Resource Assessment, Techniques & Reporting

The Geothermal Institute
University of Auckland

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Te Whare Wānanga o Tāmaki Makaurau

Introduction & Outline

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1. **Resource Assessment & Project Stages**

2. **Resource Assessment Methods**

3. **Resource-Reserve Reporting**

4. **Use of Resource-Reserve Reporting (regulation): NZ - Philippines examples**

5. **Examples from Petroleum Reporting**

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1. Sources & background reading

- World Bank; Geothermal Handbook: Planning and Financing Power Generation; 2012 (also in Spanish) www.esmap.org/Geothermal_Handbook
- IRENA/GI; DRAFT Discussion Document on Geothermal Policy and Regulation; 2014
- SKM/NZGA (2005); Review of Current and Future Personnel Capability Requirements of the NZ Geothermal Industry www.nzgeothermal.org.nz/publications/Reports/NZGA_Geothermal_Capability_Review.pdf
- SKM (2009); Assessment of Current Cost of Geothermal Power Generation (2007 basis)
- SKM/EW (2002); Resource Capacity Estimates for High Temperature Geothermal Systems in the Waikato Region
- AGEA (2010); The Australian Geothermal Reporting Code

  http://www.agea.org.au/geothermal-energy/fact-sheets-resources/

  http://www.agea.org.au/media/docs/The%20Geothermal%20Reporting%20Code%20Ed%202_1.pdf

1. Resource Assessment & Project Stages

- Remember Project Stages and Investment Go/No-Go Decisions
- Resource Assessment at every stage
- Investments go up at every stage
- Uncertainty/risk should go down at every stage
- Two main perspectives:
  - Developer: doing the risky investment
  - Regulator: manager/guardian of the public resource, sustainable use, royalties, and social/environmental impacts

1. Resource Assessment & Project Stages

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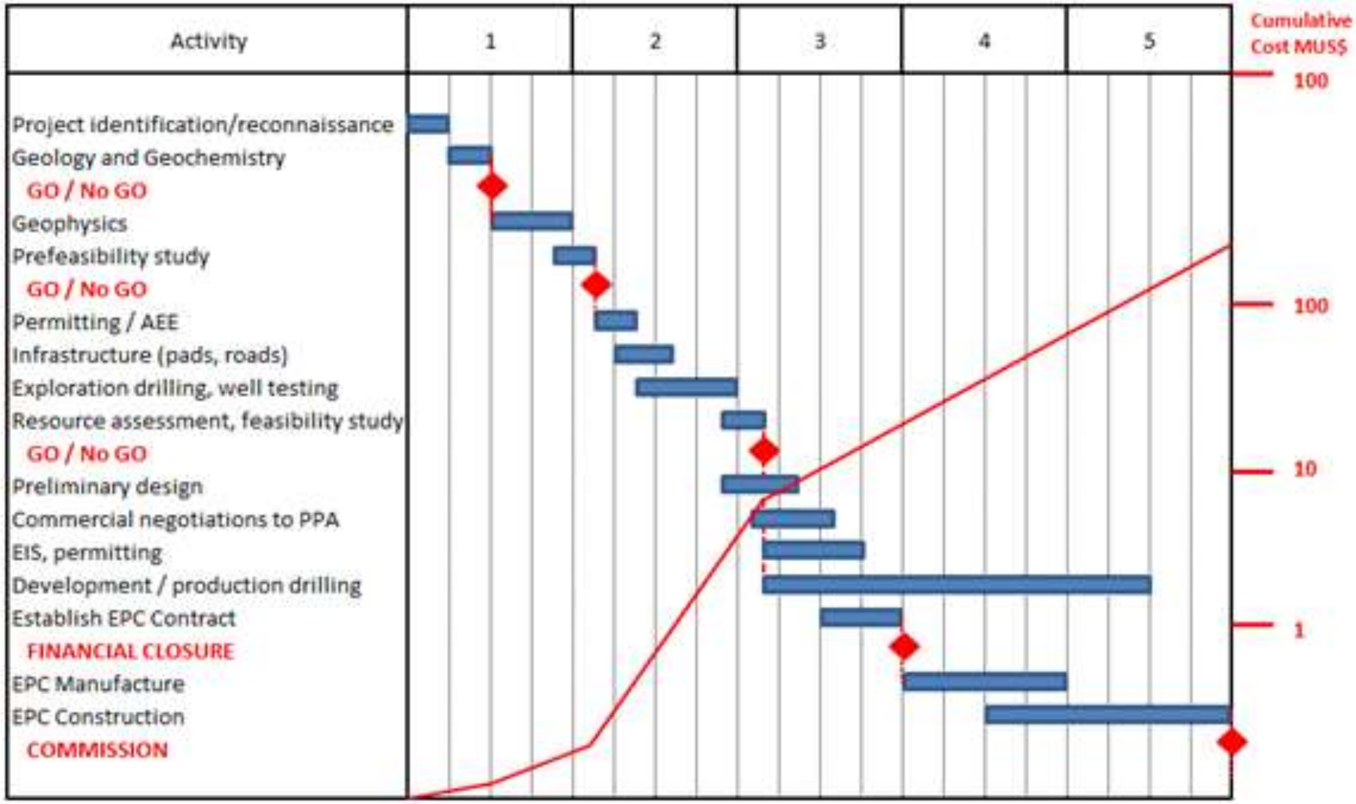

- Risky geothermal investments with decision points and resource assessment at regular stages

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1. What information available at what stages

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Project Stage	Data availability	Certainty Levels	Methods
1. Start-up&Pre-exploration	Limited data. First results from geoscientific (geophysical) studies.	Generally not sufficient data to allow 'any reasonable estimates of Geothermal Resources' (AGEA, 2010)	Estimated Natural Heat Flow, Volumetric Stored Heat, Areal Analog/Power Density
2.Conceptual Model & Prefeasibility Study	Sound basis for Geothermal Play; estimate of temperature & some indication of extent of field, rock properties, etc	Estimates (against stated base & cut-off Temp) only with low level of confidence. Assumed to be unverified viz deliverability (no production well testing)	(Probabilistic) Volumetric Stored Heat
3. Exploration drilling & feasibility study	Direct Measurements (at least 1 well: rock properties, temp, fluid chemistry) are sufficiently spaced to indicate (but not confirm) continuity in reservoir	'More likely than not'	(Probabilistic) Volumetric Stored Heat, Lumped Parameter modelling
4 & 5 Production drilling and Commissioning	(on top of above): at least temperature, reservoir volume and well deliverability. Spacing sufficient to confirm continuity in reservoir.	High confidence level	(Probabilistic) Volumetric Stored Heat, Lumped Parameter modelling, (initial) numerical reservoir modelling (but no production history)
6. On-going Production, Operation & Maintenance	(on top of above): expanding knowledge on basis of more wells, monitoring and production data	Increasing confidence level for several (all) levels of reserves/ resources as production progresses and data/knowledge improves	Numerical Reservoir Modelling for Reserve under production (~P90); other resource categories with Probabilistic Volumetric Stored Heat

2. Resource Estimation Methods
(source: AGEA- Geothermal Lexicon, 2010)

Methods with no production data

- Heat Flow
- Areal Analogy (Power Density)
- **Volumetric Methods (Deterministic & Probabilistic)**

Methods with production data

- Lumped Parameter Models
- Decline Curve Analysis
- **Numerical Reservoir Simulation**

2. Heat flow

- Measure natural heat (MWth) flow from springs, fumaroles, ground radiation
- Possibly supplemented with chemical (chloride, NZ) content in river to capture subsurface & minor flows
- Natural heat flow (MWth) times assumed efficiency would be minimum Mwe-production
- Sanyal&Sarmiento (2005) suggest 5-10-25 times for potential ‘sustainable’ capacity
- Very rough estimate

2. Analogy – Power Density

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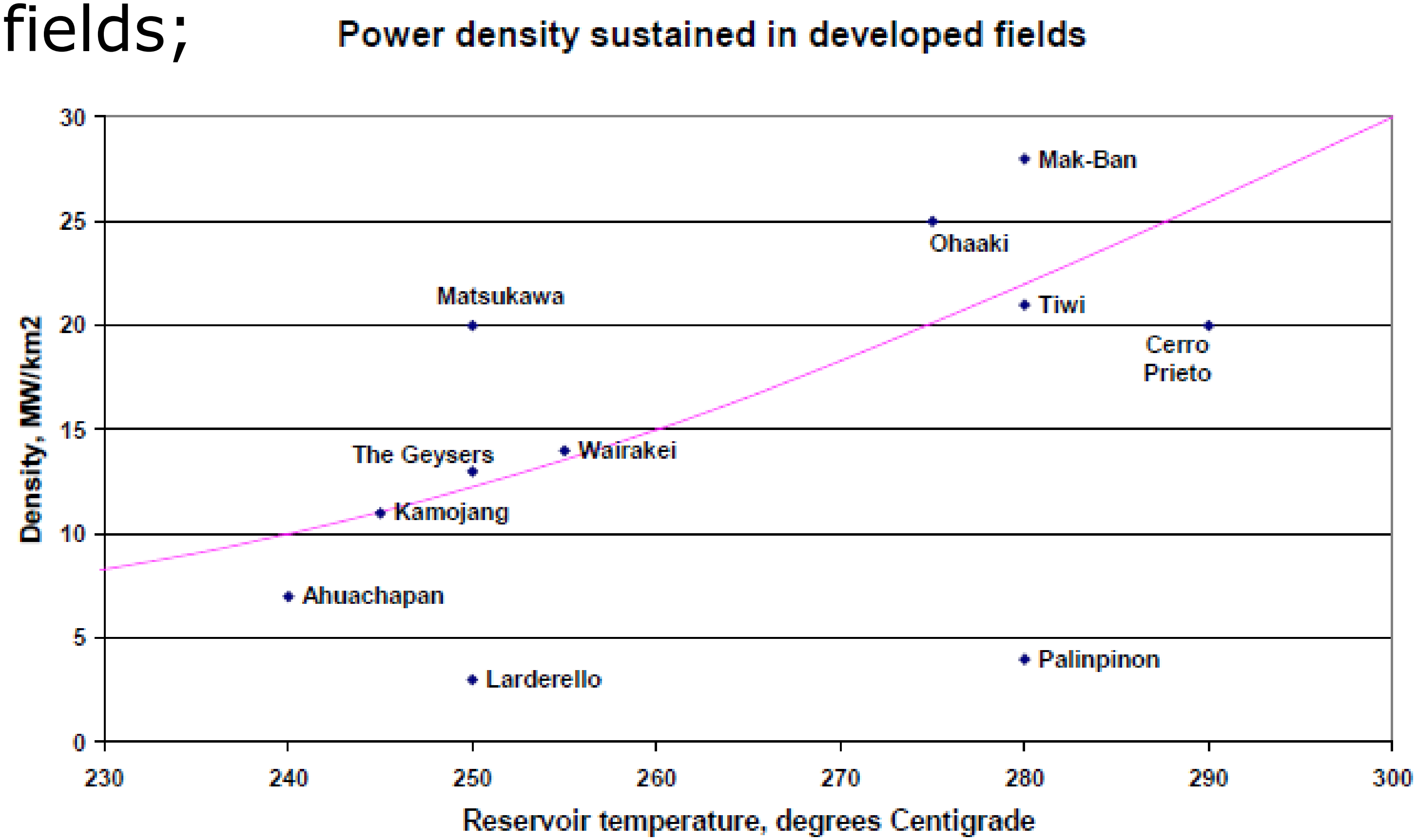
- Very rough method at stage where resource temperature can 1st be estimated;
- Assumes (sound) statistical correlation with similar, producing fields;



Source: Grant, 2000 quoted in Ngatamariki consent Proceedings, Grant Evidence, 2009

2. Volumetric stored heat estimation

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- One of the most widely and consistently usable methods during all stages
- Introduced in a seminal USGS-study (Muffler, 1979), but adjusted and varied many times since.
- The basic method involves:
  - Calculating **(usable) heat in place (PJ)** using estimated reservoir volume, rock and fluid characteristics and average temperature, against a reference temperature.
  - **Recoverable heat (PJ)** is then estimated by introducing a *Recovery Factor* , which can be seen as fraction of the (usable) heat in place that could be produced feasibly by actual production wells over a reasonable (project) timeframe;
  - Finally a **feasible, sustainable plant capacity (MWe)** for a given/estimated plant life, conversion efficiency, and power plant availability.
-

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2. Many factors can be uncertain

a. Reservoir Temperature & Reject Temperature;
b. Reservoir Area/Size & Reservoir Thickness;
c. Recovery factor (varying from 0.05-0.20 (Sanyal ea., 2004), 0.25 (USGS-Muffler (1979), Ogena&Freeston (1988), Watson&Maunder (1982)) to 0.5 Nathenson (1975));
d. Rock Porosity (affecting c);

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2. Volumetric Stored Heat

in formulas:

- Estimated Initial Heat in Place (PJ) against reference temp:

$$Q = A.h.\{[C_r.\rho_r(1-\varphi).(T_i - T_f)] + [\rho_{si}.\varphi.(1-S_w).(h_{si} - h_{wf})] + [\rho_{wi}.\varphi.S_w.(h_{wi} - h_{wf})]\} \qquad -(1)$$

heat in rock — heat in steam — heat in water

Most of the heat is likely to be in the rock, not in the fluid, so this will be the dominant factor;

- Calculate Electricity Generating Capacity (MWe) by assuming recovery factor, plant efficiency, plant factor & project Life

$$E = \left\lfloor \frac{Q \cdot R_f \cdot \eta_c}{F \cdot L} \right\rfloor \qquad -(2)$$

2. Can add natural heat flow

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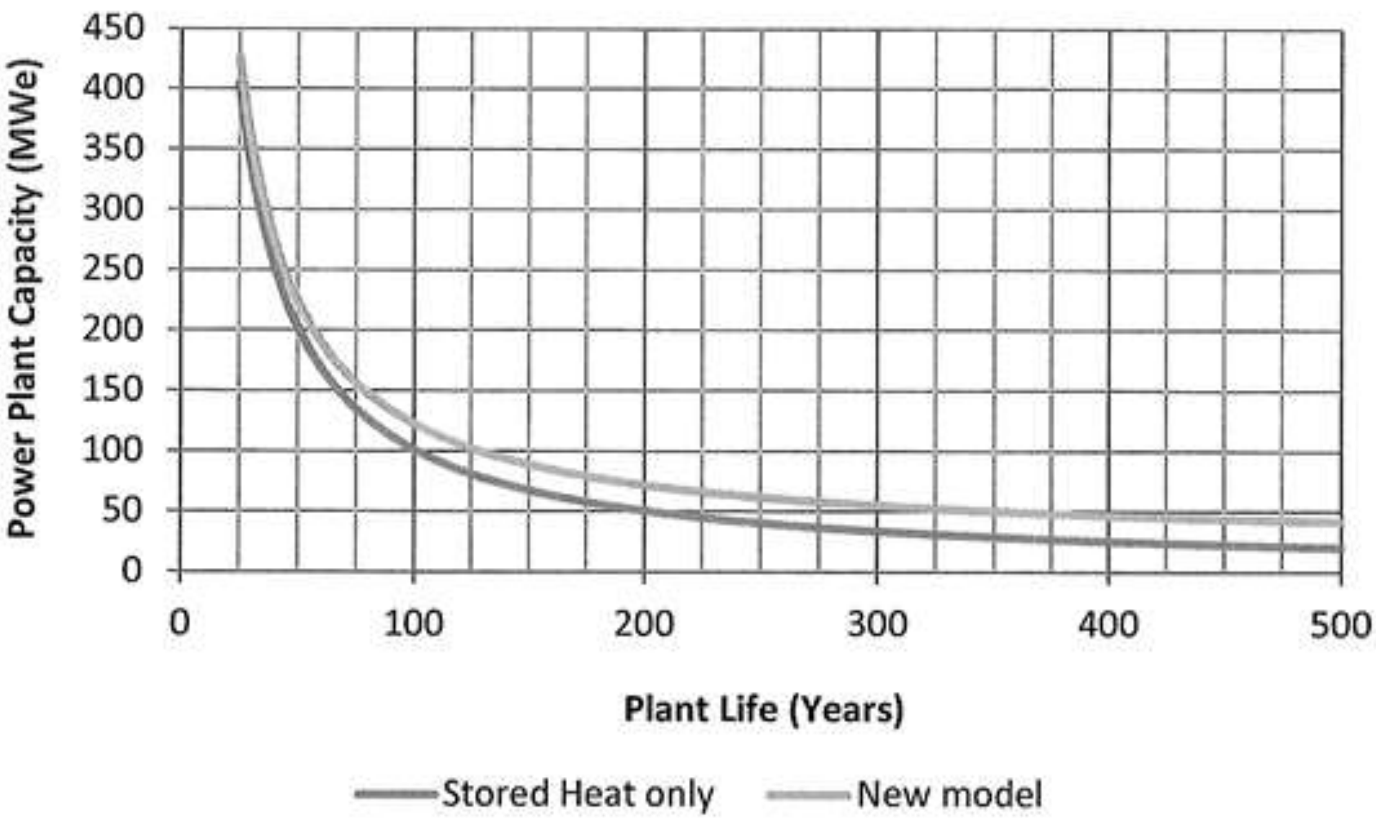

Example from Zarrouk (2013) including natural heat flow to stored heat calculation & impact for different time/project horizons

2. Probabilistic Simulation

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- Stored heat calculations can be done probabilistically for key (uncertain) parameters:
  - Resource Area
  - Resource Thickness
  - Mean Temperature
  - Void space/porosity (and link to recovery factor)

- Vary above input parameters randomly and do many runs (Monte Carlo) registering resulting Stored Heat

- Create Cumulative Probability Density Function of Stored Heat outcomes

- Estimate P10, P50, P90 for Inferred, Probable & Proven Resource/Reserve

2. Examples from NZ & Philippines

- NZ: Used as basis for EW Sustainable Resource Management (EW/SKM, 2002)
- See Regulation & Environment presentations
- Philippines: used by Department of Energy to map resources for energy planning (Pastor/Fronda, 2010)

Other references: AGEA (2010, Zarrouk (2013), Sanyal&Sarmiento (2005), Simiyu (2013)

2. Numerical Reservoir Simulation

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- Based on the detailed (but still approx/simplified from reality) mathematical description of estimated reservoir (natural geothermal anomaly)
- Describes interactions in accordance with physical and mathematical laws, in a way that is logically and internally consistent over space and time
- With enough production/calibration data reservoir simulation is the preferred method to calculate a natural state and simulate production scenarios
- Generally deterministic approach (best fit)
- Can be done probabilistically, but computationally challenging
- More in next presentation

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2. Numerical Reservoir Modelling

- Specific, concrete production scenarios (heat/fluid take for x MWe-production) are modelled over project life (or more) for known/drilled areas, giving more 'realistic' potential – hence generally seen as ~ **Proven Reserve** (Recoverable Heat/Electricity)
- Estimate remaining (Inferred) Resources (with recovery factor)?
- Resource (Initial Heat in Place) can be calculated (for natural state and project end)

2. Lumped Parameter Modelling

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- Simplified form of Reservoir Modelling
- One or limited number of cells
- Generally simplified laws (single phase, laminar flow)
- Less used these days
- Seen by many as inferior (for resource/reserve assessment) to full numerical simulation (AGEA, 2010; Sanyal&Sarmiento, 2005)

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2. Decline Curve Analysis

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- Method to match historic, declining production for existing wells (curve matching)
- Then extrapolate for future production scenarios
- Assumes no change in reservoir management
- Eg used at Cerro Prieto, Ohaaki and The Geysers
- But Geysers originally estimated 9% decline; by 2002 changed to 3% because of management changes (Sanyal *et al.*, 2000)
- Similar management at Ohaaki changed to change estimated 14% decline rate (Ohaaki consent hearings, 2013)

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3. Reporting Methods for Resources & Reserves

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Project Stage	AGEA Resource/Reserve Reporting Categories			Data availability	Certainty Levels	Methods
1. Start-up&Pre-exploration	Exploration Result Reporting			Limited data. First results from geoscientific (geophysical) studies.	Generally not sufficient data to allow 'any reasonable estimates of Geothermal Resources' (AGEA, 2010)	Estimated Natural Heat Volumetric Stored Heat Analog/Power Density
2.Conceptual Model & Prefeasibility Study	Inferred Geothermal Resource	Modifying Factors	N/A	Sound basis for Geothermal Play; estimate of temperature & some indication of extent of field, rock properties, etc	Estimates (against stated base & cut-off Temp) only with low level of confidence. Assumed to be unverified viz deliverability (no production well testing)	(Probabilistic) Volumetr Heat
3. Exploration drilling & feasibility study	Indicated Resource		Probable Reserve (~P50)	Direct Measurements (at least 1 well: rock properties, temp, fluid chemistry) are sufficiently spaced to indicate (but not confirm) continuity in reservoir	'More likely than not'	(Probabilistic) Volumetr Heat, Lumped Paramet
4 & 5 Production drilling and Commissioning	Measured Resource		Proven Reserve (~P90)	(on top of above): at least temperature, reservoir volume and well deliverability. Spacing sufficient to confirm continuity in reservoir.	High confidence level	(Probabilistic) Volumetr Heat, Lumped Paramet modelling, (initial) num reservoir modelling (bu production history)
6. On-going Production, Operation & Maintenance	Use Production data & reservoir modelling to recalibrate Reserve (&Resource) Estimates & account for previous extraction history		Use Production data & reservoir modelling to recalibrate Reserve (&Resource) Estimates & account for previous extraction history	(on top of above): expanding knowledge on basis of more wells, monitoring and production data	Increasing confidence level for several (all) levels of reserves/ resources as production progresses and data/knowledge improves	Numerical Reservoir Mo Reserve under producti other resource categori Probabilistic Volumetri Heat

3. Reporting codes: why?

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- Independent, transparent reporting of resources and reserves important for investment certainty
- Regulators often also want insight in state of (public) resource and possible income streams (tax/royalties)
- Very common in minerals & petroleum industries
- Petroleum reporting reasonably standardized around the world (SPE Guidelines, 2011), but different emphasis, requirements and public openness
- No geothermal codes before mid-2000s, now at least 6 codes – none obligatory
- IGA trying to harmonize

3. Petroleum Regulator Reporting

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International reserves reporting requirements

	Information required to be reported								
					Reserves				
Country	STOIIP[1]	GIIP[2]	Estimated recoverable oil and gas	Cumulative recovery	P90	P50	P10	Contingent resources	Prospective resources
New Zealand	Yes	Yes	Yes	Yes[3]	Yes	Yes	No	No	No
United States	No	No	No	Yes	Yes	No	No	No	No
Norway	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
United Kingdom	Yes	Yes	Yes	Yes[4]	Yes	Yes	Yes	Partially[5]	Partially[5]
Australia	Yes	Yes	Yes	Yes[6]	Yes	Yes	No	Yes	No[7]

	Information publicly available								
					Reserves				
Country	STOIIP[1]	GIIP[2]	Estimated recoverable oil and gas	Cumulative recovery	P90	P50	P10	Contingent resources	Prospective resources
New Zealand	No	No	Yes	Yes[3]	No	Yes	No	No	No
United States	No	No	No	Yes	Yes	No	No	No	Yes
Norway	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
United Kingdom	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Australia	No	No	Yes[8]	Yes	No	Yes	No	Yes	Yes

1. Stock Tank Oil Initially In Place

2. Gas Initially In Place

3. This can be derived from production data published in the Energy Data File

4. DECC derives this information from information provided

5. Information is gained from a mixture of company information reported to DECC and internal DECC modelling

6. This can be derived from production data provided.

7. Australin authorities come to their own view of prospective resources

8. This can be derived from production data provided.

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Source: NZ Crown Minerals, 2010

3. Reporting: AGEA & CanGEA

- Codes since mid-2000s (AGEA-2008; 2nd edition 2010)
- Almost identical & Interchangeable Codes
- For Natural Hydrothermal Systems **AND** EGS
- AGEA applied in Philippines (Maibara) and Indonesia (PGE & STAR), Vanuatu
- CanGEA: USA (Nevada), Nicaragua and Argentina
- NZGA supports and wants to use for new National Assessment
- IGA investigating common, global code largely based on Australian & Canadian

3. Principles

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- AGEA (2008); 2nd Edition in 2010
- Similarities and Differences between Minerals and Petroleum Codes Vs. Geothermal:
  - Different technical (energy) processes
  - Renewable through recharge
  - Rate of extraction over defined period important in geothermal resource/reserve assessment
  - Commercial: oil a global commodity & price, but electricity local (often regulated?) commodity & price
- 2 dimensions: Geological knowledge & Commerciality
- Modifying factors
- Independent, 'Competent' Person needs to verify

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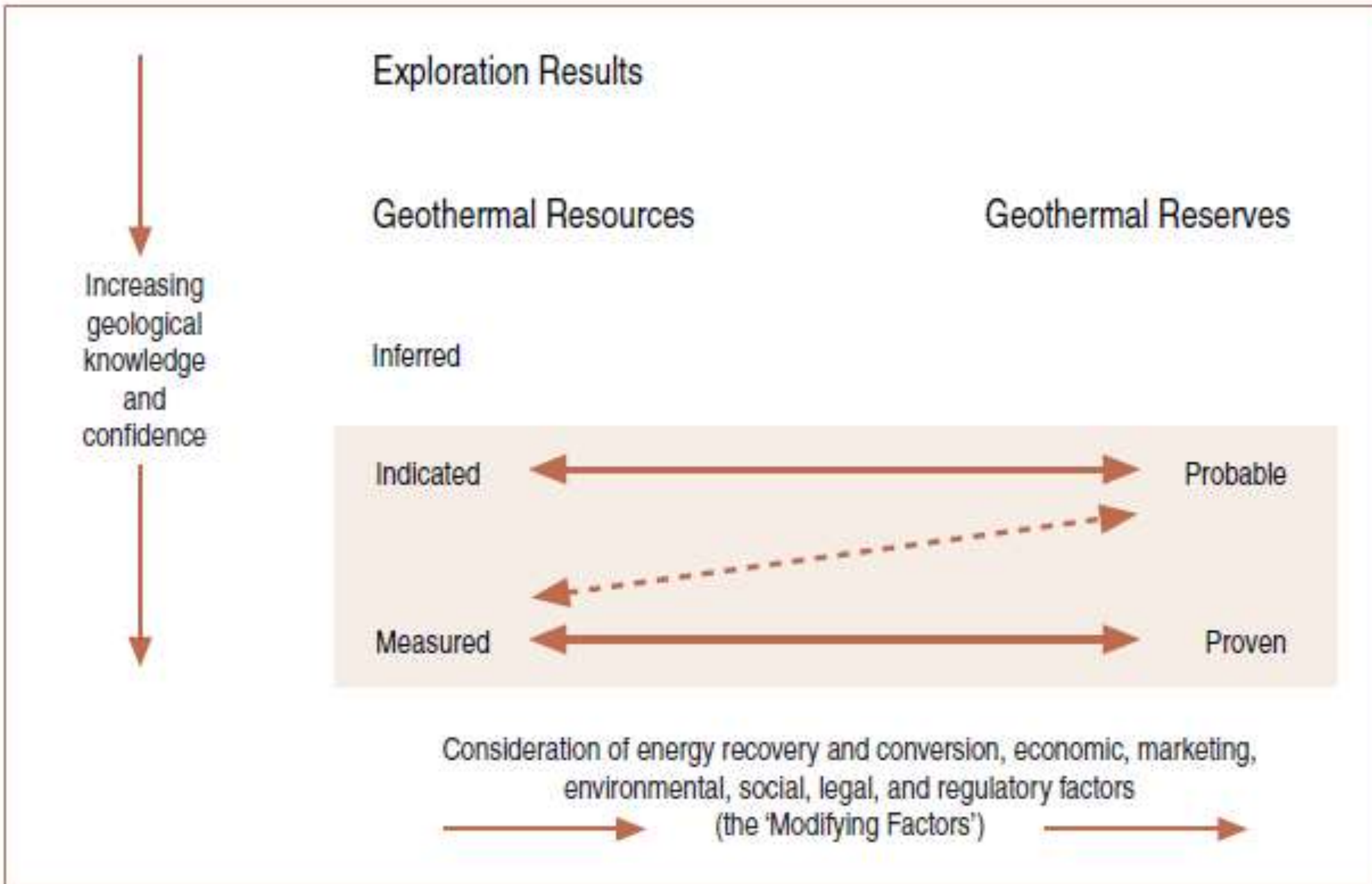
3. Code & Lexicon will

1. Provide a basis that is satisfactory to investors, shareholders and capital markets such as the Australian Securities Exchange, in the same way that there are recognised Codes for mineral and petroleum deposits.
2. Be applicable to the type of geothermal projects that are likely to be undertaken in Australia, given that many of the Australian Geothermal Plays currently under investigation are different from most of those which have so far been developed commercially in other countries.
3. At the same time, be applicable to Geothermal Plays in other countries, since the geothermal energy industry is expanding globally. This includes established projects with a production history as well as greenfield sites.
4. The Code Committee has developed two documents, which have been based on extensive discussions, public presentation and review of earlier drafts.
   a. The first is the Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves (the 'Geothermal Code' or 'Code'). It covers a minimum, mandatory set of requirements for the public reporting of geothermal resource and reserve estimates.
   b. The second is this document, the Lexicon. This document provides guidance on how Geothermal Resources and Reserves can be estimated for reporting purposes. The techniques described in the Lexicon are generally not a mandatory part of the Geothermal Code. However, *any* significant deviations from the Lexicon should be disclosed and explained when reporting under the Geothermal Code.

   The one exception to this in the Second Edition of the Code is the default mandatory use of the Lexicon as the source of values for Recovery Factors to convert stored heat to recoverable energy which in the Second Edition of the Code, is by definition the Resource (which is a major change from the first edition of the Code).

3. AGEA (2010) categories



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3. Back to overview

Project Stage	AGEA Resource/Reserve Reporting Categories			Data availability	Certainty Levels	Methods
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3. Other guidance

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- Reporting in recoverable thermal energy; or if electricity: recoverable electric energy/power at x rate (Mwe) over a defined time period
- Before sufficient geoscientific exploration only reporting of '**Exploration Results**'
- **Resources**: there must be a 'technically justifiable basis for defining the energy in place and the fraction of it that can reasonably expected to be economically extracted
- Reserves: 'The term **Reserves** is only to be used for those portions of Indicated or Measured Resources that are judged by a **Competent Person** to be commercially extractable with existing technology and prevailing market conditions. For a Reserve to be declared there must be a defined and proven means of extracting the energy and converting it into a saleable form.'
- Conceptually: P90~Proven; P50~Probable

In practise little experience: still 'settling'

- How to position Estimates/Scenarios from Reservoir Modelling?

  => generally (if sufficient data): proven reserve for specific, modelled project, production scenario & timeframe

- Much heat left after project finished: how to assess?

  ⇒ generally as Inferred Resource

- Not used systematically yet in any jurisdiction, but examples of approach from NZ & Philippines

Example Proven & Probable Reserve vs Probable Resource: Ngatamariki consenting (2009/2010): drilled & tested around wells – rest is indicated resource or probable reserve?

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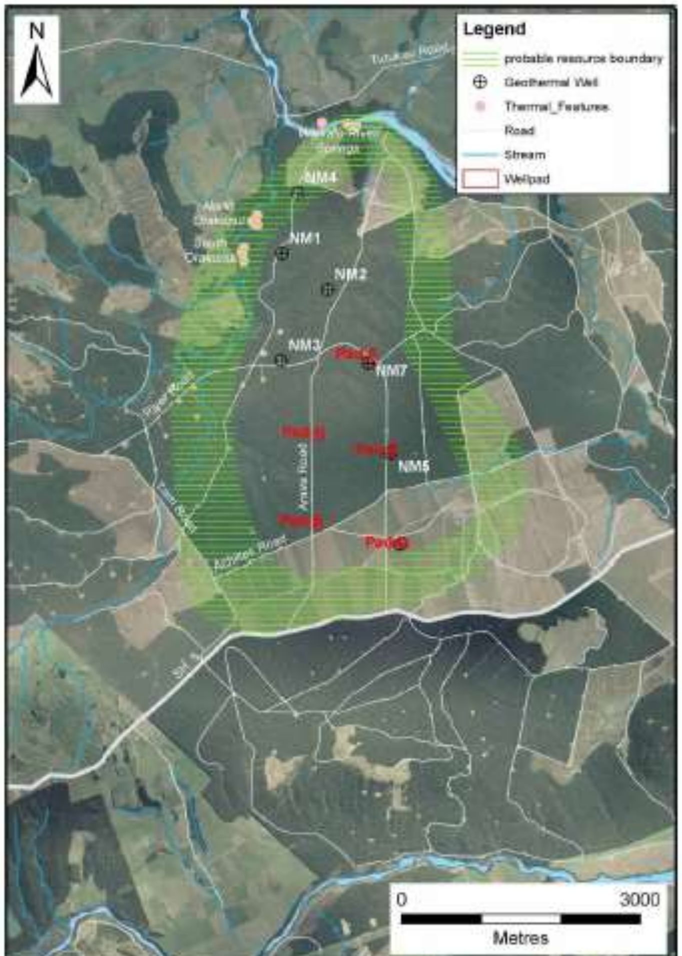

Figure 6: Aerial photo of the Ngatamariki geothermal field showing the probable geophysical resource boundary in the hatched area.

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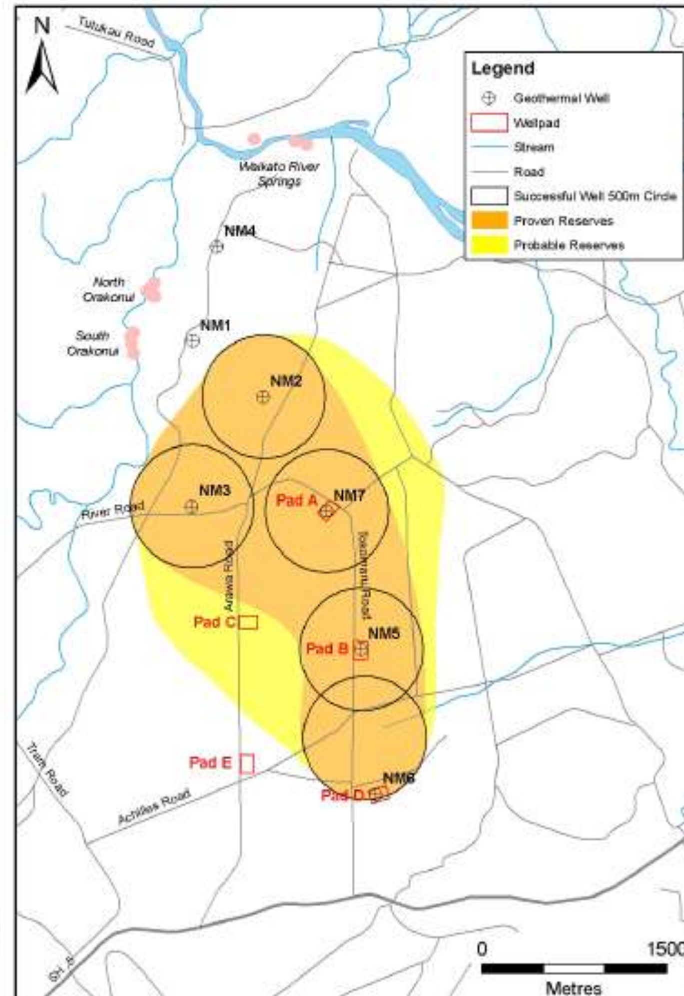

3. Geothermal Regulatory Reporting?

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- AGEA also considered for Regulatory/National reporting (very common in Petroleum, not in Geothermal yet)
- No long-term consistent, public data series in Geothermal (as in Petroleum)
- Some examples/indications for NZ & Philippines

4. Example Philippines: Pastor-Fronda-2010

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- DoE did a probabilistic stored heat assessment for major Philippine geothermal resources and 'classified'
- Not AGEA-code, but broadly similar:

a. **Proven Resource**: 'refers to the calculated economically recoverable geothermal energy contained in the geothermal reservoir identified by delineation/development drilling, geological, geochemical and geophysical evidences. A proven resource should have been adequately defined in three dimensions by surface exploration and the drilling and testing of wells. Proven resources are those found in producing fields and areas of advance exploration. The estimated potential is taken from wellhead potential.

b. **Probable Resource: '**refers to the estimated geothermal energy available based on exploration drilling, geophysical, geochemical and geological evidences that may be extracted economically at some reasonable time. Probable resources are in prospect areas of advance exploration.

c. **Possible Resource '**refers to the estimated geothermal energy that may be available based on geophysical, geological and geochemical evidences. Possible resources are mostly in prospect areas that have impressive thermal manifestations and intermediate to high estimated reservoir temperature.'

- Unclear how much (private) data they used

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4. Results Philippines

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Table 2: Reservoir Parameters use in Resource Estimate

Parameters	Assumption
Area (km^2)	Variable
Thickness (km)	1.5
Reservoir Temperature (°C)	Variable
Reference Temperature (°C)	180
Rock Density (kg/m^3)	2,700
Rock Specific Heat (kJ/kg °C)	0.90
Rock Porosity	0.05
Fluid Density (kg/m^3)	792
Fluid Specific Heat (kJ/kg °C)	Variable
Recovery Factor (%)	15
Conversion Efficiency (%)	0.1
Load Factor (%)	0.75
Plant Life (years)	25

Table 3: Geothermal Resource Estimate, in MWe

PROVINCE	PROSPECT	PROVEN	PROBABLE	POSSIBLE
Cagayan	Cagua		25.00	40.00
Benguet	Acupan		10.00	10.00
	Daklan		30.00	30.00
Benguet-Ifugao	Buguais-Tinoc			80.00
Kalinga	Batong-Buhay			120.00
Mt. Province	Mainit			80.00
Bataan	Natib		15.00	185.00
Batangas	Mabini			20.00
Laguna	Mak-Ban	429.10		
	Maibarara	30.00		
Oriental Mindoro	Montelago			20.00
Albay	Tiwi	198.80		
	Manito		20.00	
Albay/ Sorsogon	Bac-Man	134.10		
Sorsogon	Rangas-Tanawon		40.00	
Camarines Sur	Mt. Labo	10.90	65.00	
Negros Occidental	Mambucal	45.30	50.00	
	Mandalagan-Silay			120.00
Negros Oriental	Palinpinon	217.70		
	Dauin		30.00	
	Lagunao		60.00	
Leyte	Tongonan	639.60		
	Mahagnao		30.00	40.00
	Biato-Lunas			60.00
Southern Leyte	Cabalian		20.00	30.00
Biliran	Biliran		25.00	15.00
Zamboanga del Sur	Lakewood			80.00
Misamis Occidental	Ampiro			30.00
Compostela Valley	Amacan		60.00	30.00
Cotabato	Mt. Apo	91.49	50.00	
Surigao del Norte	Mainit			60.00
Total		1,796.99	530.00	1,050

4. Environment-Waikato- SKM-2002

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- 2002 EW-exercise in estimating all major Waikato Geothermal Resources
- Was pre-Geothermal Codes, but used probabilistic stored heat calculations
- Differentiation in producing/development vs protected fields
- No access to detailed production data/reservoir models, though
- Detailed overview of assumptions
- Used for resource planning

4. Results E Waikato (2002)

Field	Resource Area (km^2)			Depth to Reservoir (m)	Resource Thickness (m)			Void Space %			Mean Temperature[4] °C			Generating Capacity[5] MWe		
	min	mode	max		min	mode	max	min	mode	max	min	mode	max	10TH	med.	90TH
Atiamuri	0	0	5	800	1500	1700	2200	8	10	12	190	220	240	1	6	18
Horohoro	0	0	5	500	1800	2000	2500	8	10	12	180	200	240	1	5	15
Kawerau	25	35	40	400	1500	2100	2500	6	8	10	260	270	280	350	450	570
Ketetahi	10	12	30	800	1500	1700	2200	4	8	12	230	240	260	70	100	150
Mangakino	0	8	10	800	1500	1700	2200	8	10	12	200	230	250	20	47	70
Mokai	5	6	16	700	1300	1800	2300	8	10	12	260	280	290	95	140	220
Ngatamariki	8	10	12	400	1800	2100	2500	5	8	10	250	260	270	90	120	160
Ngawha	10	18	25	400	1800	2100	2500	3	4	6	220	240	260	50	75	120
Ohaaki	6	10	12	400	1800	2100	2500	6	8	10	260	270	280	100	130	170
Orakei-Korako	8	10	12	400	1500	1800	2200	8	10	12	240	250	260	90	110	135
Reporoa	0	9	12	700	1000	1500	2000	8	10	12	220	230	240	20	42	65
Rotokawa	12	18	20	500	1800	2100	2500	6	10	12	260	280	290	230	300	400
Rotoma	4	5	6	500	1700	2000	2500	6	8	10	220	240	245	28	35	46
Rotorua[1]	2	4	8	500	1500	1800	2000	8	10	15	220	240	250	25	35	55
Tauhara	7	15	35	500	1700	2000	2500	10	12	15	240	260	270	200	320	500
Te Kopia	6	10	12	500	1700	2000	2500	6	10	12	230	240	250	75	96	120
Tikitere-Taheke[2]	15	35	40	500	1000	1800	2200	8	10	12	220	240	260	160	240	350
Tokaanu	10	20	30	800	1500	1700	2200	4	8	12	250	260	270	130	200	300
Waimangu	9	12	30	400	1800	2100	2500	8	10	15	250	260	270	180	280	420
Waiotapu[3]	15	20	30	500	1200	1800	2500	8	10	12	260	275	280	250	340	450
Wairakei	15	20	30	350	2000	2150	2650	10	15	20	250	255	265	380	510	670
Means and Totals:								**9.5**			**250**			**2500**	**3600**	**5000**

4. Existing Public Data Reporting in NZ-Waikato

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- Consent Applications require resource proofing (some re-consented once or twice);
- Annual Reports;
- Resource Management Plans;
- Regular Peer Review Meetings and Reports;
- An overall Waikato Geothermal Resource Assessment (EW/SKM, 2002);

- BUT: No hard (AGEA) criteria and common categories
- BUT: Many other jurisdictions have less data, not as long a history, not publically available, less easy access
- Possibly Philippines, but deemed commercially sensitive

5. Examples from Petroleum: Crown Minerals use to project production (royalties)

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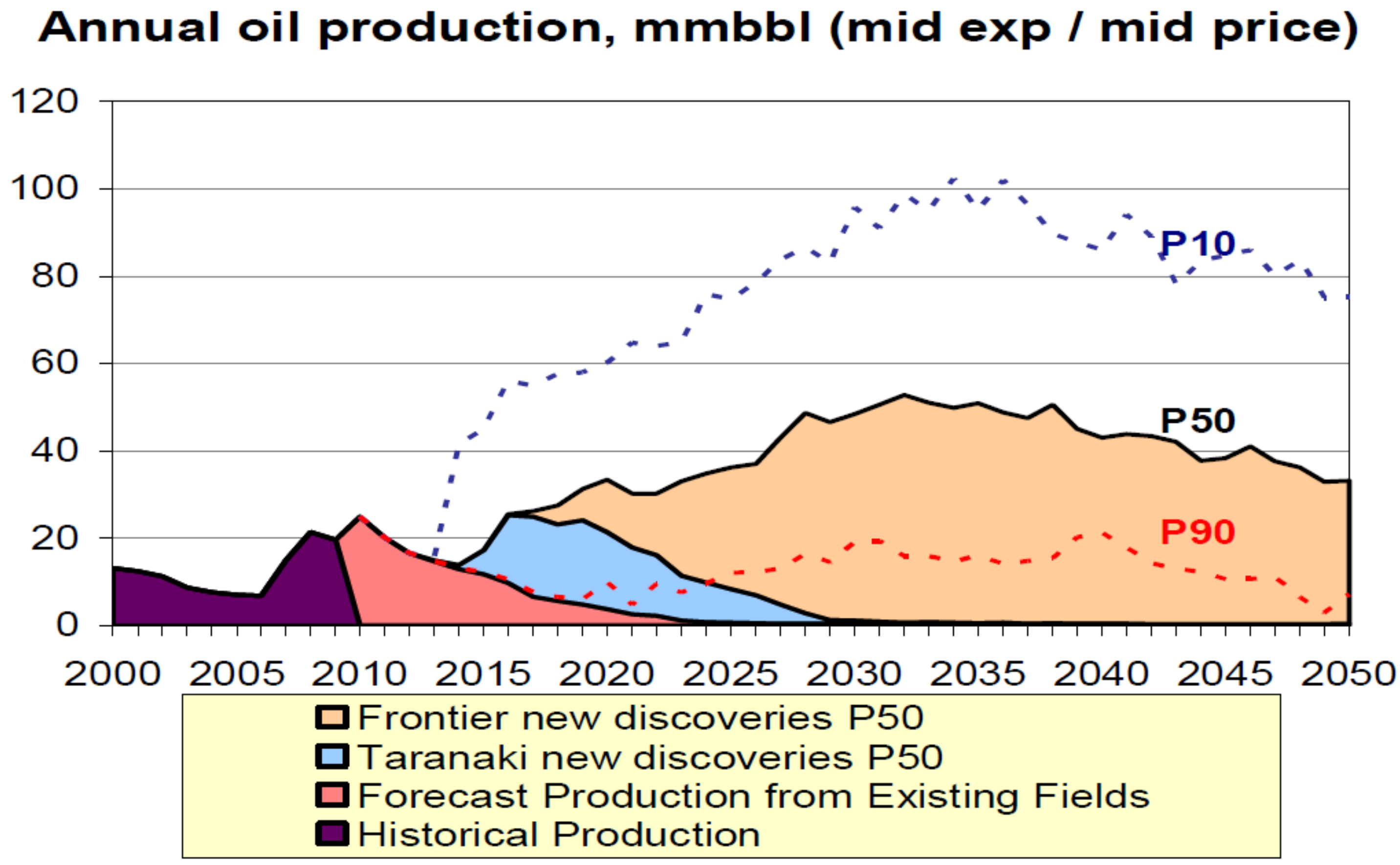

Source: NZ Crown Minerals, 2010

Research works *wonders*

5. Resource estimates are not static

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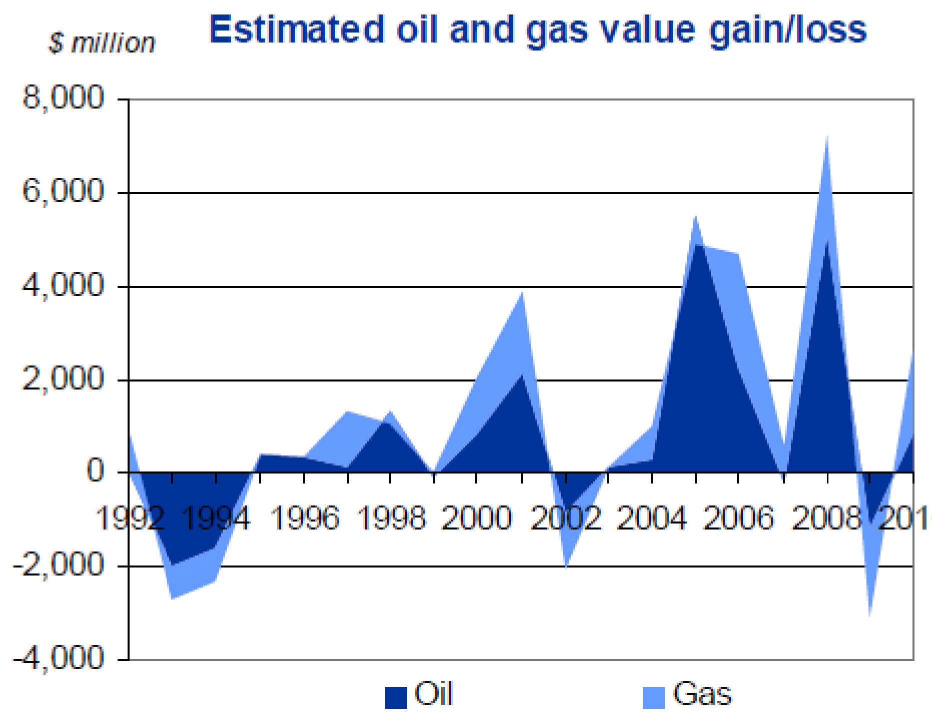
Change over time, due to:

- Improved knowledge
- Improved technology
- Changed product price
- Change in ownership & risk appetite
- On-going production (& recharge)



Example from NZ Petroleum: (monetized) changes in a whole portfolio of (producing) Reserves

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5. Example Reserves Growth – Post Production

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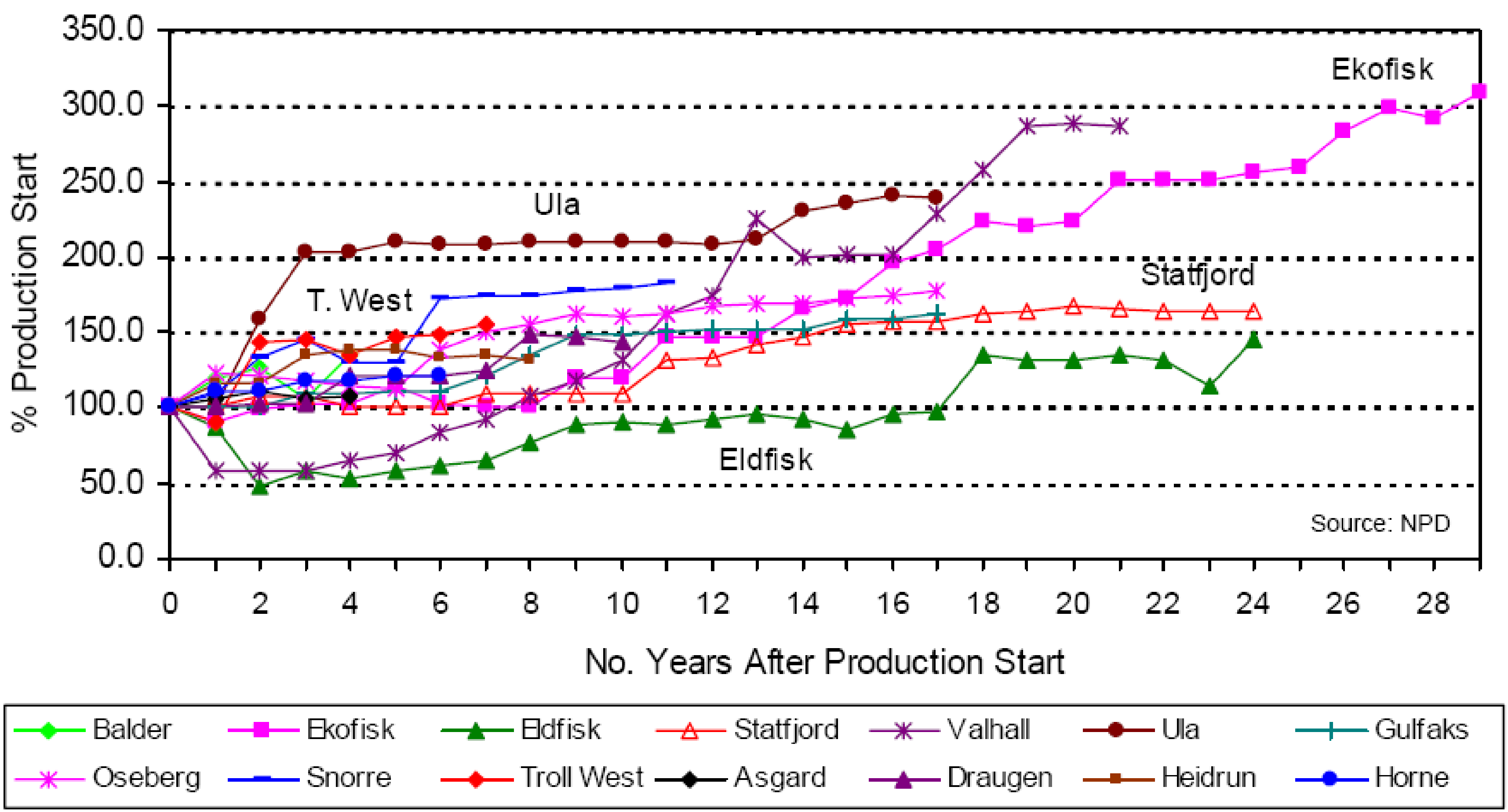

Source: From Society of Petroleum Engineers paper, SPE 94680

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5. Example econometric analysis of reserves from regulated Norway petroleum Portfolio

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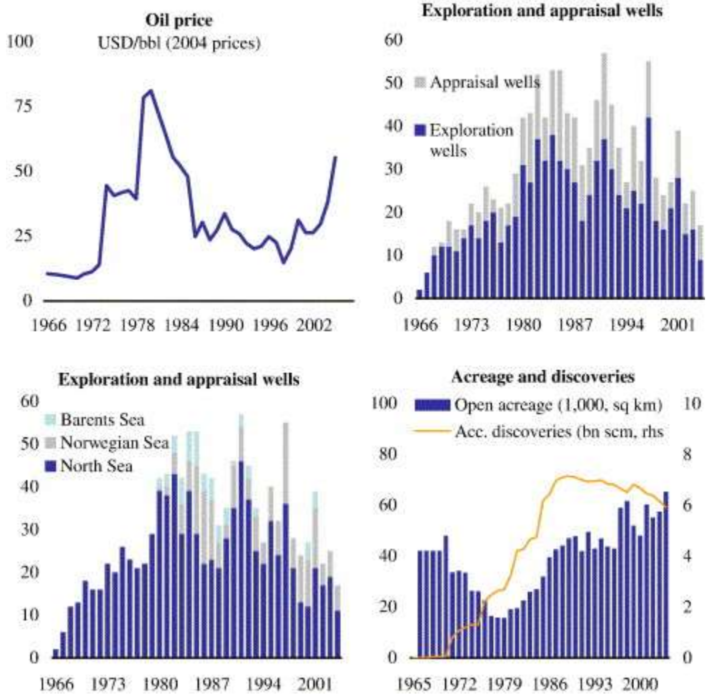

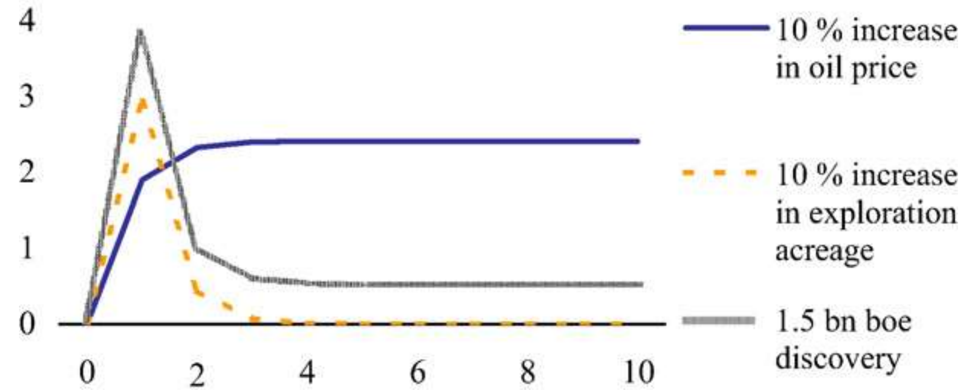

From input variables (incl wells drilled, oil price, acreage, (standardized) resource assessments;

⇒ To: establishing relationships, esp price & acreage

⇒ Estimate (manage) future Resource Use

⇒ Advantage of portfolio approach = should take probabilistic element out

- Source: Mohn, 2008

Research works *wonders*