Outline

- The stationary energy sector
- Characteristics of the electricity industry
- The electricity industry design challenge
- Energy flow & climate change constraints
- Characteristics of renewable energy generation
- Key issues for high levels of renewable energy
Energy service delivery in the stationary energy sector (many decision-makers involved)

Primary energy forms e.g: coal, gas, nuclear, renewable

The electricity supply industry
- generation
- transmission
- distribution

Equipment providers

The natural gas supply industry
- treatment
- transmission
- distribution

end-use equipment delivering energy services eg: light, heat, motive power

energy losses & external impacts
Electricity industry characteristics

- Complex & fragile energy conversion chain:
  - Continuous flow from primary to end-use energy forms:
    - Electrical energy is a non-storable intermediate energy form subject to shared network losses & shared flow constraints
    - Some primary energy forms are also flow constrained
    - Industry-wide, “just-in-time” nature & long asset lives:
      - Infused with shared, short-term & long-term risks
    - Network-related, location-specific behavior & risks:
      - Device-related & system security flow constraints & network losses, only some of which are readily commercialized

- Societal infrastructure role:
  - Public as well as private values
The electricity industry design challenge

- Overarching objective: to design, implement & then improve a “decision-making framework” that:
  - Appropriately allocates tasks to all industry decision-makers, with meaningful incentives & penalties
  - Delivers socially-beneficial future outcomes:
    - From very short-term to very long-term
    - Sensitive to location & to infrastructure role

- Process objective: implement processes that can:
  - Achieve an initial industry design that is adequate
  - Deliver sound implementation of that design
  - Improve the decision-making framework over time
Critical issues in electricity industry design

- Governance & rule-change process:
  - On-going, forward-looking, monitoring & enhancement
- Temporal risk management:
  - Coherent framework from very short to very long term
- Primary energy flow-constraint risk management:
  - Wind & solar energy, natural gas
- Locational risk management:
  - Systematic combination of market representation & regulated network services
- Active end-user participation:
  - To establish time-varying values of energy services
Decision-makers in a restructured electricity industry

- Politicians & bureaucrats
- Regulators
- System & market operator(s)
- Regulated industry participants
- Competitive industry participants

Other societal stakeholders
### Decision-making framework for a restructured electricity industry (EI)

| Governance regime | ▪ Formal institutions, legislation & policies  
|                   | ▪ *Informal social context including politics* |
| Security regime   | ▪ Responsible for core integrity on local or industry-wide basis, with power to override |
| Technical regime  | ▪ Engineering design to allow industry components to function as single, industry-wide machine when connected together |
| Commercial regime | ▪ Decentralised decision-making according to commercial criteria within a market context  
|                   | ▪ Includes formally designed markets  
|                   | ▪ *Needs adequate competitive pressures* |
Comparison of decision-making styles

- **Engineering decision making** *(security & technical regimes)*:
  - Assumes participants act in “good faith”
  - Data is best estimate of actual phenomena
  - Criterion is engineer’s interpretation of “public good”

- **Commercial decision-making** *(commercial regime)*:
  - Assumes participants act to maximise their own outcomes
  - Data is probably biased towards participant self interest:
    - “Under conditions of competition, standards are set by the morally least reputable agent” (attributed to John Stuart Mill)
  - Criterion is the “private good”

- **Governance decision-making**:
  - Some stakeholders may have excessive influence
Trading in electricity: an abstraction from reality

- **Main commercial markets** (humans; individual; abstract)
  - **Externalities**
  - **Economic models** (humans; collective; abstract)
  - **Engineering models** (equipment; collective; abstract)
  - **Physical electricity industry** (equipment; collective; concrete)

- **Security regime & Regulation** (centralised)

Policy, legal & regulatory context
The Australian National Electricity Market (NEM)

Generation Sector:
- Large generators
  - Gen 1
  - Gen 2
  - Gen 3
  - Gen X

Transmission Sector:
- NSW
- Victoria
- South Aust.
- Queensland
- Tasmania

Multi-region National Electricity (spot) Market (NEM)

Financial instrument & REC (emission) trading

Retail sector:
- Retailer 1
- Retailer 2
- Retailer Z

Electricity

Distribution sector:
- Distributor 1
- Distributor 2
- Distributor Y

Retail Markets

Electricity

End-use sector:
- Embedded generators
- Contestable end-users
- Franchise End-users

Electricity

End-use Equipment & Distributed resources

Network access

Tx network pricing

Intentions offers & payments

Intentions bids & payments

Networking diagram illustrating the integration of renewable energy into the Australian electricity industry.
Each offer is for one 5-minute dispatch period; must be submitted 1 day ahead but then changeable until ~1 minute before dispatch period.

A simplified representation of bids from a 600 MW generating unit that indicates the capacity the generator is willing to offer to the NEM at a range of prices.
NEM commercial & security processes

- **1 hr ahead, 5 min res.  5 min update**
- **10 yr ahead, 1 yr update**
- **30 min predispatch**
- **Medium Term (MT) PASA**
- **Short Term (ST) PASA**
- **5 min dispatch & pricing** (4 sec AGC, online security processes)
- **5 min disp.**
- **upto 40 hr ahead, 30 min res. 30 min update**
- **1 wk ahead, 30 min res., 2 hr update**
- **upto 2 yr ahead, 1 day (MD) res., 1 wk update**

**Pre-dispatch, PASA & SOO processes are advisory only & have no commercial significance**

**Statement of Opportunities**

**Prices for the next 5 minutes are the only commercial prices**

Source: NEMMCO; S Thorncraft

(PASA: Projected Assessment of System Adequacy)
Scope of the NEM:

- Serves a population of about 18 million
- Network length ~2,500 miles
- Uniform National Electricity Rules for market & security
- Single state-owned system & market operator (NEMMCO)
- Six market regions with “hub & spoke” approximation to nodal pricing (Snowy region to be removed)
Evolution of Australian electricity industry design

- Conceptual foundation (based in Engineering & Economics):
  - Outhred & Schweppe, *Quality of Supply Pricing*, IEEE, 1980
  - Outhred, *Principles of a Market-Based Electricity Industry*, IEE, 1993

- Practical implementation:
  - COAG brief to NGMC, 1990: *Design an electricity industry that is economically efficient & environmentally sound*
  - Differing & evolving Victorian & NSW internal market designs, 1994-97, including computer simulation of NEM trading rules at UNSW, 1995-6
  - Australian National Electricity Market (NEM) from 1998
Governance for Australia’s stationary energy sector

- Council of Australian Governments (COAG):

  - Monitors energy markets & regulates Network Service Providers

  - Manages rule change for electricity & gas markets
  - Undertakes investigations for MCE

- Australian Energy Market Organisation (AEMO):
  - Enhanced version of National Electricity Market Management Company (www.nemmco.com.au) that will implement national electricity & gas markets & associated security regimes
National Electricity Law: Overall objective for the National Electricity Market (NEM)

- **NEL Section 7:**
  - The national electricity market objective is to promote efficient investment in, and efficient use of, electricity services for the long term interests of consumers of electricity with respect to price, quality, reliability and security of supply of electricity and the reliability, safety and security of the national electricity system.

- **Features of this objective:**
  - Group & individual perspectives; short & long timescales
  - But ambiguous with respect to interpretation & trade-offs between sub-objectives
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Prices for key energy commodities (BP Review 2007)

Consistent with the ‘peak-oil’ scenario; gas & coal also affected

Index 1991=100

- Oil (dated Brent)
- Gas basket
- Coal basket
- Weighted average

Actual emissions at or above “BAU” (Raupach et al, PNAS, April 2007)
Issues for enhancing EI sustainability

- Energy security & rapid climate change are challenging problems
- Response tasks must largely be delegated to industry participants (companies & individuals)
- Policies must correctly assign incentives & penalties to deliver a rapid, coherent response:
  - Through “socially-organised decision-making”
  - Emphasizing frugality, enhanced end-use efficiency & low emission generation technologies
- Must overcome fierce vested-interest opposition
Socially-organised decision-making

- Most human decision-making occurs within a social (group) context supported by public policy:
  - “Effective policies are those that support socially valued outcomes not only by harnessing selfish motives but also by evoking, cultivating and empowering public spirited motives” (Gintis, Bowles & Fehr (eds), *Moral Sentiments and Material Interests*, MIT press)
  - Electricity industry policy should have both goals

- An electricity industry is a complex technological system:
  - Electricity industry policy should reflect this
The Art of Knowing and Doing

The study of **technology** concerns *what* things are made and *how* things are made. Technology, from the Greek *science of (practical) arts*, has both a *material* and an *immaterial* aspect.

Technology = Hardware + Software + "Orgware"

**Hardware:** Manufactured objects (artifacts)

**Software:** Knowledge required to design, manufacture, and use technology hardware

"Orgware": Institutional settings and rules for the generation of technological knowledge and for the use of technologies

Technology's most important characteristic: **Continuous change**
Characteristics of renewable energy

- Energy fluxes with limited storage:
  - Solar, wind, hydro, biomass, geothermal, ocean

- Characteristics of renewable energy forms:
  - Geographical distribution is a function resource type
  - Energy fluxes may be time-varying & uncertain

- Characteristics of renewable energy technologies:
  - Electricity generation, direct end-use or fuels
  - May have economies of scale
Drought & electricity gen’n (coal & hydro)

Rainfall Deficiencies: 12 months
1 June 2006 to 31 May 2007
Distribution Based on Gridded Data
Product of the National Climate Centre

www.bom.gov.au
Prices apparently reflecting the impact of drought on coal & hydro power stations (may also be affected by speculation)
Australian wind resource

(Estimate of background wind (m/s) – Australian Greenhouse Office)

Approx. 4500 km
Rottnest Island, WA: 600kW

Emu Downs, Geraldton, WA: 80 MW, 48x1.65MW

Albany, WA: 22MW, 12x1.8MW

Alinta, Geraldton, WA: 90 MW, 55x1.65MW
Wind farm response to varying wind conditions

Power (MW) vs. Wind Speed (ms⁻¹) for 31st August 2005 (UTC)

- Blue line: Power (MW)
- Red line: Wind Speed (ms⁻¹)

Turbine cut-off at 25 ms⁻¹
This approach may be valuable for predicting the timing of large changes in summated wind farm output.

*Note: Timing of wind changes cannot be forecast with precision and positions are best estimates.*
PV Case Study for NSW Dept of Planning: Newington Solar Village (PV+SWH)

Photo: BP Solar
PV output variability (30 houses)
Geothermal energy - radioactive rock

Australia has plentiful radioactive rock at ~3,000m covered by insulating layers:- safe nuclear energy eg: Geodynamics trial at Cooper Basin, SA

Geothermal energy - grid connection

(Geodynamics, 2006)
Security & commercial regimes (global & local)

Unreachable or unacceptable futures

Present state

Secure operating limits (probabilistic)

Emergency control

Renewable energy increases future uncertainty but forecasts can help

Commercial regime Possible futures managed by decentralised decisions

Security regime Possible futures managed by centralised decisions

Growing uncertainty

Integrating Renewable Energy into the Australian electricity industry
Integrating Renewable Energy into the Australian electricity industry

Enhanced industry structure

**Generation Sector:**
- Large generators
  - Energy flow
  - Kinetic energy

**Transmission Sector**
- Energy flow

**Distribution sector**
- Energy flow

**End-use sector**
- (including DR)

**Multi-region five-minute energy & FCAS markets**
- Intentions, offers & payments
- Intentions, bids & payments

**Market & system operator (eg NEMMCO)**
- Access contracts

**ESCO’s**
- Services
- Cash flow

**Commercial Physical**

**Commercial Physical**

ESCOs: the missing players in the restructured electricity industry

AMI: the missing interface in the restructured electricity industry
Key electricity industry issues for high-penetration renewable energy #1

- **Structural issues:**
  - Robust security regime with security-constrained dispatch
  - Efficient commercial regime (operation & investment)
  - Effective regulation of network services
  - Compatible arrangements for gas industry

- **Development issues:**
  - Innovation in renewable energy technologies
  - Forecasting for security & commercial regimes
  - Active end-user participation (value, timing, efficiency)
  - Education & training in all relevant areas
Key electricity industry issues for high-penetration renewable energy #2

- Auction-style, security-constrained markets:
  - For spot energy, ancillary services & derivatives
  - Active end-users supported by ESCOs & equity policies

- Efficient network service regime:
  - Augmentation; availability & quality; distributed resources

- Renewable energy forecasting tools for:
  - Security, commercial & governance regimes

- Internalisation of un-costed fossil fuel externalities:
  - Carbon taxes
  - Development & deployment of low emission technologies
Many of our publications are available at:
www.ceem.unsw.edu.au