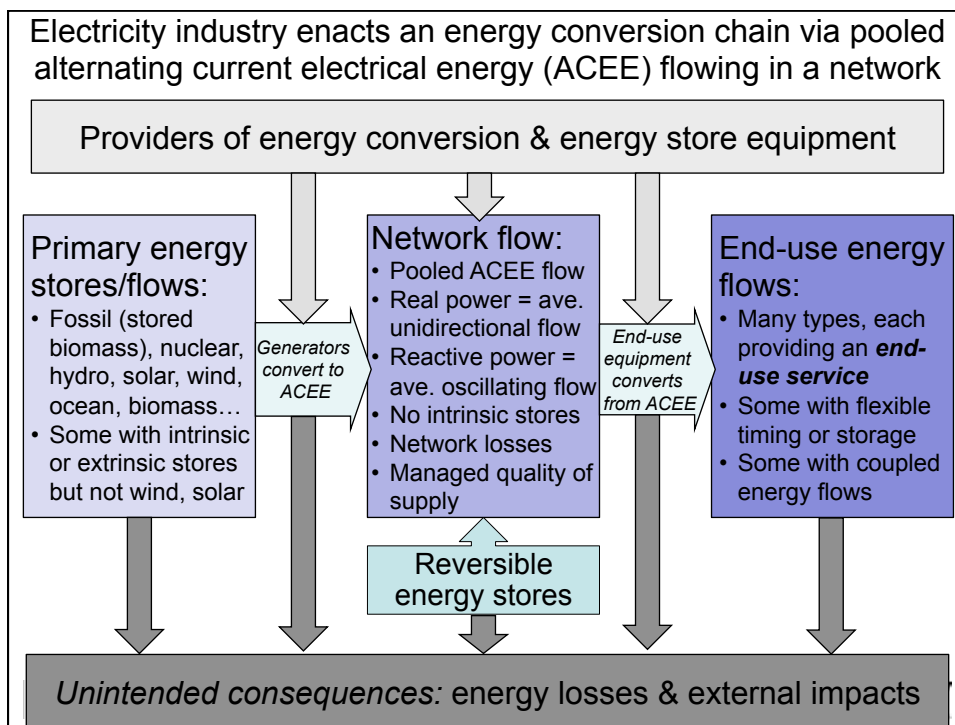


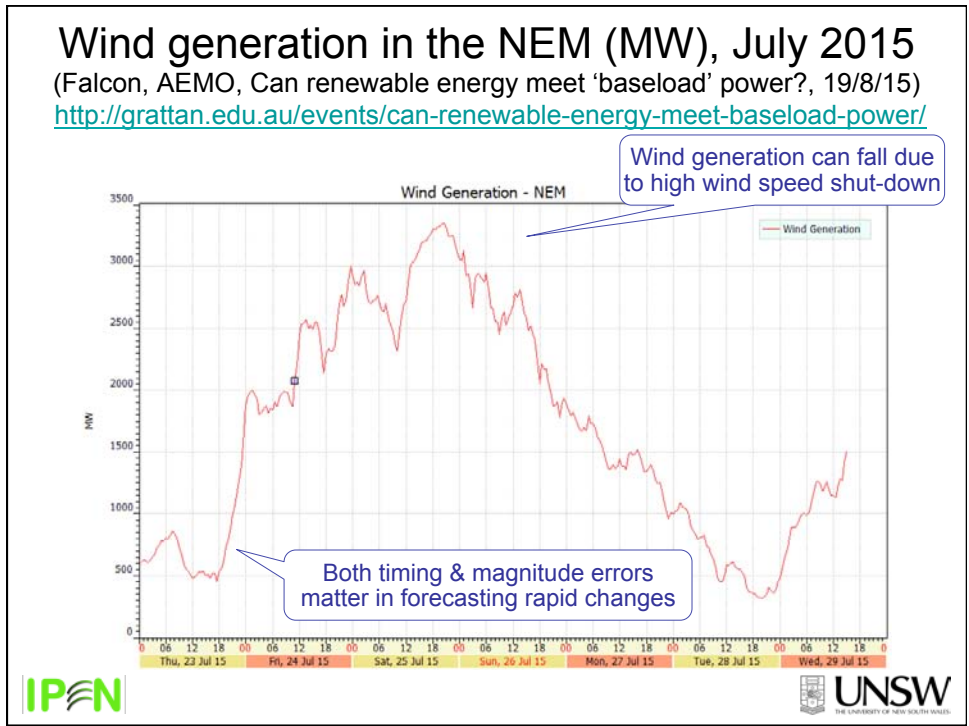
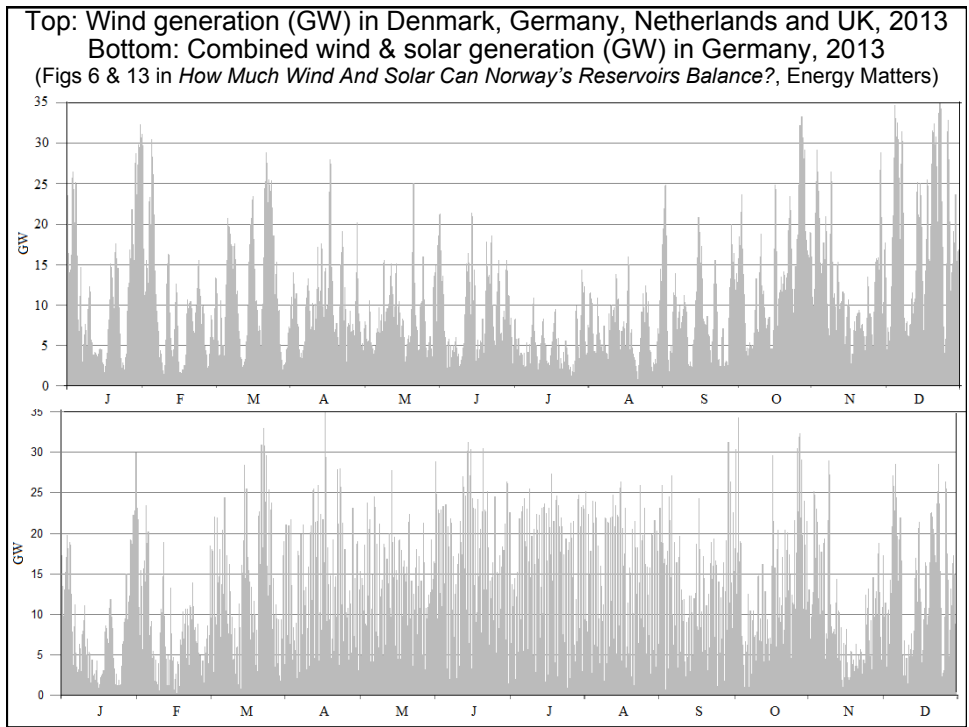
## Implications of high-penetration solar & wind generation & energy storage for the National Electricity Market

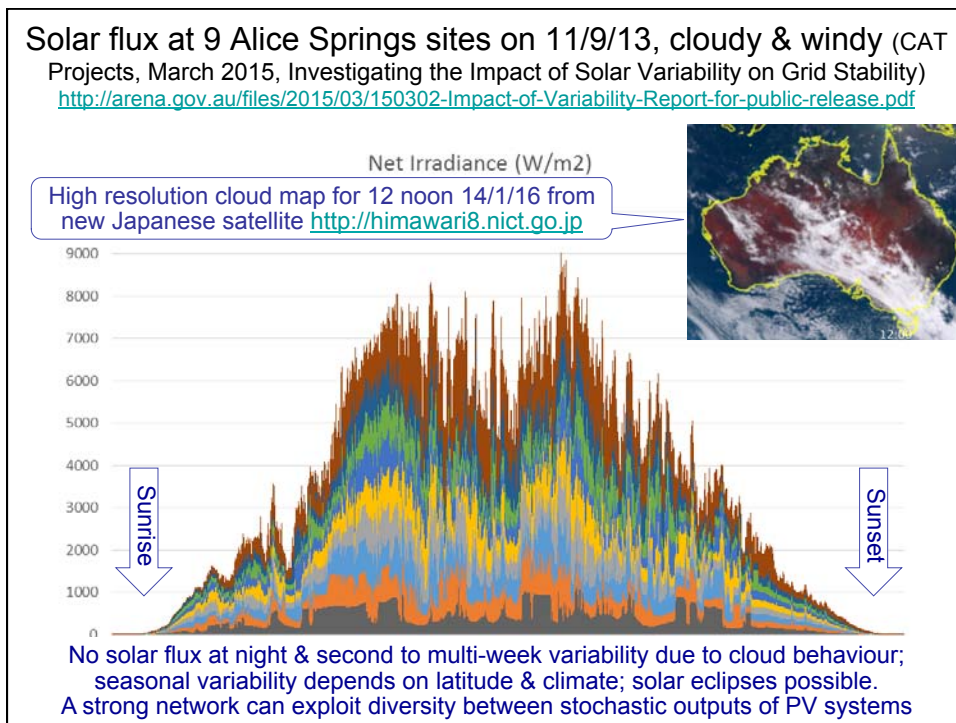
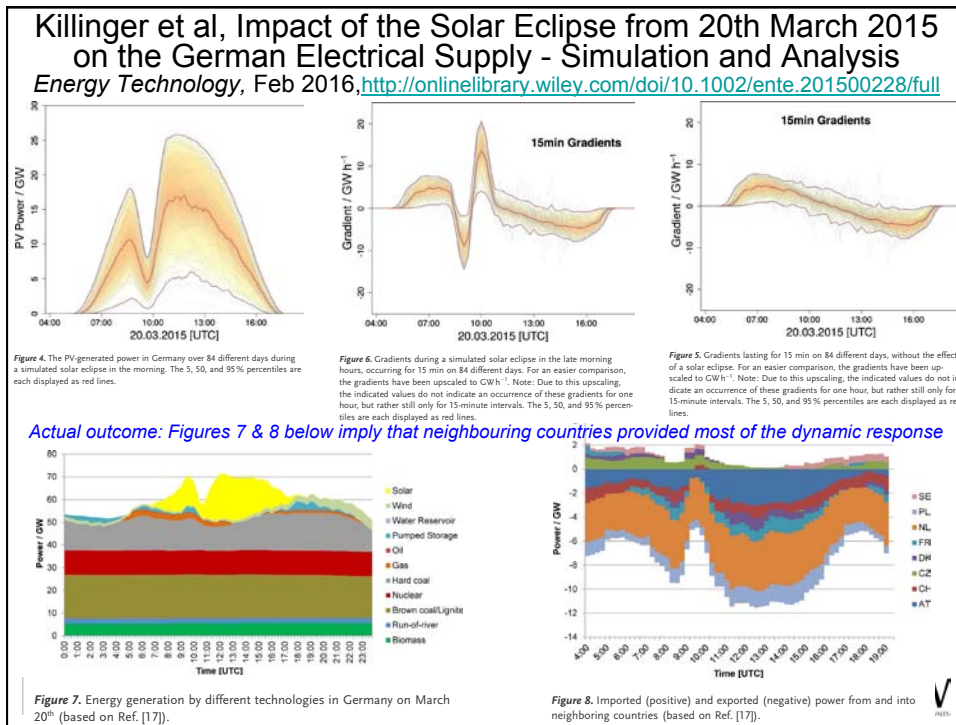
Australian Institute of Energy Seminar, Sydney, 28/4/16

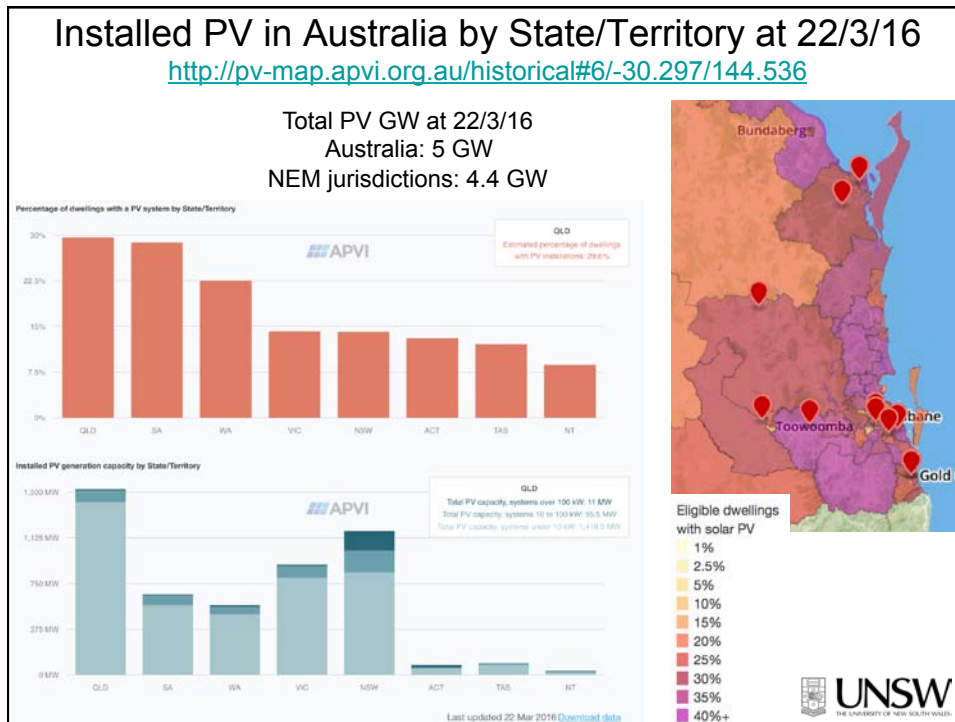
Hugh Outhred  
University of New South Wales and Ipen Pty Ltd

*The scope of this talk will be more fully addressed in  
Australian Energy Week Learning Session D, 20/6/16*  
<http://www.questevents.com.au/australian-energy-week-2016/depth-learning-sessions>

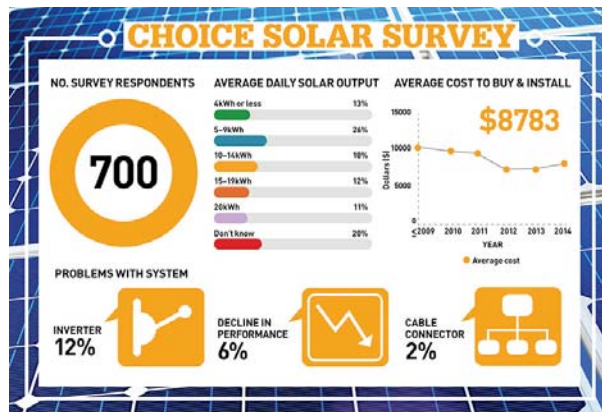








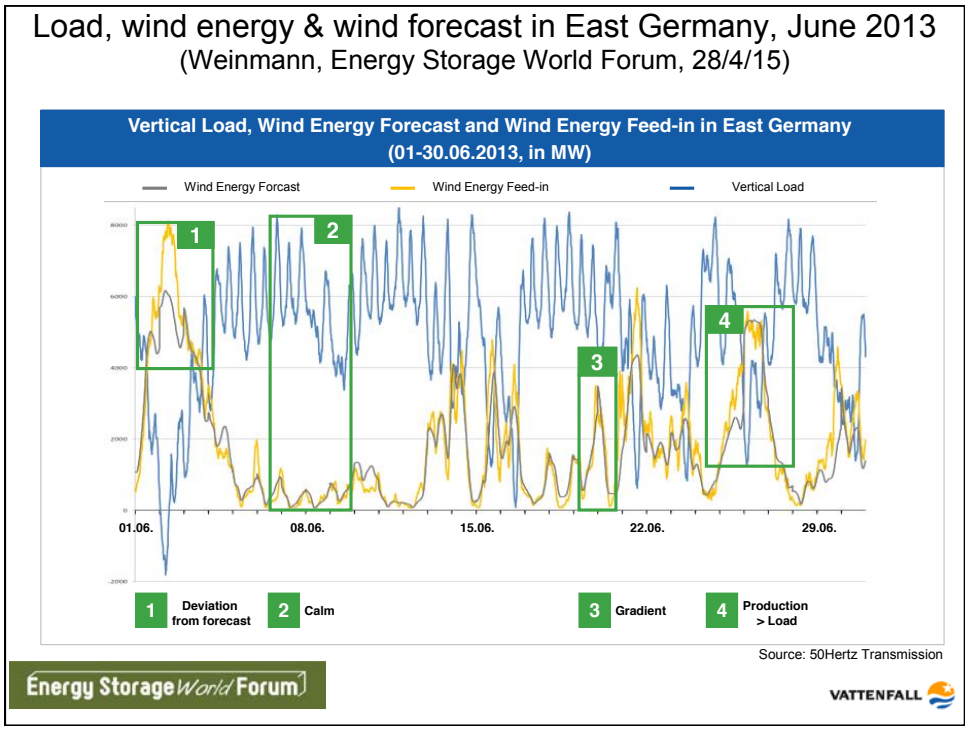
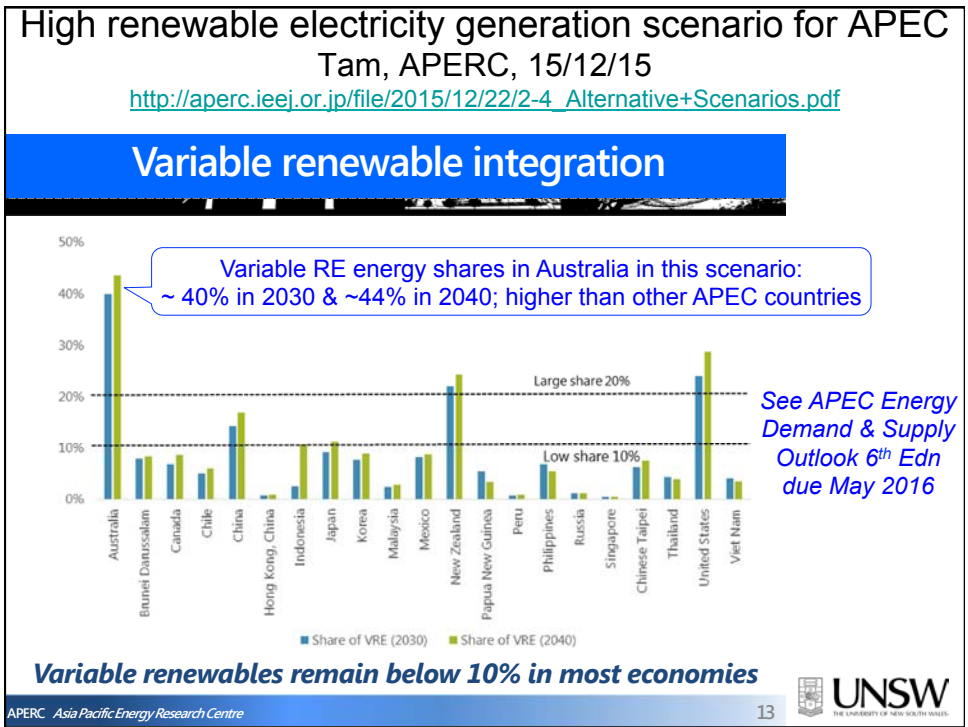
<https://www.choice.com.au/home-improvement/energy-saving/solar/articles/solar-power-survey-results>

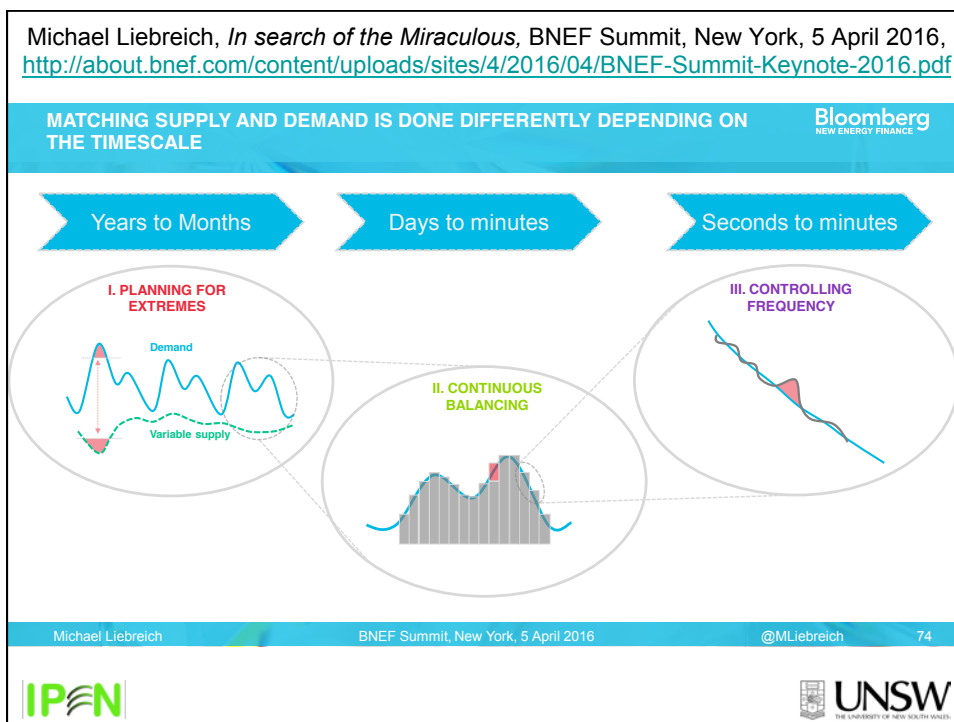
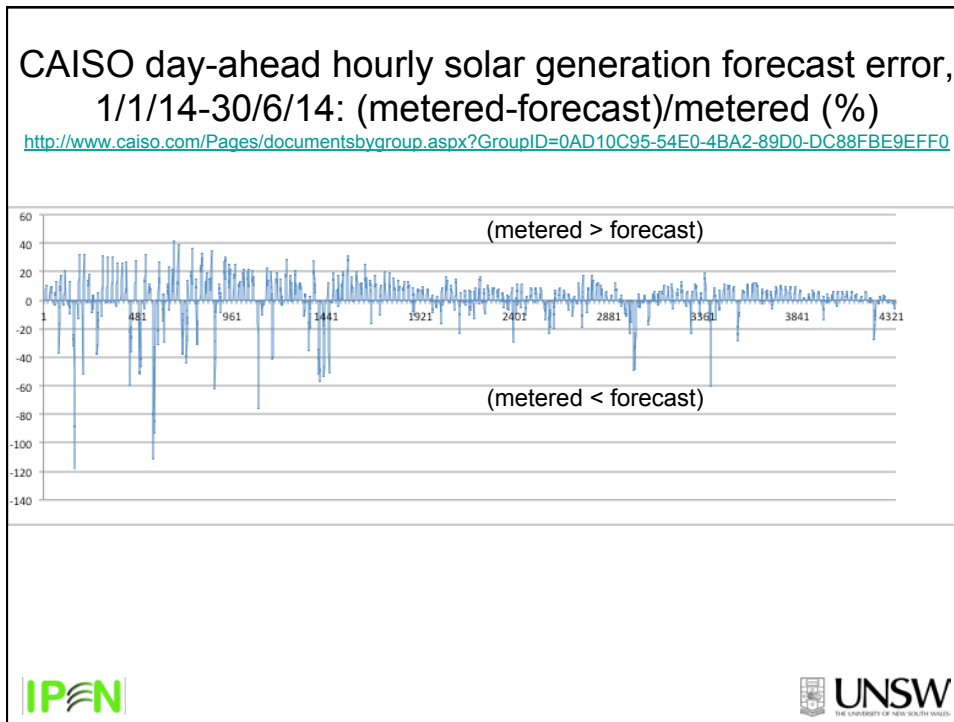


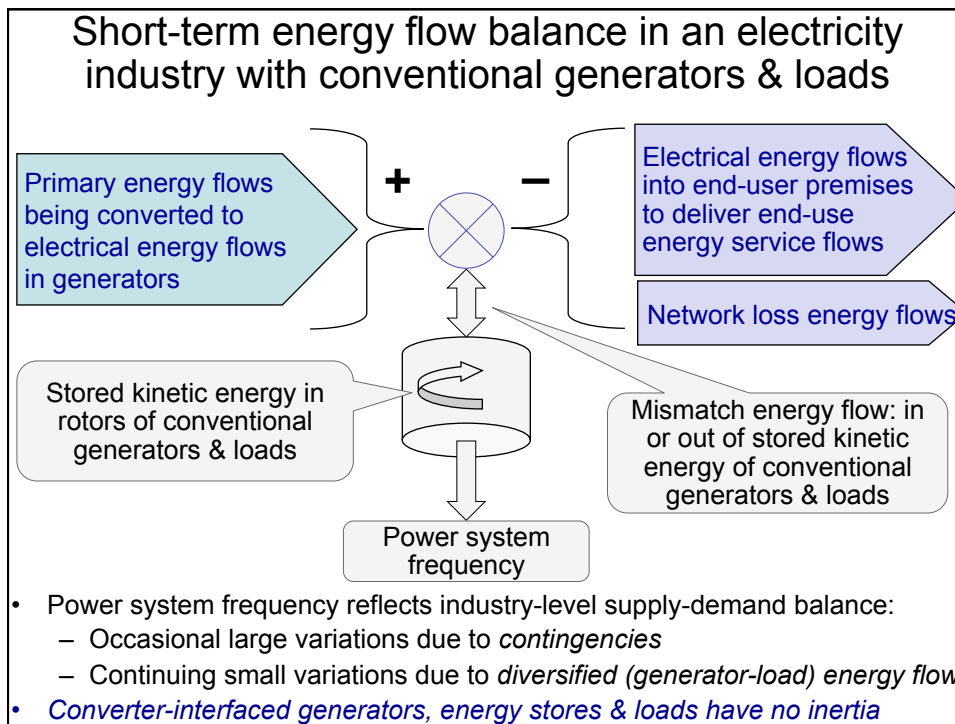
AEMO, 2015 National Electricity Forecasting Report, Detailed Summary, June

Table 5 Proportion of rooftop PV relative to residential and commercial underlying consumption

	Queensland	New South Wales	South Australia	Victoria	Tasmania
2014-15	5.7%	2.4%	8.4%	2.7%	3.0%
2017-18	9.1%	3.7%	11.9%	4.4%	4.9%
2024-25	16.0%	6.3%	22.1%	8.6%	11.0%
2034-35	20.2%	9.3%	28.5%	13.7%	17.4%

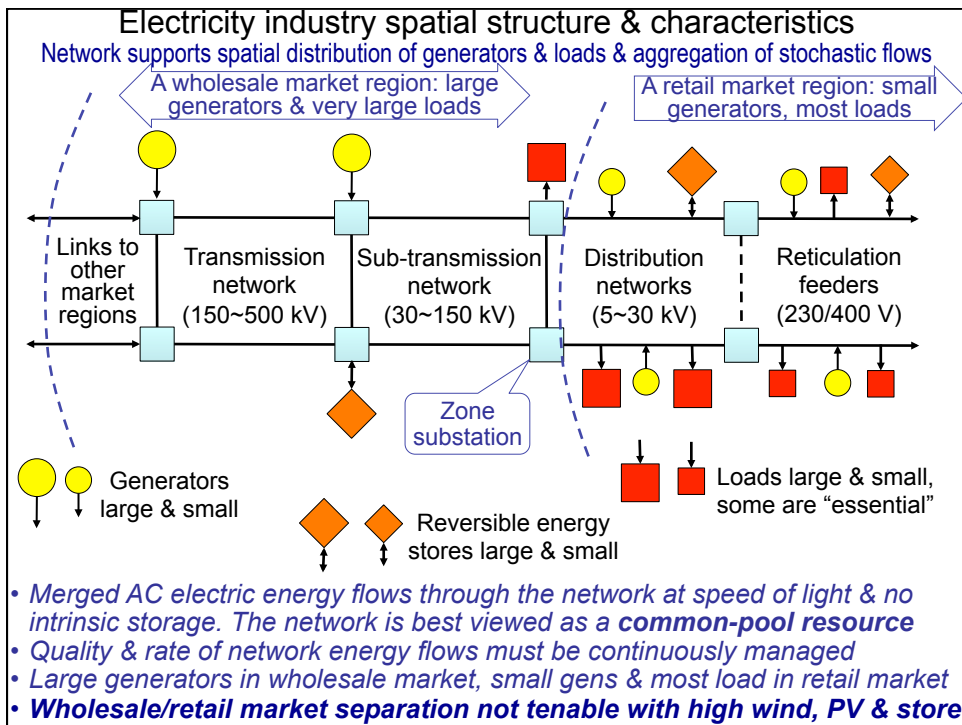
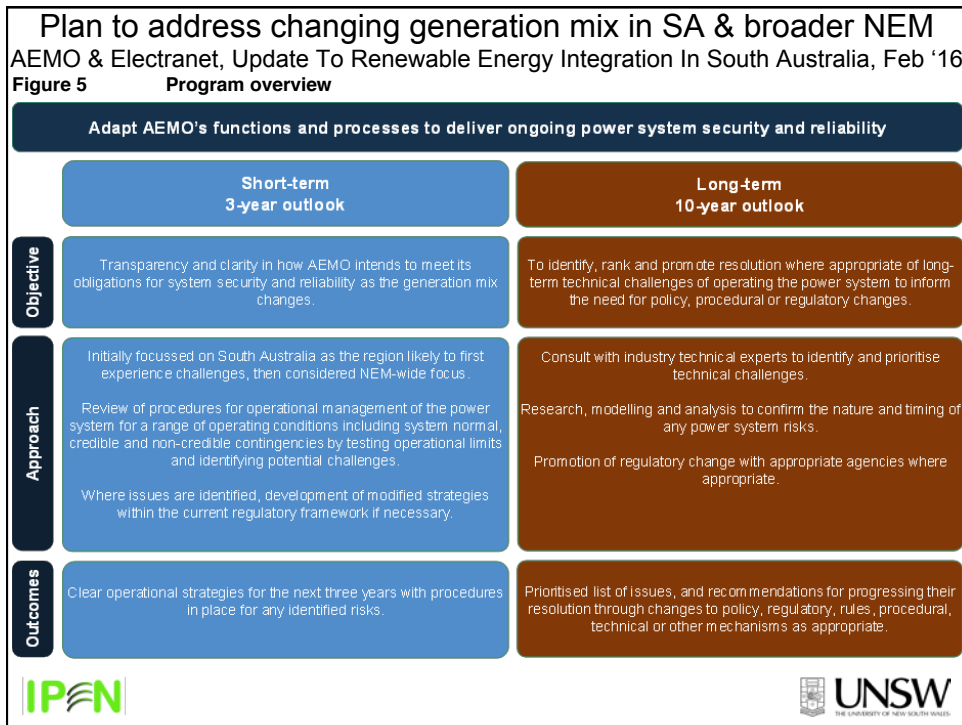







(AEMO, Renewable Energy Roadshow, August 2015, [www.aemo.com.au](http://www.aemo.com.au))

- **Develop a systematic / comprehensive approach to studying the operating limits of the power system as the generation mix changes**
- **Develop comprehensive range of technical issues associated with managing a power system with little or no synchronous generation**
- **Develop the analysis tools and models to analyse performance of a power system with little or no synchronous generation**





THE UNIVERSITY OF NEW SOUTH WALES



SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE  
DEPARTMENT OF ELECTRIC POWER ENGINEERING  
REPORT DEPE 87.132  
**Welfare Maximizing Prices Under Uncertainty**

R. John Kaye & Hugh R. Outhred

School of Electrical Engineering and Computer Science  
University of New South Wales  
Kensington, Australia

October 1987  
Revised: January 1988

*Abstract: This paper presents a new result in the theory of optimal pricing for public utilities or regulated monopolies. The derivation is based on a detailed model of consumers and suppliers which represents uncertainty and inter-temporal linking effects such as investment and storage. Thus the time evolution of the industry is accounted for. The optimal pricing structure would cause individual profit maximizing responses to be welfare maximizing. It contains two terms: Short Run Marginal Cost (SRMC) pricing as well as a new "incentive term" to account for the interaction of participants at different time points. A probabilistic forecast of pricing structures at future times is also required.*

[http://ipenconsulting.com/yahoo\\_site\\_admin/assets/docs/198801\\_WelfareMaxPricingKayeOuthred.113191834.pdf](http://ipenconsulting.com/yahoo_site_admin/assets/docs/198801_WelfareMaxPricingKayeOuthred.113191834.pdf)

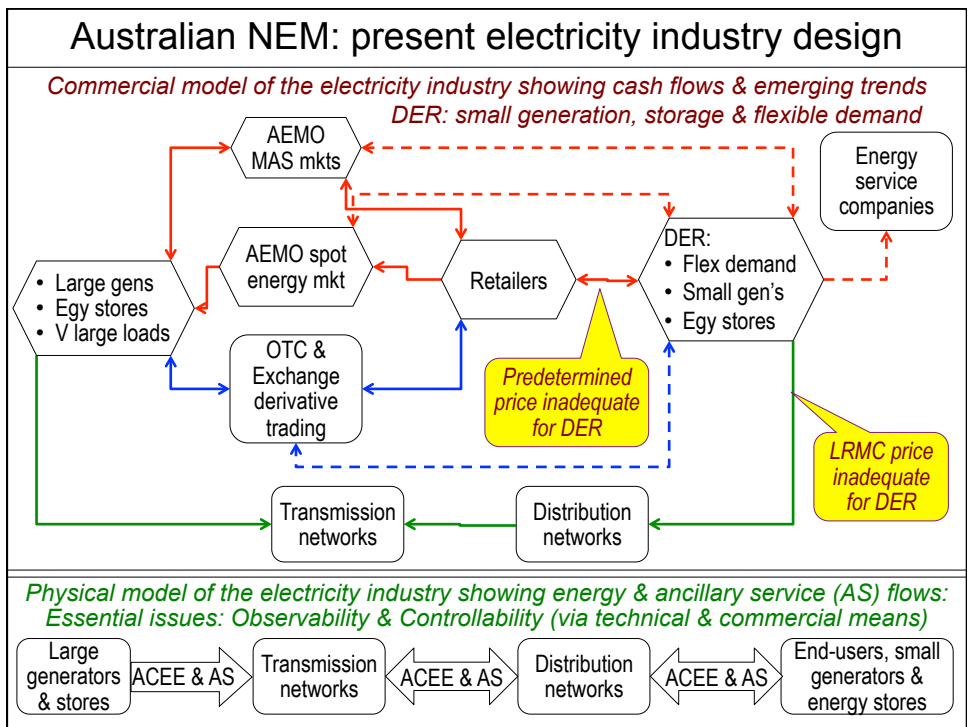
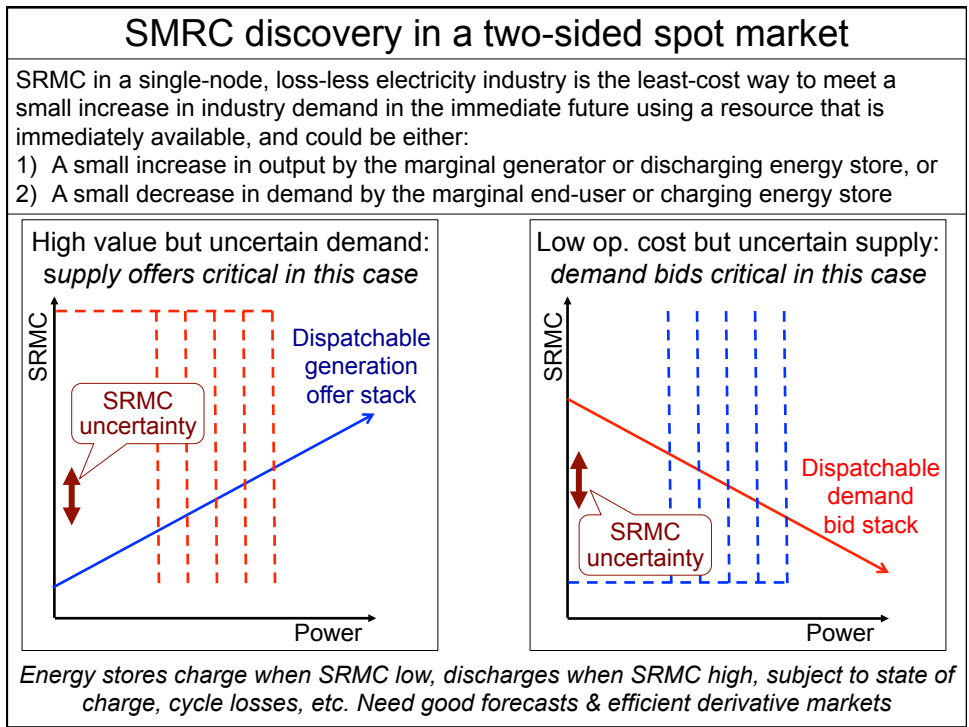
*"...all models are wrong but some are useful" George EP Box (1987)  
Markets alone, e.g "Power Of Choice" are not enough*

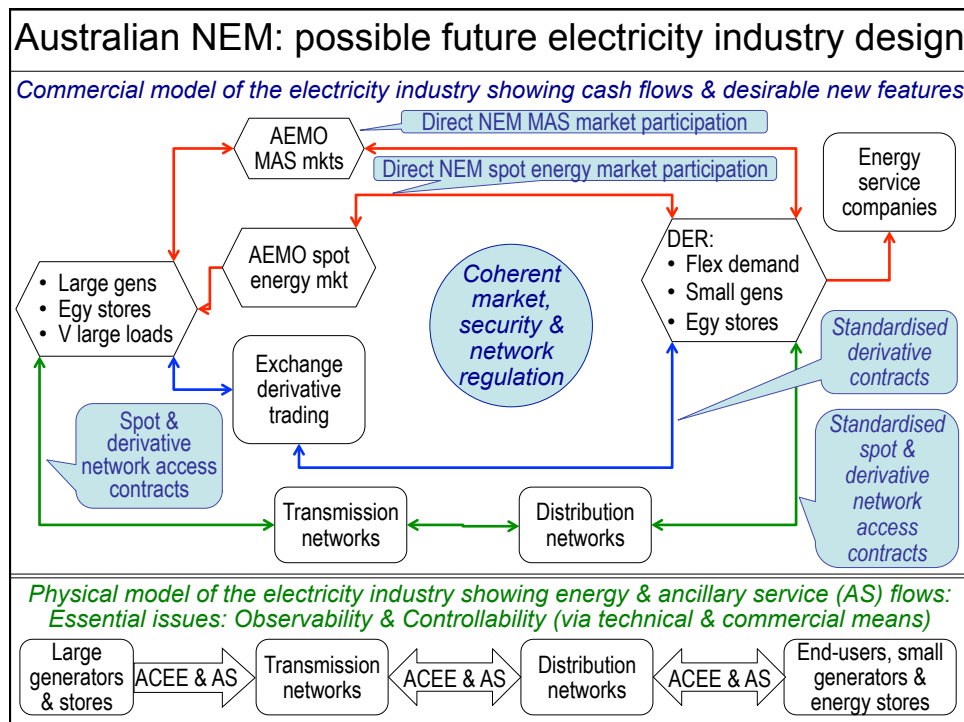
**Key properties of *efficient pricing policies under uncertainty*:**

- Apply symmetrically to buyers & sellers, support efficient decisions with inter-temporal links, such as storage or investment; guide network pricing
- *The efficient pricing policy* for a participant is ex-ante SRMC *plus* an incentive term exposing it to the effect of its decisions on the future profits of all participants *plus* probabilistic forecasting of future policies.
- *The efficient pricing policy* depends on quantity information & evolves. It can be implemented via spot & derivative markets for energy or price/quantity contracts for network access. *A predetermined price, e.g. LRMC, is wrong*
- The incentive term is negligible for small participants in context (price takers)

**Some publications that expand on Report DEPE 87.132:**

- Kaye and Outhred (1989), A theory of electricity tariff design for optimal operation and investment, IEEE Trans. Power Systems, Vol. 4, No. 2, pp 606-613, <http://ieeexplore.ieee.org/xpl/tocresult.jsp?isnumber=5012>
- Outhred et al (1988), Electricity pricing for optimal operation and investment by industrial consumers, Energy Policy, August, pp 384-393  
<http://www.sciencedirect.com/science/article/pii/0301421588901851>
- Kaye, Outhred & Bannister (1990), Forward contracts for the operation of an electricity industry under spot pricing, IEEE Trans. Power Systems, Vol. 5, No. 1, pp 48-52, DOI: [10.1109/59.49085](https://doi.org/10.1109/59.49085)





## Conclusions

- Increasing wind, PV & storage penetration is having a disruptive effect on NEM design & operation:
  - Small generators, energy stores and flexible demand need to participate directly in NEM MAS, spot energy & derivative markets, with improved forecasting integration
  - Energy services companies should replace retailers
  - Network access contracts require a spot & derivative commercial/technical structure that contributes to managing flow quality, network constraints & investment
  - Ancillary services need ongoing review with respect to evolving technology, eg. converter interface generators
- Constraints on wind, PV &/or storage penetration may still be required in some circumstances

## Hugh Outhred Bsc, BE (Hons 1), PhD



Hugh Outhred is the Managing Director of Ipen Pty Ltd, which provides advisory and educational services on energy, society and the environment. He is also a Senior Visiting Fellow at the University of New South Wales, Sydney and Guru Besar Luar Biasa (Visiting Professor) at STTNAS Jogjakarta, Indonesia.

Hugh retired in 2007 after a 35-year career at the University of New South Wales, most recently as Presiding Director, Centre for Energy and Environmental Markets and Head, Electrical Energy Research Group, School of Electrical Engineering and Telecommunications.

Hugh has been a Fulbright Senior Fellow at the University of California Berkeley, a Member of the National Electricity Tribunal, a Member of the New South Wales Licence Compliance Advisory Board, a Board Member of the Australian Cooperative Research Centre for Renewable Energy, an Associate Director of UNSW's Centre for Photovoltaic Devices and Systems, a Member of CSIRO's Energy Flagship Advisory Committee and a Lead Author for the IPCC Special Report on Renewable Energy Sources & Climate Change Mitigation, 2012.

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