decisions with confidence

Reservoir Engineering and Reserves

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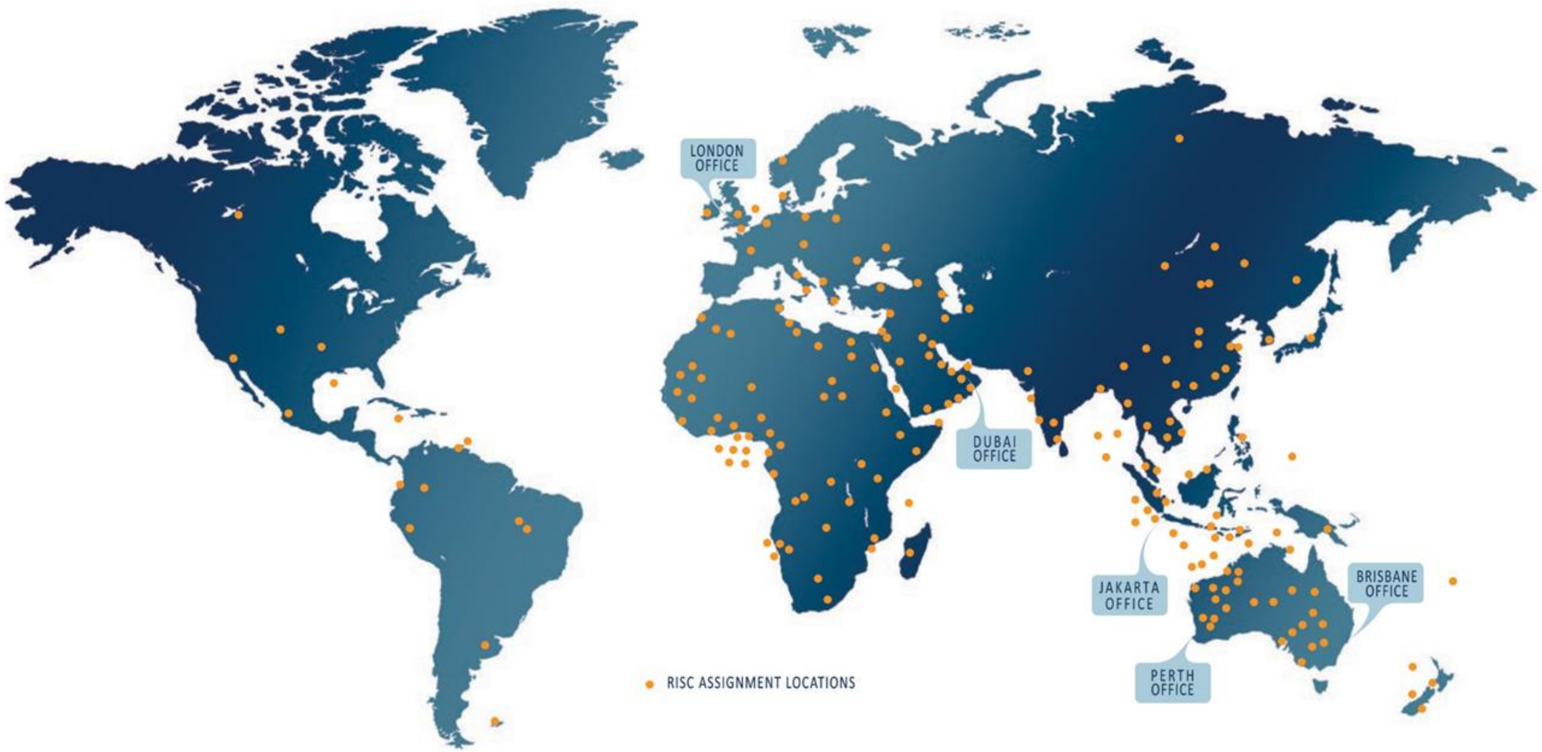

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	Exploration and Appraisal				Development			Production		Market		
	Exploration Strategy	Acreage Evaluation	Field Definition	Resource Assessment	Concept Selection	Brown/ Greenfield Development	Onshore/Offshore/LNG	Project Execution	Reservoir/ Production Management	Australian Domestic Gas Market	International Oil Markets	Asia-Pacific LNG Supply/Demand
Geoscience and Geology	■	■	■	■	■	■		■	■			
Petroleum Engineering	■	■	■	■	■	■	■	■	■			
Development Planning	■	■		■	■	■	■	■	■			
Commercial	■	■		■	■	■	■	■	■	■	■	■
Acquisitions + Divestments	■				■	■	■	■	■	■	■	■

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NOC's

Ecopetrol, CNOOC, Qatar Petroleum, KNOC, KUFPEC, Pertamina, Petrobras, PetroChina, Petronas, Sinopec, Sinochem

Japan

Itochu, INPEX, JX, Toyota Tsusho, Sojitz, Marubeni, MIMI, Mitsubishi Corporation, Mitsui & Co., Ltd.

ASX listed

Woodside, Tap Oil, AWE, Beach Energy, Drillsearch, Horizon Oil, Karoon Gas Australia Ltd, Buru Energy, Oil Search Limited, Santos (We have the energy.), Tlou Energy, Sino Gas & Energy

LSE/AIM

Cairn, Afren, Caracal Energy Inc., Chariot Oil & Gas, Dragon Oil, Exillon Energy, Heritage, Ophir, Tullow Oil, Premier Oil, SOCO plc International

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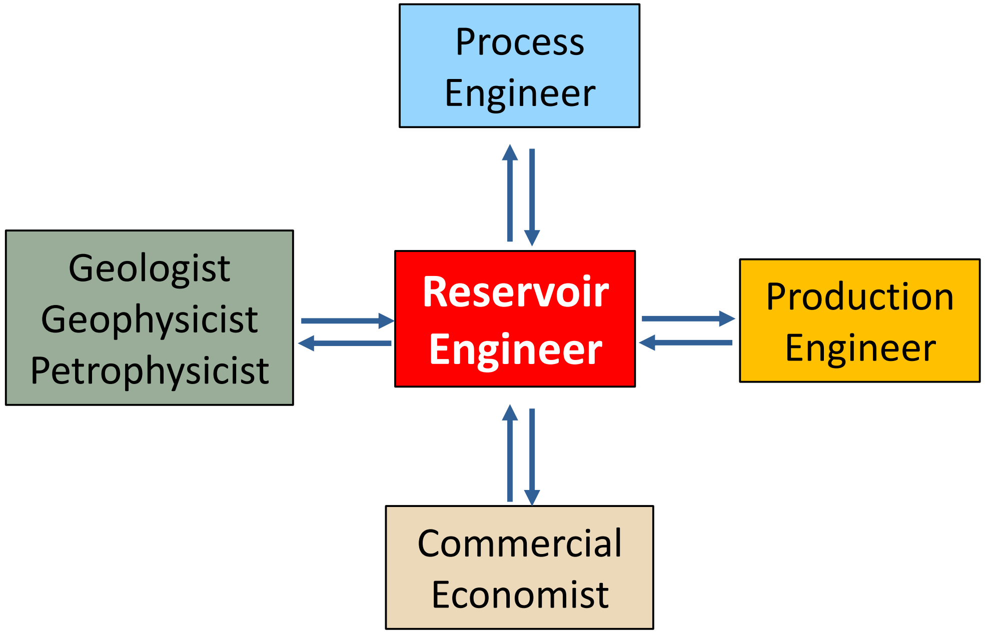
- BARCLAYS
- J.P.Morgan
- IFC International Finance Corporation World Bank Group
- SOCIETE GENERALE
- RBS The Royal Bank of Scotland
- BOSI
- MIZUHO
- MACQUARIE
- RAND MERCHANT BANK A division of FirstRand Bank Limited

What is Reservoir Engineering?

- Reservoir engineering is the discipline that assesses and plans the recovery of oil and gas reservoirs
- We work with the other disciplines to find opportunities to optimise the value of oil and gas assets
- Reservoir engineers need to understand the dynamics of reservoir rocks, fluids, wells and the surface facilities, all tied together with economics in mind



What is Reservoir Engineering?

Reservoir engineering is the discipline that:

- Creates forecasts of oil, gas and water rates
- Determines the number of wells required in a field, the well types and locations

We work with other disciplines to optimise:

- The field rates vs capital expenditure
- Production capacity vs gas contract rates

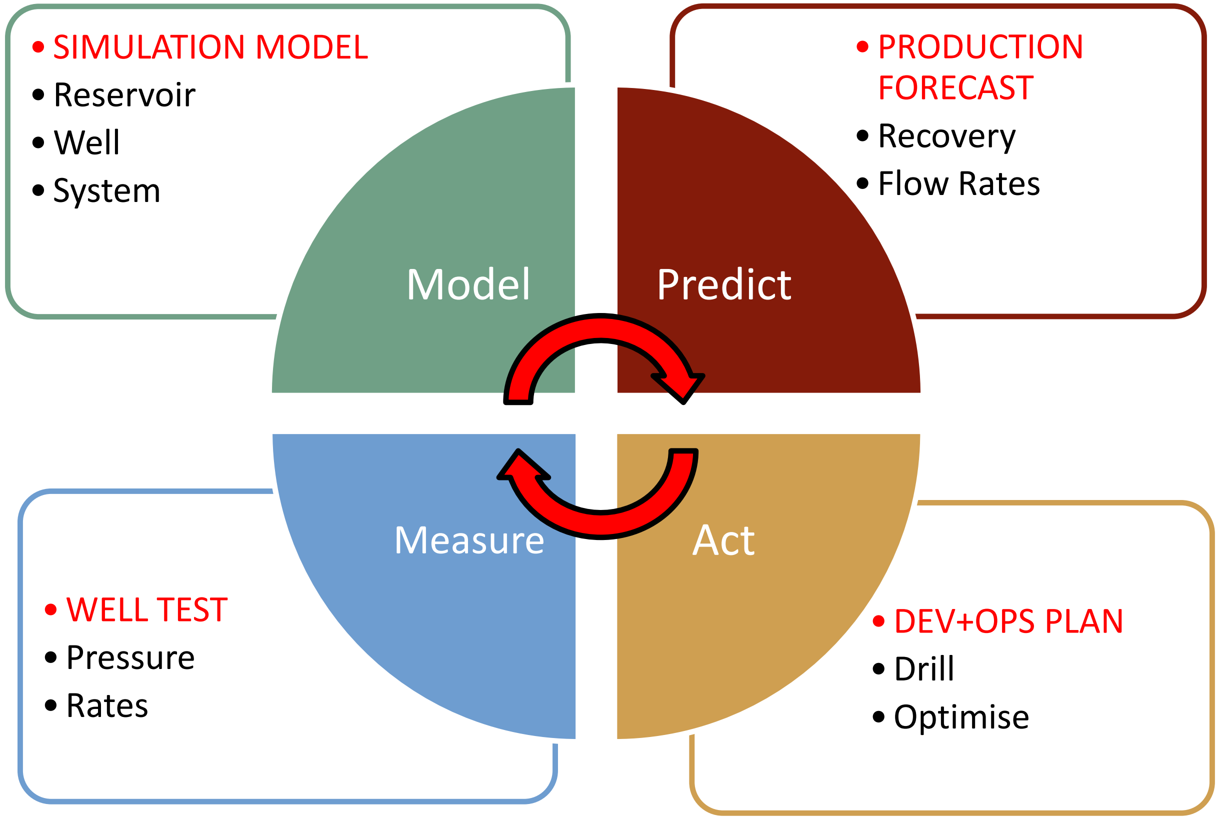



What is Reservoir Engineering?

You can't see into the reservoir!

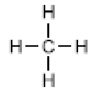
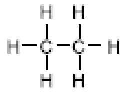
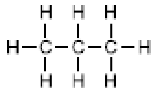
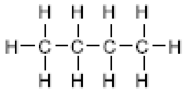
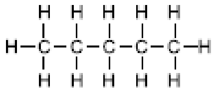
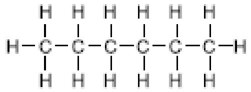
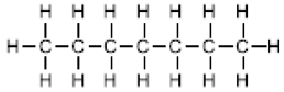
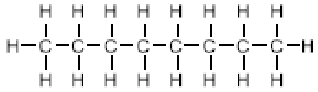
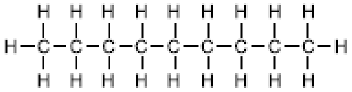
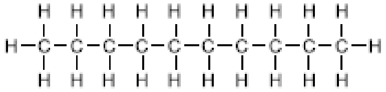
We need to measure, make assumptions, and create models to manage and reduce uncertainties in oil and gas recovery.

We continue taking measurements, to check the models against reality, and can re-calibrate the models to improve our forecasts.



What are oil and gas?

- Hydrocarbons are found in a range of states such as gas, oil and tar
  - Methane, ethane, etc
- Oil and gas are not separate, distinct molecules
  - Gas is mostly CH_4 but also contains heavier molecules (condensate)
  - Oil is mostly molecules of C7+ but also contains significant % of CH_4 (solution gas)
- One reservoir can provide multiple sales products

Name	Molecular Formula	Condensed Formula	Structural Formula
Methane	CH_4	CH_4	
Ethane	C_2H_6	H_3CCH_3	
Propane	C_3H_8	$H_3CCH_2CH_3$	
Butane	C_4H_{10}	$H_3C\,(CH_2)_2CH_3$	
Pentane	C_5H_{12}	$H_3C(CH_2)_3CH_3$	
Hexane	C_6H_{14}	$H_3C(CH_2)_4CH_3$	
Heptane	C_7H_{16}	$H_3C(CH_2)_5CH_3$	
Octane	C_8H_{18}	$H_3C(CH_2)_6CH_3$	
Nonane	C_9H_{20}	$H_3C(CH_2)_7CH_3$	
Decane	$C_{10}H_{22}$	$H_3C(CH_2)_8CH_3$	

http://dev.elearn.punjab.gov.pk/home/read_book/14/63

Reservoir Rocks and Fluids

Understanding rocks is not just for geologists!

Hydrocarbon flow is influenced by large + small scale rock properties, by fluid saturations and pressures.

The physical properties of the oil, gas and water in a reservoir change over time:

- Pressure changes mostly occur in the reservoir (depletion) and in wellbores
  - Initial pressure varies widely, but can be 5000 psi. This is 350x atmospheric pressure!

- Temperature changes mostly occur in wells and production facilities
  - Temperatures circa 200 degF. Near boiling point of water!

Reservoir Rocks and Fluids

Basic reservoir rock properties:

- **Permeability** (Darcies) is a measure of a rock's ability for fluid to flow
- **Porosity** (%) is the proportion of void space in rock that might contain oil, gas or water

Basic reservoir fluid properties:

- **Viscosity** (centipoise) is a measure of a fluid's resistance to flow
- **API Gravity** (degrees) is a scale to measure the density of petroleum liquids
- **Gas Expansion Factor** (scf/rcf) measures gas volume at surface, compared to its volume in the reservoir
- **Condensate-Gas Ratio** (bbl/MMscf). Condensate is liquid at surface conditions, but gas in the reservoir

Reservoir Drive Mechanisms

Drive mechanisms are the energy sources that transport hydrocarbons from the reservoir to the well.

These are slightly different at every field and rely on the oil, gas, aquifer, pressures and the geometry.

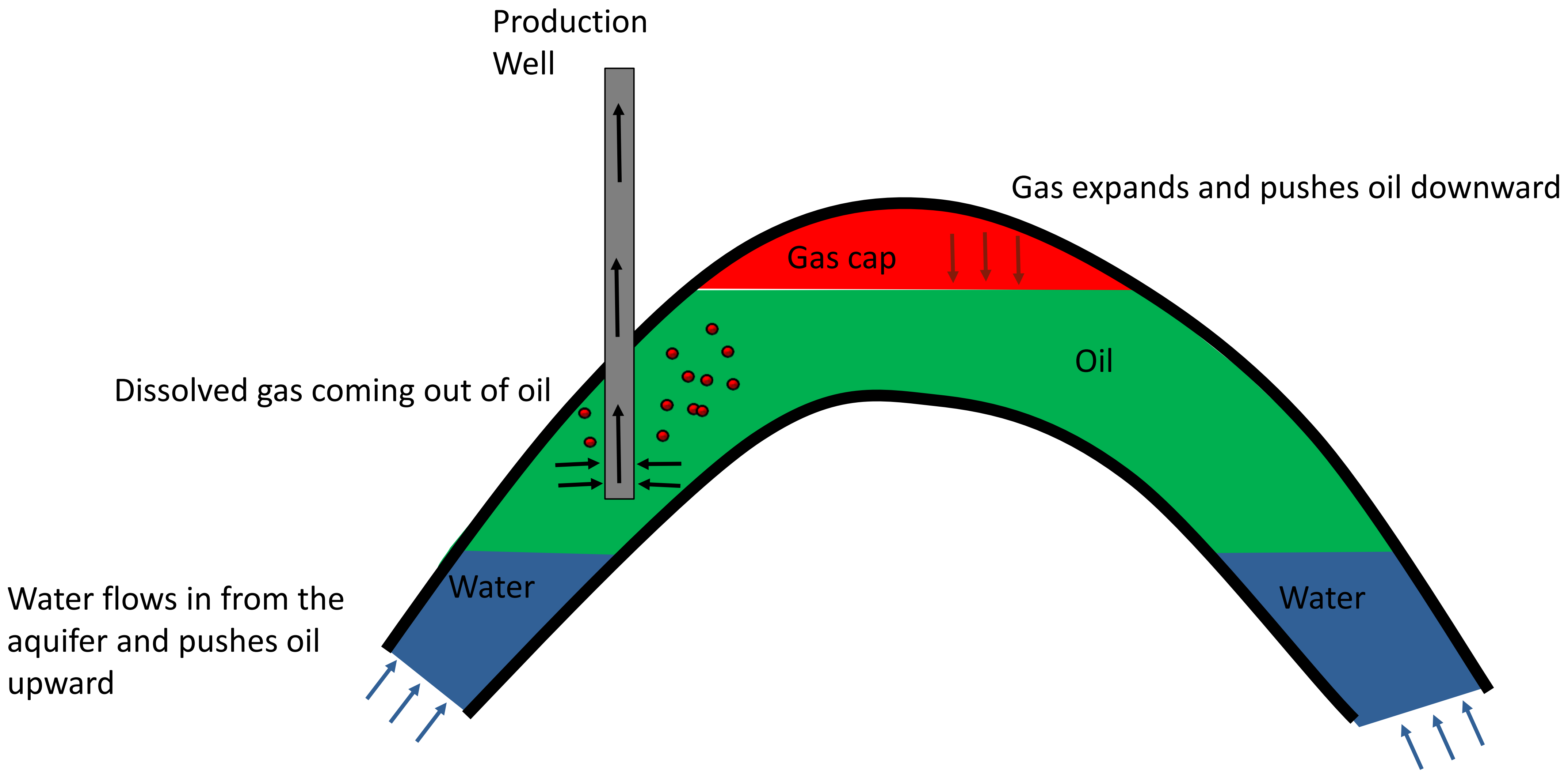
Primary Drive

First stage of production. This recovers oil and gas using the natural energy in the reservoir

- Water drive (aquifer)
- Gas cap expansion drive
- Solution gas drive
- Gravity drainage
- Combination drive

Reservoir Drive Mechanisms

A cross-section through a reservoir showing the gas cap, oil, water and one well.



Reservoir Drive Mechanisms

The wells' rates can be improved by pumping (for oil) and using compressors (for gas).

Secondary Drive

Later stage of production. This recovers oil by injecting water or gas into the reservoir

- It keeps the reservoir pressure high and can sweep oil toward the wells
- An injection well is required, or an old production well can be turned into an injector

Tertiary Drive - Enhanced Oil Recovery (EOR)

Some reservoirs can be enhanced by heating (eg steam injection), chemical injection (viscosity modifiers) or other techniques.

- EOR can recover a further 10%, but may be very expensive to implement
- Needs forecasts of production and costs in an economic model (does EOR add value?)

Recovery Factors

We will never produce ALL of the oil or gas in a field

- Microscopic and macroscopic sweep

The ‘Recovery Factor’ is the proportion of the initial volume that is removed

- This will depend on the fluid type, drive mechanism, wells, etc

Fluid	Drive Mechanism	Recovery Factor
Oil	Solution gas	5% - 30%
	Gas cap	15% - 50%
	Water drive	30% - 60%
	Gravity drainage	15% - 85%
Gas	Aquifer	35% - 65%
	Gas expansion (volumetric)	70% - 90%

Oil and Gas E&P Life Cycle

- The role of the reservoir engineer starts during the Exploration process

- After a discovery, the reservoir engineer is key during Appraisal, Development and Production

Exploration
- Seismic
- Regional Geoscience
- Drilling

Appraisal
- Drilling and Testing
- Investment Decision

Development
- Drilling
- Construction
- Production Facilities

Production
- Flow Wells
- Sell Hydrocarbons
- Return on Investment

Abandonment
- Remove and Restore

A Discovery! Then Well Testing

A well test is a controlled flow, often flared (burned), to gather information for later analysis.

We need answers to questions like:

- Does it flow oil, gas or just water?
- What flow rates, pressures and temperature?
- Is it connected to other wells in the field?
- What is the permeability, and other reservoir properties?
- How large is the reservoir?

Samples of the fluids are taken for laboratory analysis.

Reservoir Engineers also learn a lot from the changes in rates and pressures in the well, even when a well is shut in

http://www.boisbv.com/wp-content/uploads/2016/03/g-Exeter_Flare2331.jpg

After Exploration - Field Appraisal

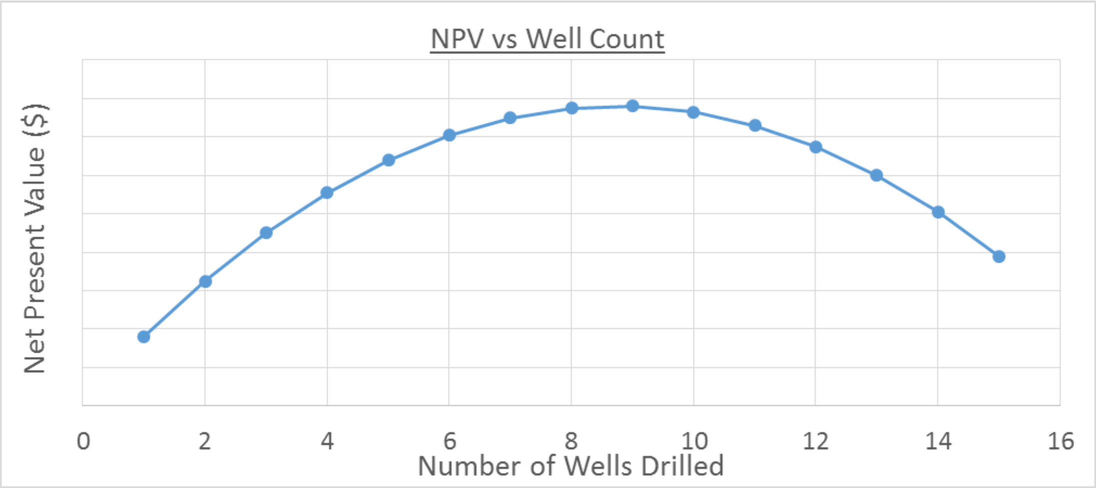
The aim of Appraisal is to provide an estimate of reserves, to make the right decision about how to best develop the discovery

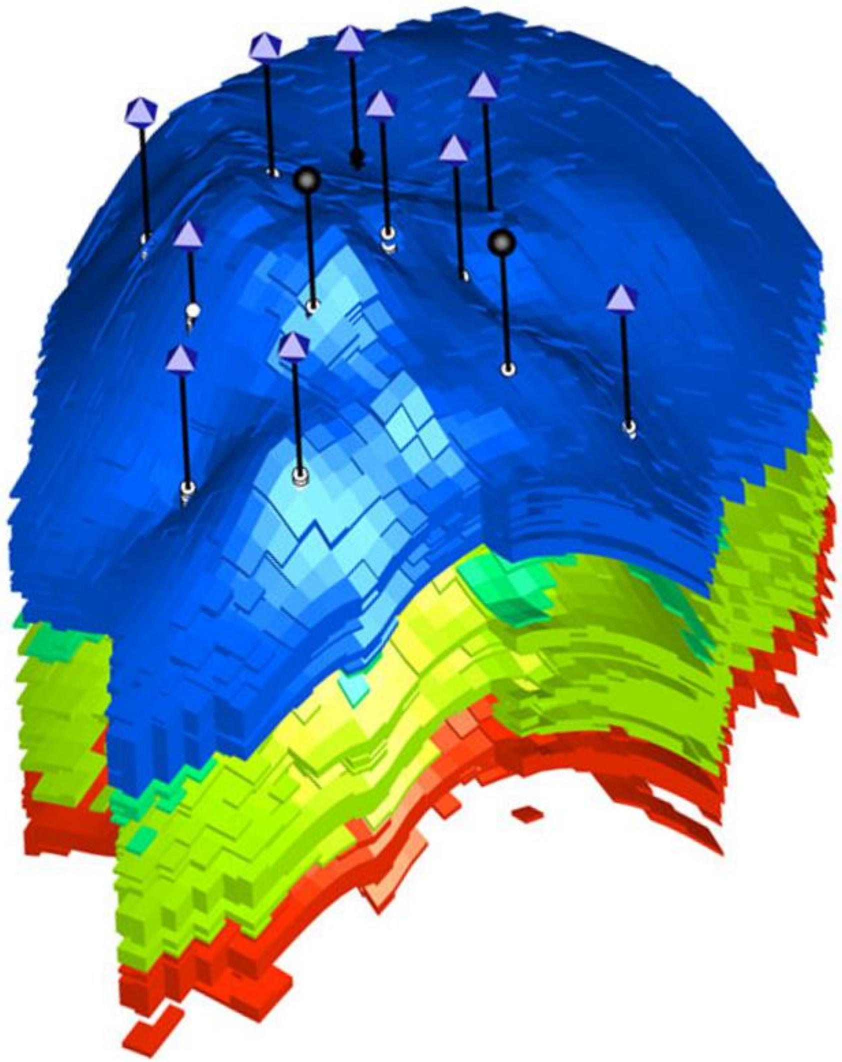
The goal is approval to develop the field

May require extra drilling, well testing and data acquisition

Key tools

- Reservoir engineering simulation model to combine geoscience, well tests and the development plan
- Economic analysis for optimisation





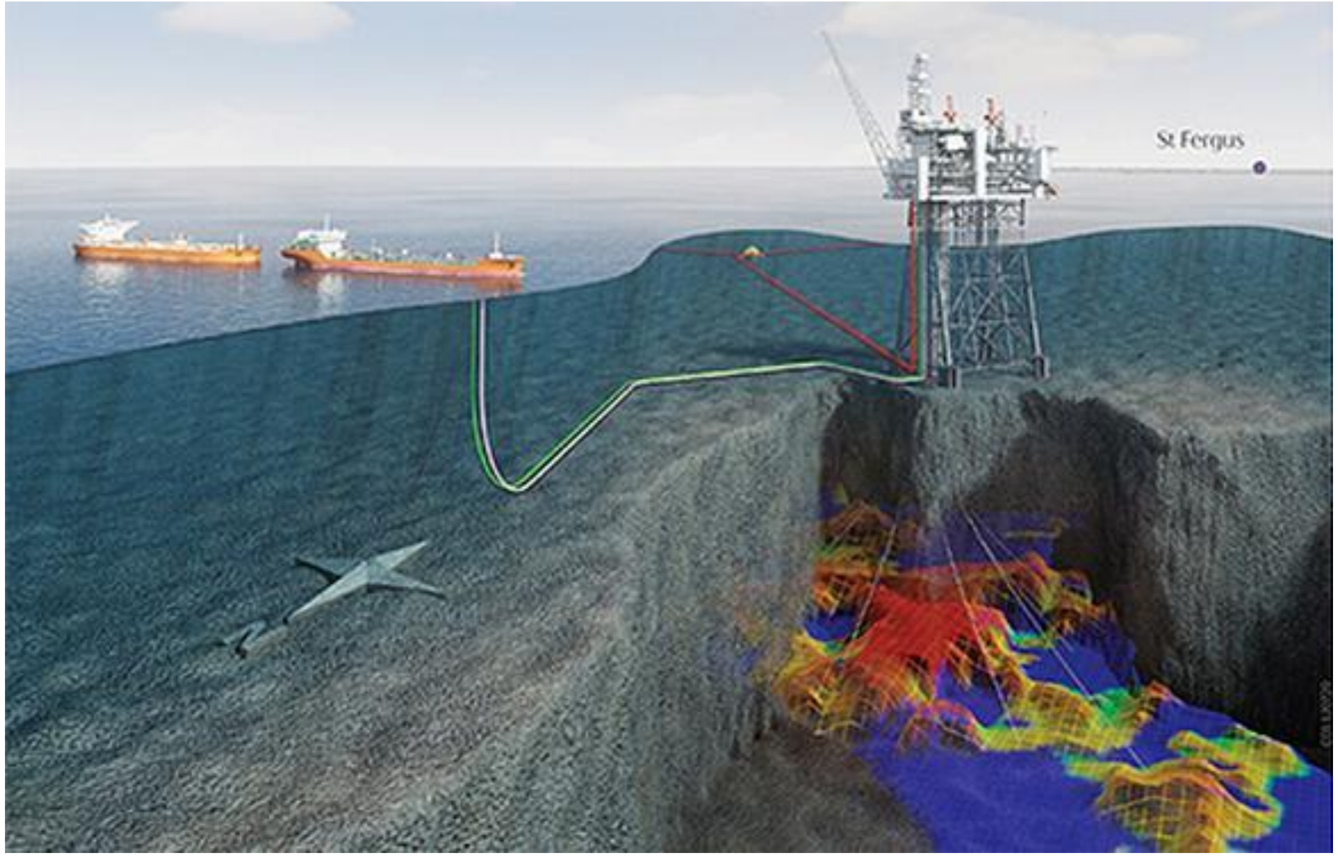
http://www.tecplot.com/wp-content/uploads/2011/10/RS-3D_Final_Images1.jpg

After Appraisal - Field Development

Once the field is appraised and the field looks to be economic, a Field Development Plan (FDP) is created.

Reservoir engineers are closely involved in every stage of the field's future:

- Number and type of wells
- Type of production facilities
- Will injection or pumps be required?
- Oil, gas and water production profiles
- Economics and reserves
- What/how/when extra information is to be gathered, and how this may alter the plans
  - Eg aquifer strength



http://www.offshoreenergytoday.com/wp-content/uploads/2012/12/Statoil-Makes-FID-for-7-Bln-Mariner-Development-UK.jpg

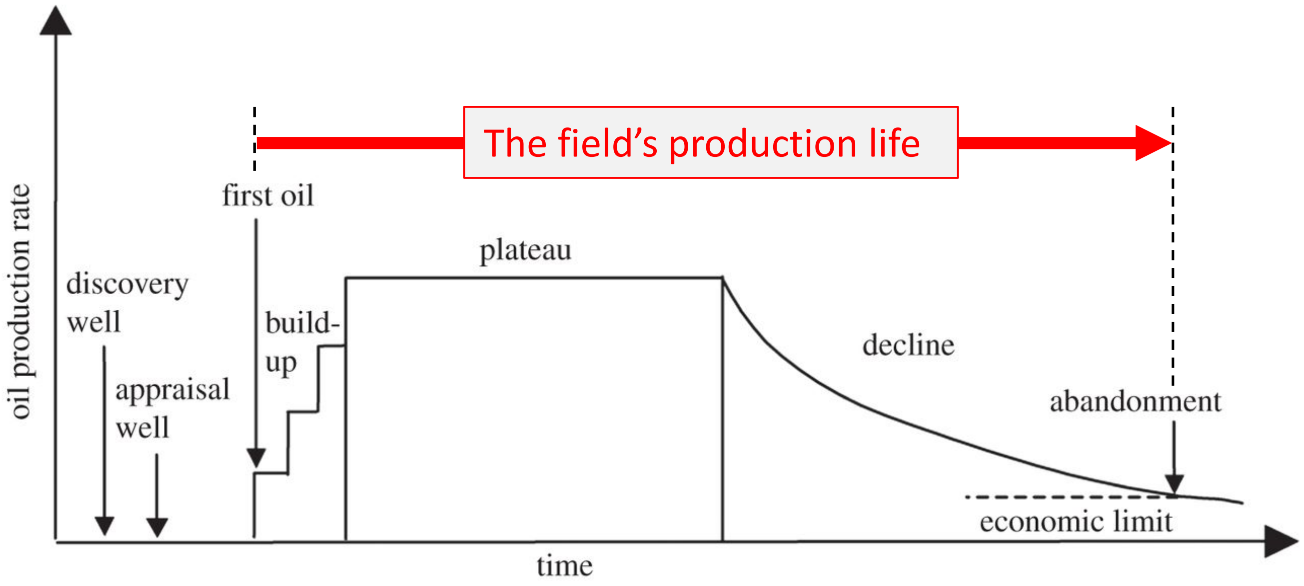
After the Development Phase - Production

Finally!

After years of technical studies, investment and work, the company can start oil and gas production to generate a return on the investment.

Reservoir engineers now enact and update the FDP

- Has each well flowed as expected?
  - If not, do the models need recalibration or does the well need modification?
- What can we do to prolong the production life?
- What can we do to maximise:
  - Production rate?
  - Reserves?
  - Profit and Value?

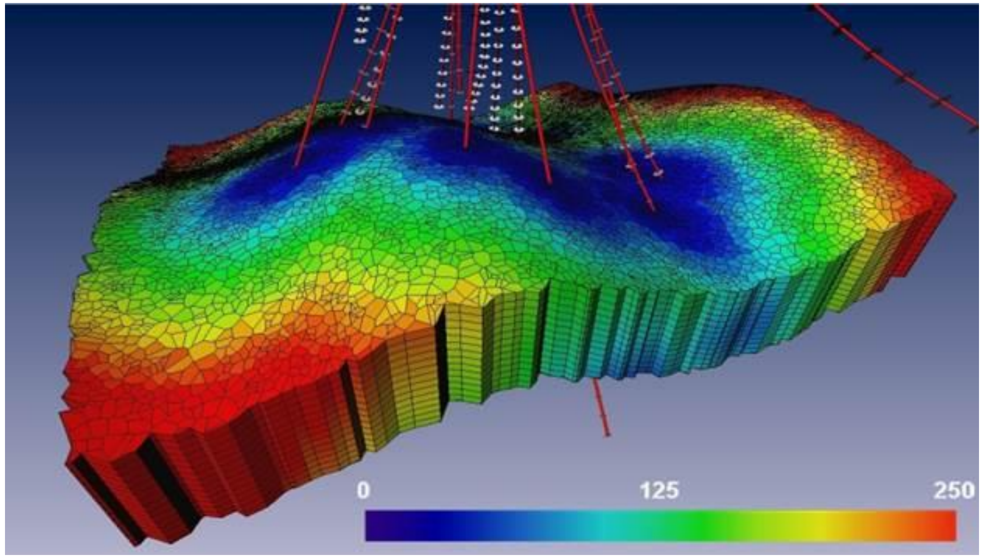


http://rsta.royalsocietypublishing.org/content/372/2006/20120448

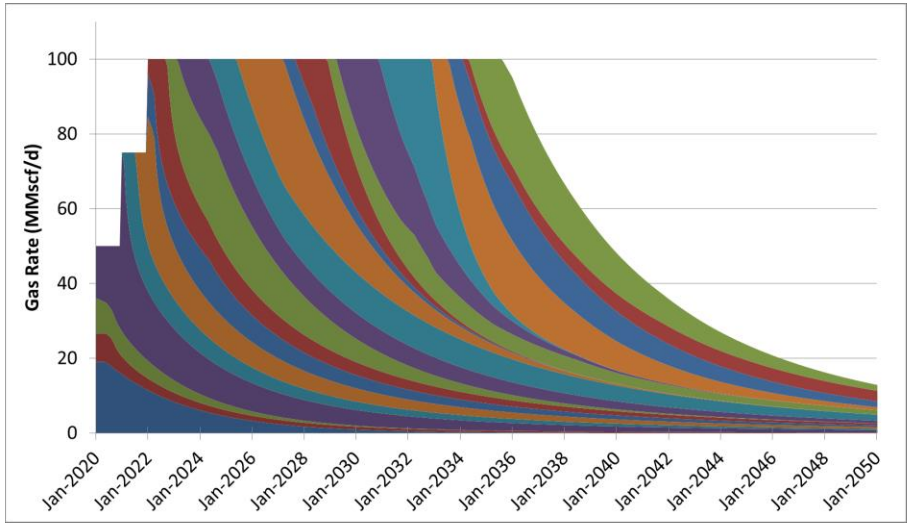
Forecasting: Reservoir Simulation

The dynamic reservoir simulation is a reservoir engineer's model to integrate all the technical work and plans to create production forecasts for a field.

- The reservoir shape and architecture use the geological model
- All existing and planned wells are included
- The model is tuned to the historical production, pressures, changes in the wells and in the production facilities
- Modelling allows investigation of 'what if' scenarios, instead of using just trial and error in the field
  - Planning for new wells, secondary and tertiary recovery
- Also useful to determine what extra data would help the most



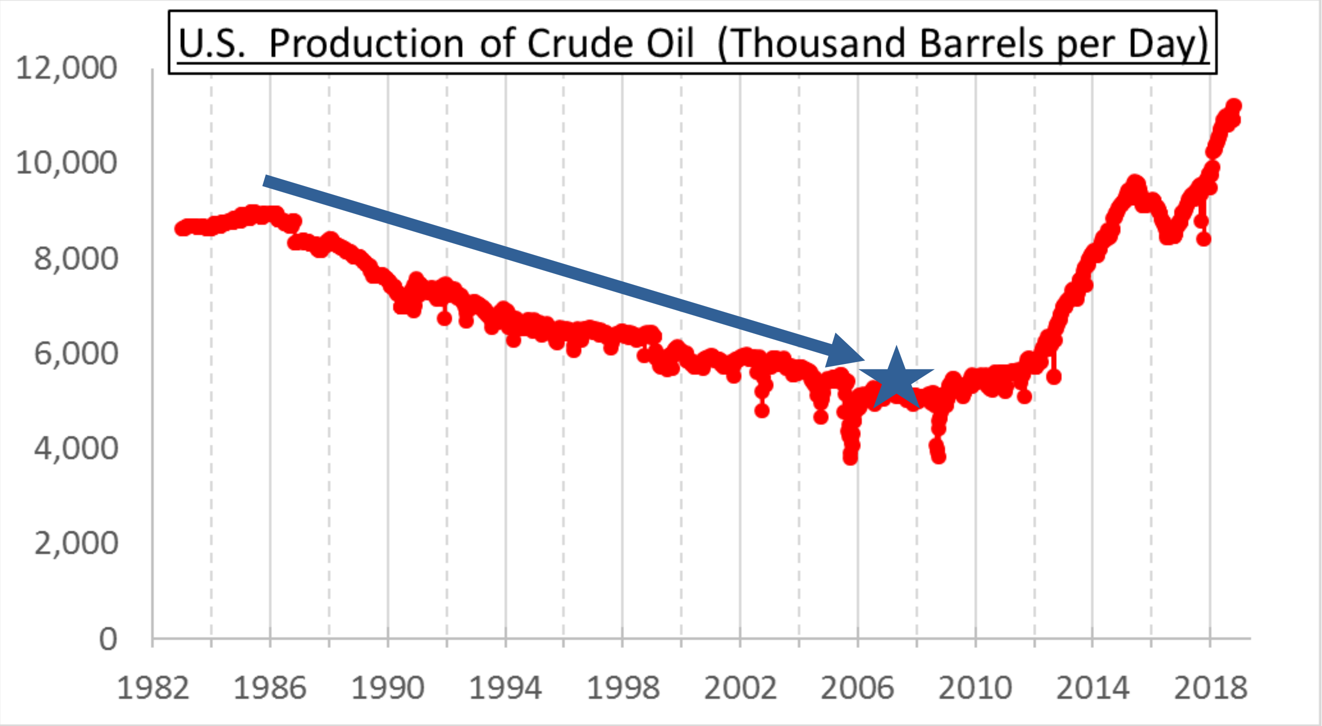
http://www.openinventor.com/en/solutions/oil-gas-and-mining/reservoir-modeling-engineering



Unconventional Petroleum Systems

- Historically, as technology improved, companies produced hydrocarbons from progressively lower quality rock.
- The ‘Unconventional’ resources were though impossible to develop economically
- A breakthrough was the combination of horizontal wells with multiple hydraulic fractures
- Shale oil in the US took off a decade ago and has changed the global industry

- Oil potential is enormous, but fields are challenging and expensive to develop
- Still no commercial UK developments… yet



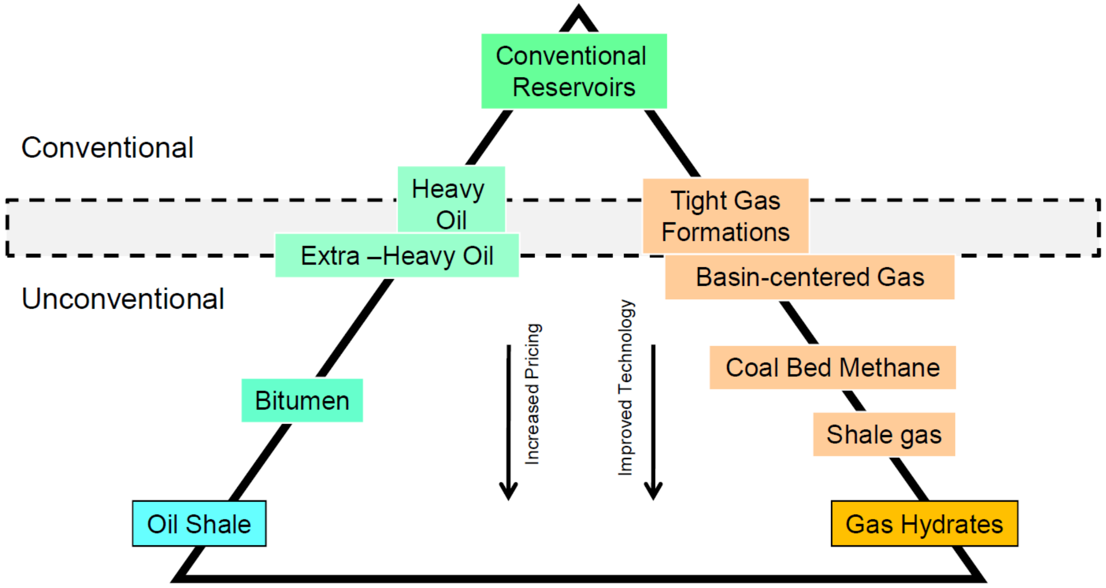
Unconventional Petroleum Systems

Important worldwide

- Tight oil and gas: low-permeability rock
- Shale oil and gas: found in organic-rich rock
- Coal Bed Methane: natural gas found in coal

Plus less common

- Extra-Heavy Oil and Bitumen: Oil with API Gravity < 10, very dense and huge viscosity (10,000 cP). Is either mined, or heated with steam to flow into wells
- Oil shale: mined as rock, then heated to over 500˚C to release oil from the rock
- Gas Hydrates: crystals of water and natural gas. Common near the sea floor but recovery is not commercial



Resources Triangle (from PRMS Guidelines)

Oil and Gas Reserves

What are Oil and Gas Reserves?

What are Reserves?

- A company’s share of remaining economically recoverable oil and gas to be produced and sold
  - See next slides for formal PRMS definition
- Reserves are the main Upstream asset of an E&P company
- They contribute to a field’s value, the company’s value and therefore share price

Reserves have many purposes:

- Corporate reporting
- Asset valuation for Acquisitions and Divestments
- Investment decisions for financing
- Government planning

They are important to governments, economists, bankers and the energy industry.

The Basics of the PRMS

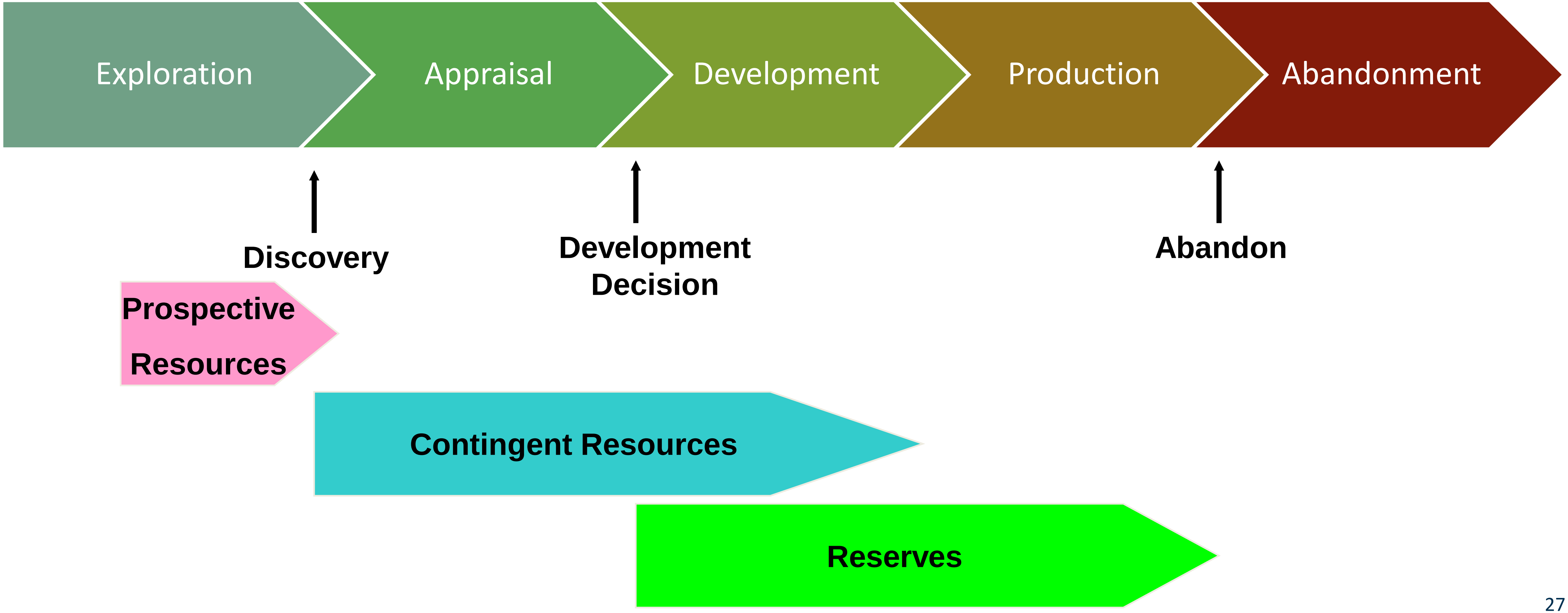
Petroleum Resources Management System (PRMS)

- A shared classification system for oil and gas reserves was adopted in 2007 and updated in 2018 by several industry bodies (SPE, WPC, SPEE and AAPG)
- Used internationally as a standardised reporting system
- In the UK: used in LSE, AIM and for bank financing

This presentation assumes PRMS framework is being used

E&P Project Life Cycle

The PRMS is “Project–Based”



Reserves

What are RESERVES?

"Those quantities of petroleum anticipated to be commercially recoverable by application of development projects to known accumulations from a given date forward under defined conditions.

Reserves must further satisfy four criteria: discovered, recoverable, commercial, and remaining based on the development project(s) applied."

- Quote from the PRMS (2018)

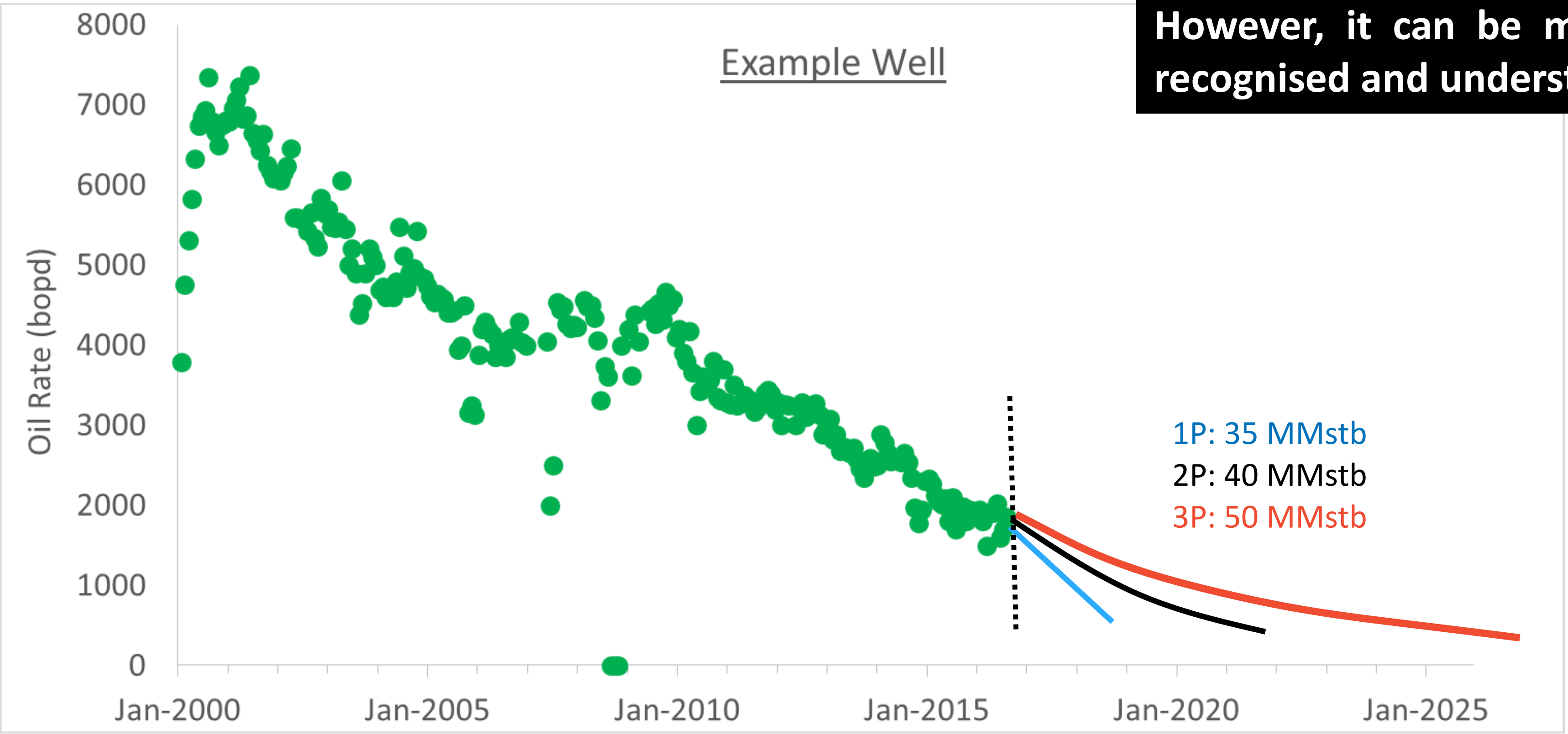
The uncertainty range in Reserves estimates: 1P, 2P, 3P categories

Expressing Uncertainty in E&P Estimates

Uncertainty gives the range of recovery for reserves

- High Confidence => Proved (1P)
- Best Estimate => Proved+Probable (2P)
- Low Confidence => Proved+Probable+Possible (3P)

Uncertainty cannot be avoided. However, it can be managed if it is recognised and understood.



Contingent Resources

What are CONTINGENT RESOURCES ?

- A discovery without an approved development
  - Eg a gas field without a market for gas; a field with high CAPEX making development uneconomic
- These might progress to become reserves in future
- From reservoirs that are

  “not currently considered to be commercially recoverable due to one or more contingencies.” (PRMS 2018)
- Categorised as: 1C, 2C, 3C

Prospective Resources

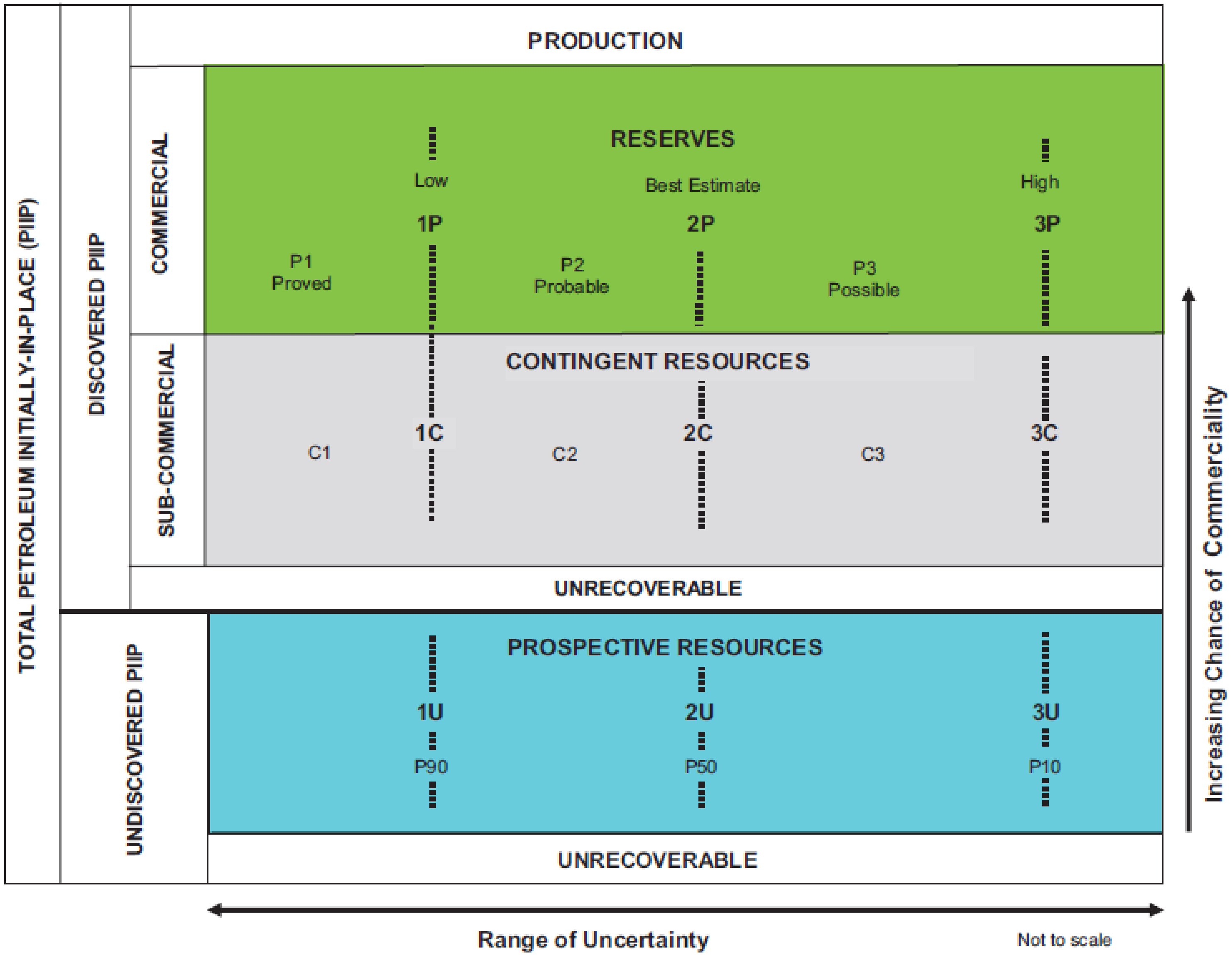
What are PROSPECTIVE RESOURCES ?

- They are a company's idea of where they should explore for hydrocarbons
- An exploration well will confirm the presence of oil or gas OR indicate a 'dry hole'
  - It becomes Contingent Resources and possibly Reserves in future
- BUT there is a risk there may not be a field at all
- They are from *"undiscovered accumulations"* (PRMS 2018)

Categorised as: 1U, 2U, 3U. Also as Low, Best Estimate and High

Prospects each have a Chance of Success. A geologist might say this is 10% or 60%

PRMS Resource Classification Framework



Reserves. 1P/2P/3P volumes
Fields are producing or are being developed

Contingent. 1C/2C/3C volumes
Needs an investment decision, market, etc

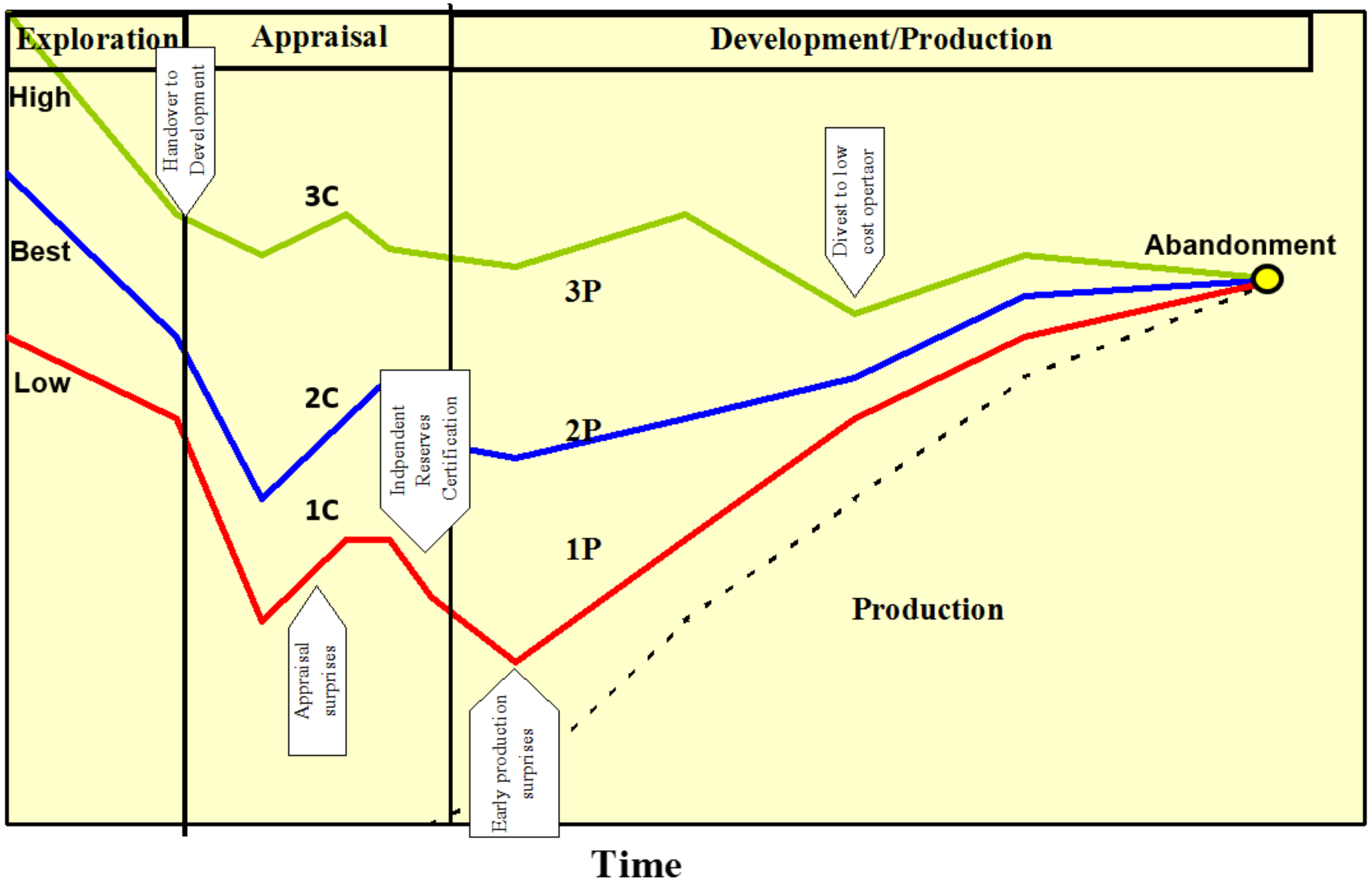
Prospective. 1U/2U/3U volumes
Needs an exploration well

Resource Uncertainty in Time

Resources and Reserves are estimates and evolve with new information over time

- The uncertainties reduce as a field progresses from Prospective to Contingent, then Reserves and production
- There is no uncertainty left on the last day of production

A reservoir engineer's role is over when the field is abandoned.



References and Further Reading

Glossary of Oil and Gas Terms

http://www.esandaengineering.com/images/Esanda%20Illustrated%20Upstream%20Oil%20and%20Gas%20Glossary%20March%202016.pdf

Technical Papers for the SPE and other organisations

www.onepetro.org

www.spe.org

www.spe-london.org

Petroleum Resources Management System

https://www.spe.org/en/industry/petroleum-resources-management-system-2018/

PRMS Guidelines

http://www.spe.org/industry/docs/PRMS_Guidelines_Nov2011.pdf decisions with confidence

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