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SPE London seminar
Introduction to Upstream Oil and Gas for the Net Zero World - Reservoir Engineering and Reserves

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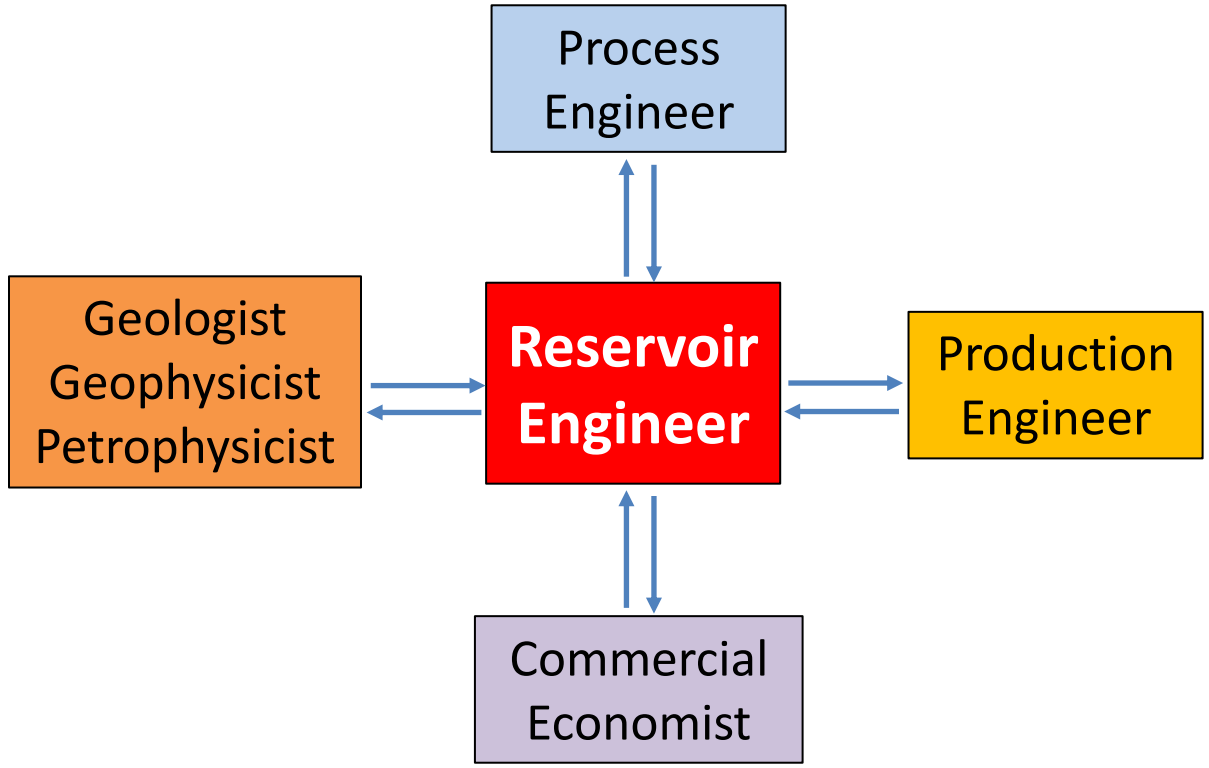
What is Reservoir Engineering?

- 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 engineers are the ones to:

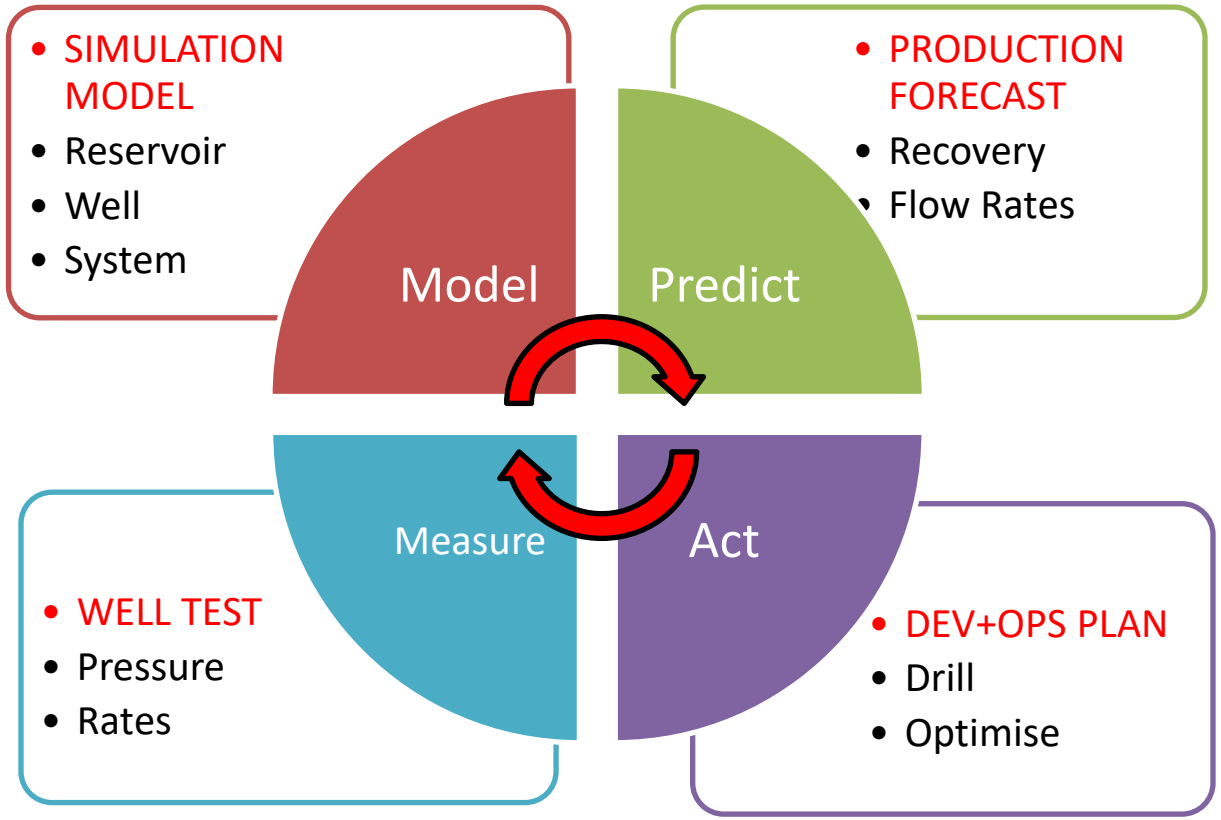
- Create forecasts of oil, gas and water rates
- Determine the number of wells required in a field, the well types and locations

We work with other disciplines to optimise:

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

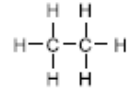
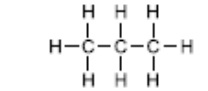
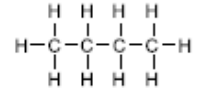
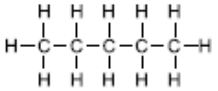
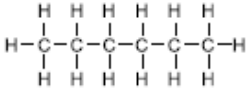
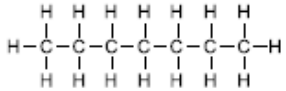
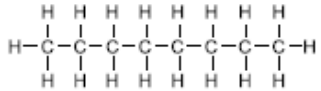
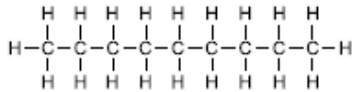
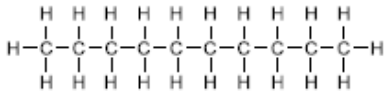
What is Reservoir Engineering?

- You can't see into the reservoir!
- We measure, make assumptions, and create models to manage and reduce uncertainties in oil and gas recovery.
- We continue taking measurements and checking the models against reality, to 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 C5+ 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.

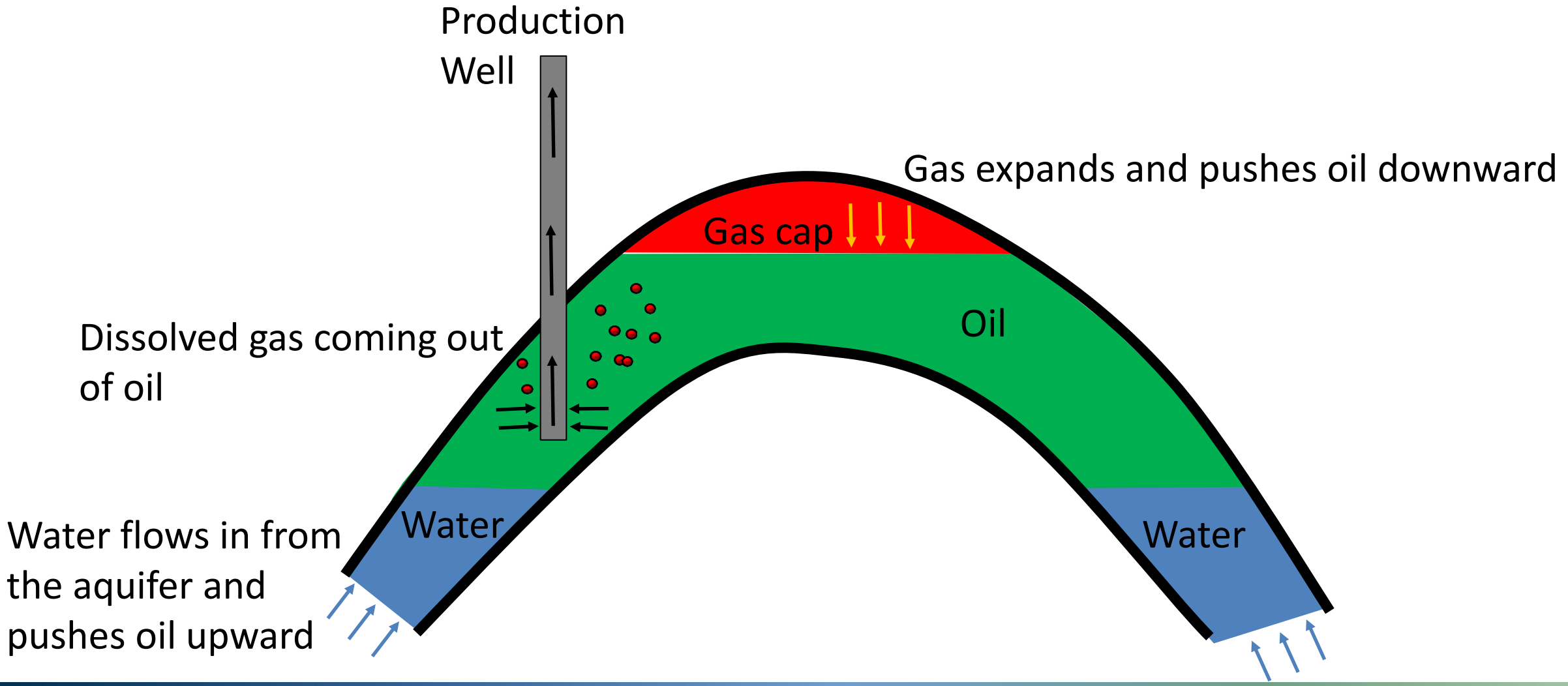
Primary Drive

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

A well's rate can be improved by pumping (for oil wells) and using compressors (for gas wells).

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

A Discovery! Then Well Testing

- A well test is a controlled flow 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?

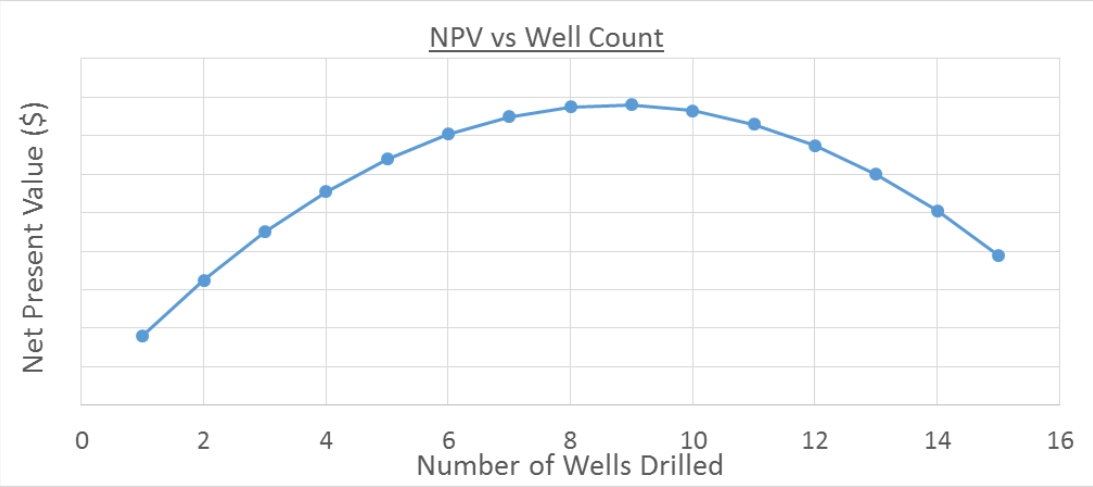
- Samples of the fluids are taken for laboratory analysis.
- Reservoir Engineers also learn a lot from the changes in rates and pressures in the well, even when a well is shut in

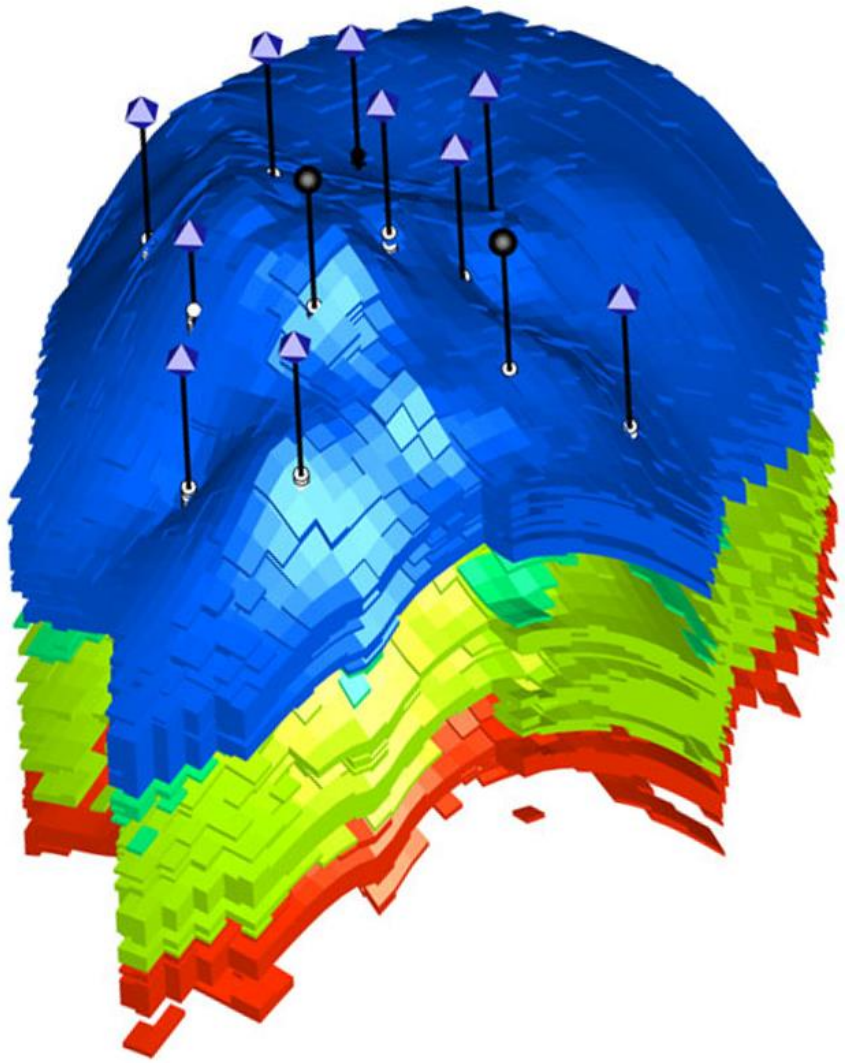
http://www.boisbv.com/wp-content/uploads/2016/03/g-Exeter_Flare2331.jpg

After Exploration - Field Appraisal

- Appraisal is collecting data to provide an estimate of oil or gas recovery.
- 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



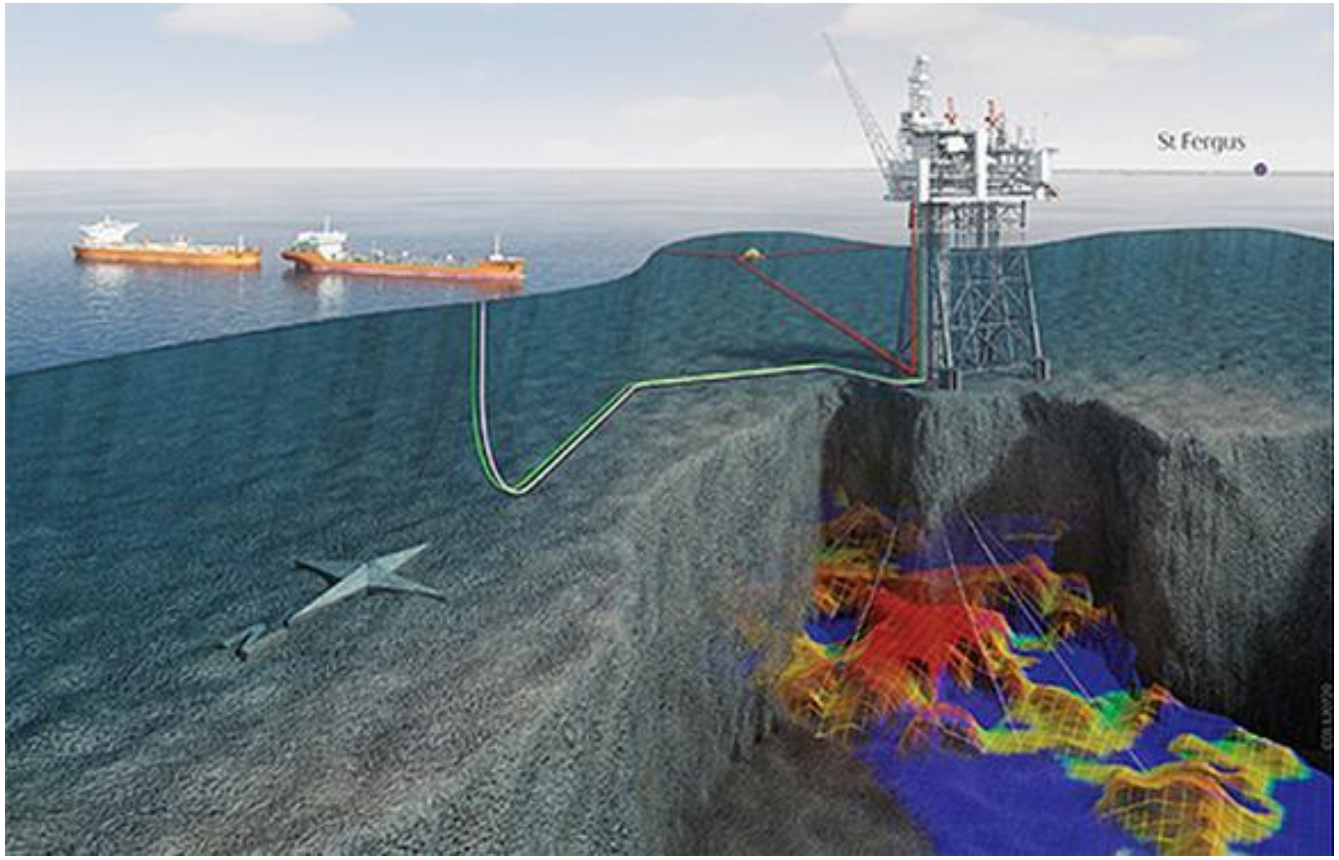


http://www.tecplot.com/wp-content/uploads/2011/10/RS-3D_Final_Images1.jpg

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



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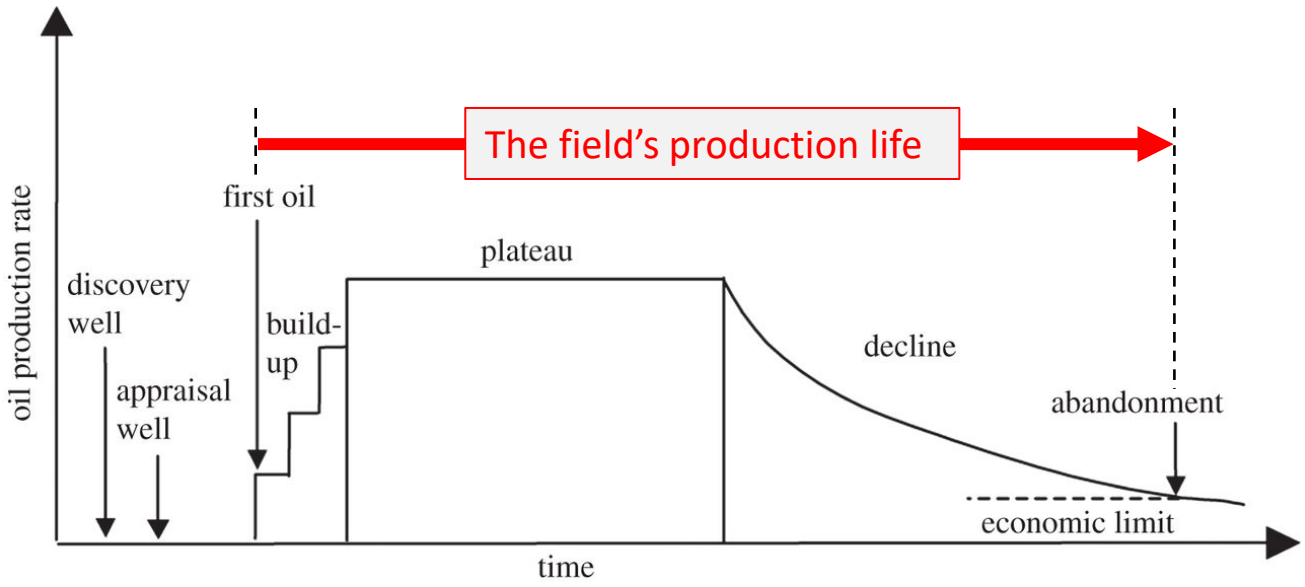
After the Development Phase - Production

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

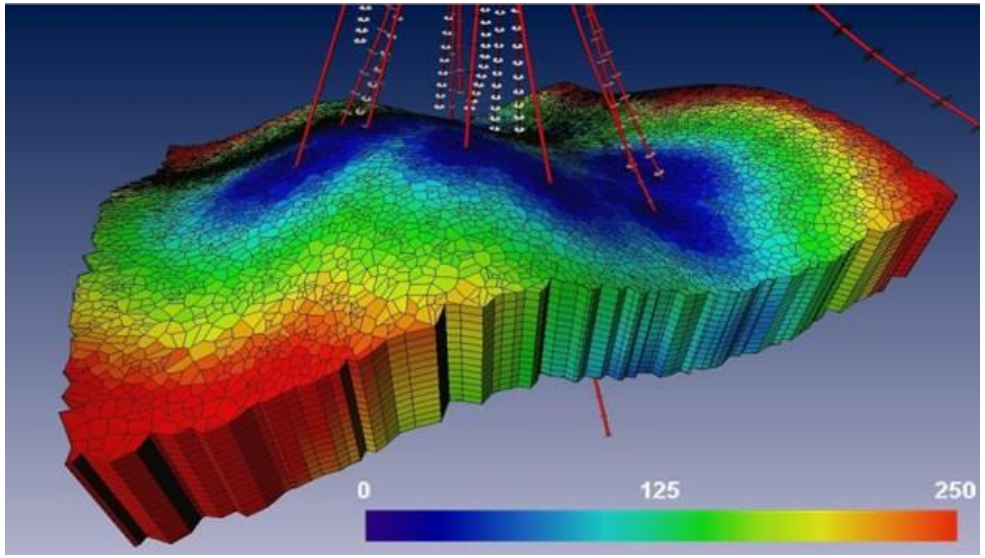
- Reservoir engineers now enact and update the FDP
  - Has each well flowed as expected?
    - If not, do the models need recalibration or does the well need modification?
  - What can we do to prolong the production life?
  - What can we do to maximise:
    - Production rate?
    - Reserves?
    - Profit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



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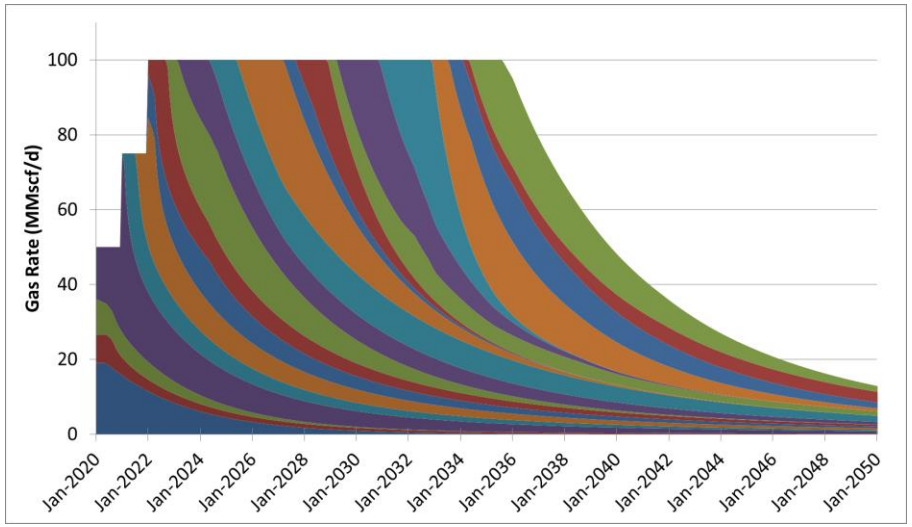
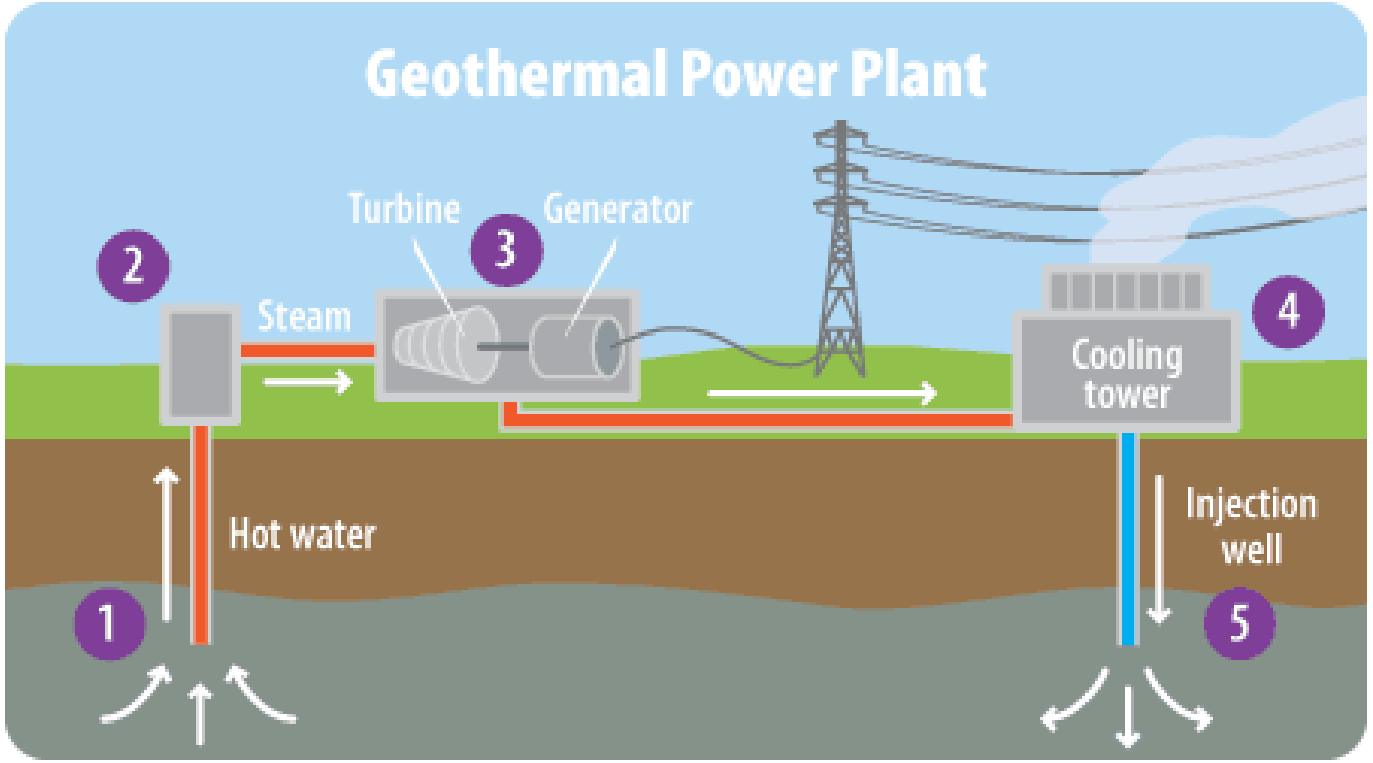


Reservoir Engineering for Net Zero

Reservoir Engineering applied to Geothermal

- The Earth's interior stays hot, despite the weather at the surface.
- Geothermal energy relies on drilling wells into deep reservoirs containing natural hot water or steam.
- This steam can then be used to drive turbines connected to generators, producing electricity.
- The steam or hot water can also be used in industry or to heat buildings.

- Geothermal energy is a renewable energy source, with minimal greenhouse gas emissions.
- The supply of heat or electricity is stable, with a project life of 20-30 years.
- It has low OPEX but high initial CAPEX.

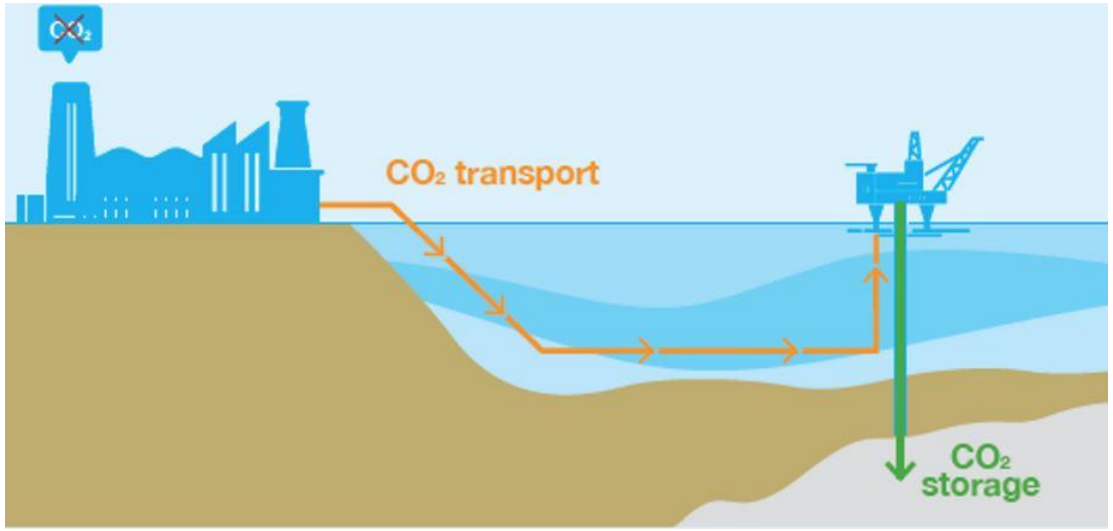


https://archive.epa.gov/climatechange/kids/solutions/technologies/geothermal.html

Reservoir Engineering applied to Carbon Storage

- Underground carbon storage, also known as geological sequestration, involves injecting CO2 into deep geological formations.
  - Capture the CO2 where it is created
  - Transport it via ships or pipelines
  - Inject deep underground for permanent storage.

- Reservoir engineers work in integrated multi-disciplinary teams to assess storage sites, manage risks, and predict the behavior of injected carbon dioxide.
- We make decisions about how to best develop the injection site. The goal is approval to develop the field for CO2 injection which may require extra drilling, well testing and data acquisition.
- Does this sound like the reverse of a production project?



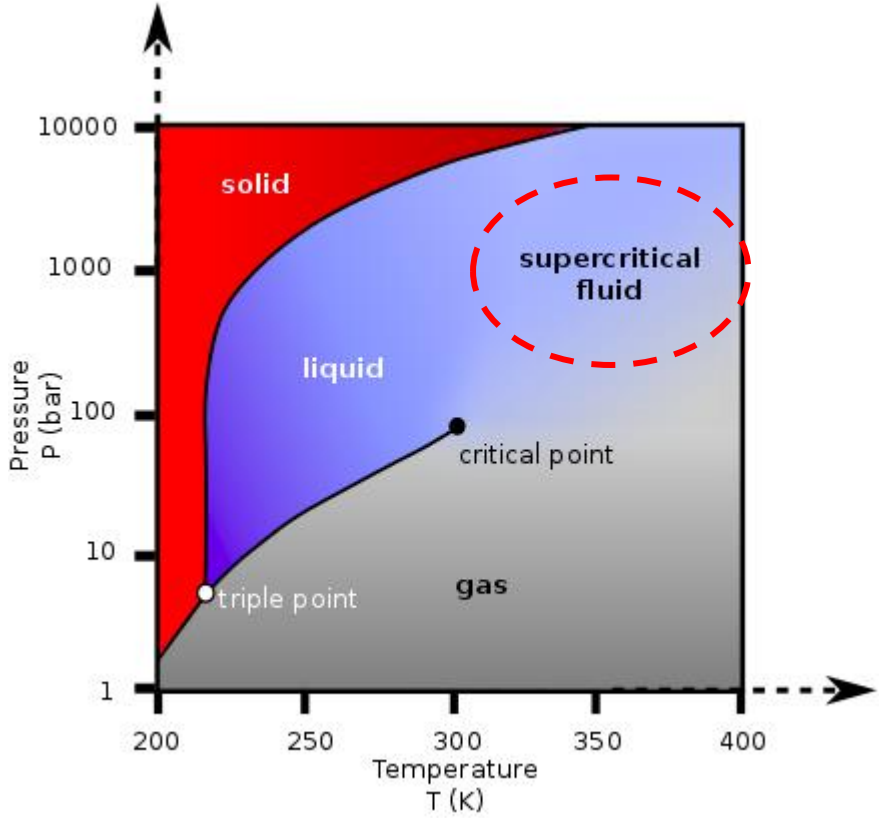
https://oeuk.org.uk/burying-co2-forever-uk-announces-first-licensing-round-for-up-to-100-geological-storage-sites-for-permanently-storing-co2/

Reservoir Engineering applied to Carbon Storage

- CO2 is injected into geological structures: deep saline aquifers, or depleted oil and gas reservoirs.

- Key characteristics of a storage site include:
- Capacity. How much CO2 can be stored?
  - 20-50 million tonnes
- Injectivity. What injection rates are possible?
  - 1-2 million tonnes per year
- Containment. What are the risks of potential leakage?
  - Detailed studies, laboratory work, seismic monitoring

- CO2 has complex physical and chemical behaviours:
  - Above the critical point (31°C, 73.8 bar) CO2 exists as a supercritical dense phase, with gas-like viscosity and liquid-like density.
  - Below the critical point it can exist as gas or liquid.
  - CO2 can dissolve in the salty waters of the subsurface



https://supercriticalfluid.net/supercritical-fluids/

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
  - 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

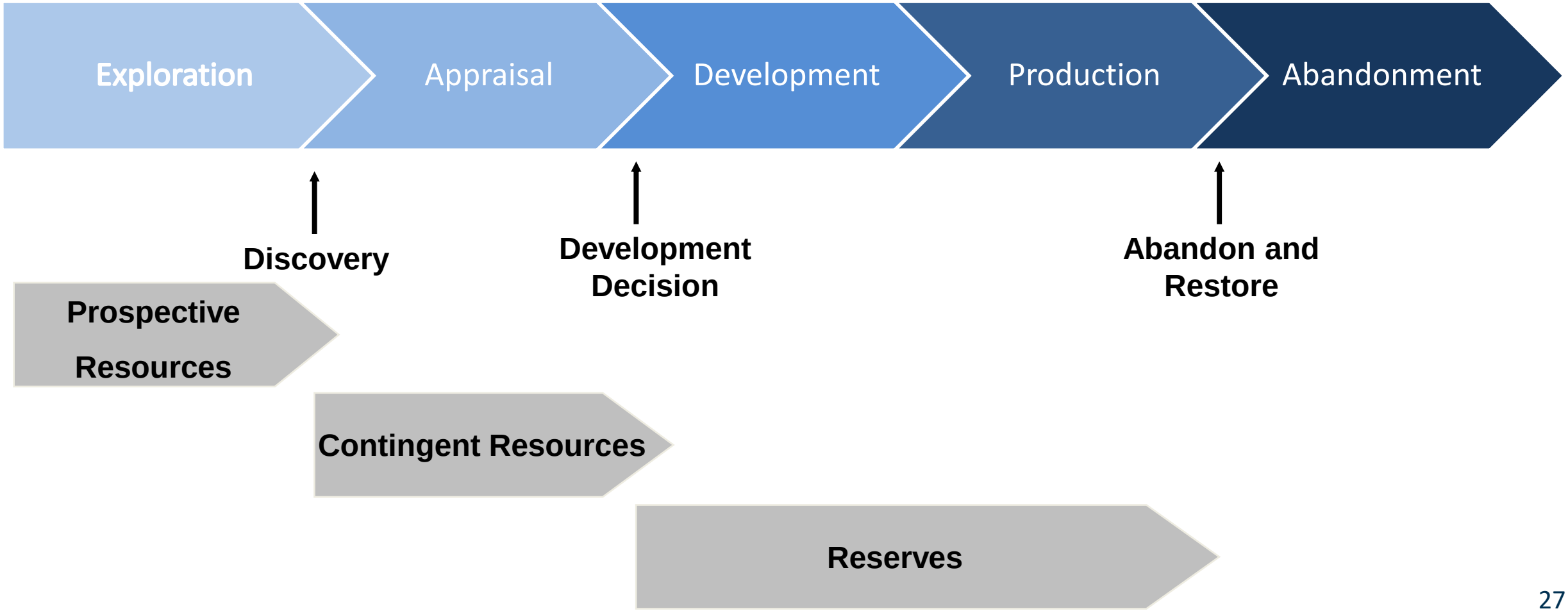
- Petroleum Resources Management System (PRMS)
  - A classification system for oil and gas reserves was adopted in 2007 and updated by industry groups
  - Used internationally as a standardised reporting system
  - In the UK: used in LSE, AIM and for bank financing

- This presentation assumes PRMS framework is being used

- The PRMS was adapted for CO2 storage as the SRMS (CO2 Storage Resources Management System) and the classifications changed to include “Capacity”, which is equivalent to reserves

E&P Project Life Cycle

- The PRMS reserves classification depends on maturity and is “project–based”



Reserves

- What are RESERVES?

- Volumes that are commercially recoverable by application of development projects to known accumulations from a given date forward under defined conditions.

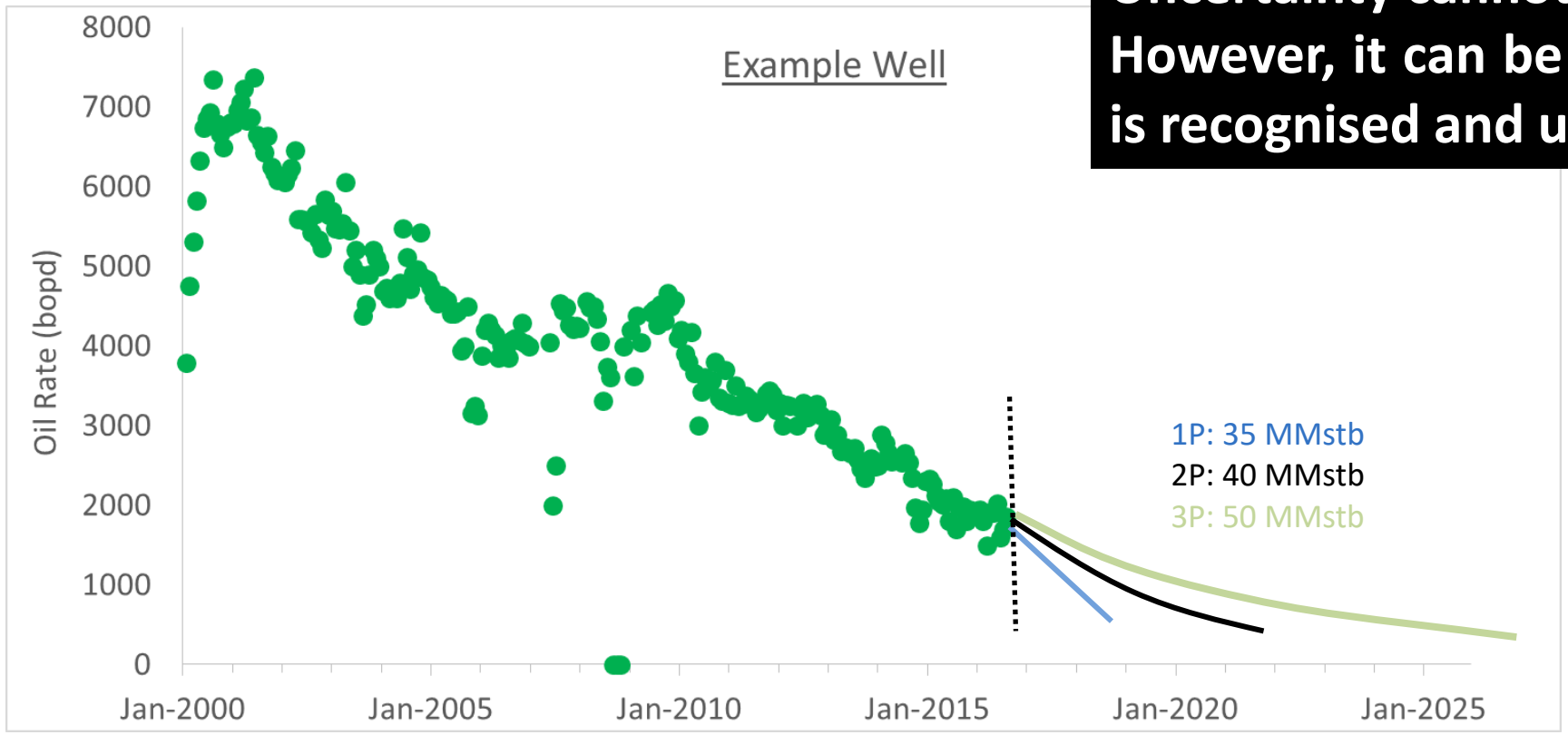
- Reserves must further satisfy these criteria for each project:
  - Discovered - not exploration
  - Recoverable - the oil or gas can be produced
  - Commercial - economically attractive, with all approvals granted by companies and regulators
  - Remaining - excludes volumes already produced

- 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 with a development project not yet Commercial, due to one or more contingencies
  - Eg a gas field without a market for gas; or a field with high CAPEX making development uneconomic

- These can progress to become reserves in future, once they pass the Commerciality criteria.

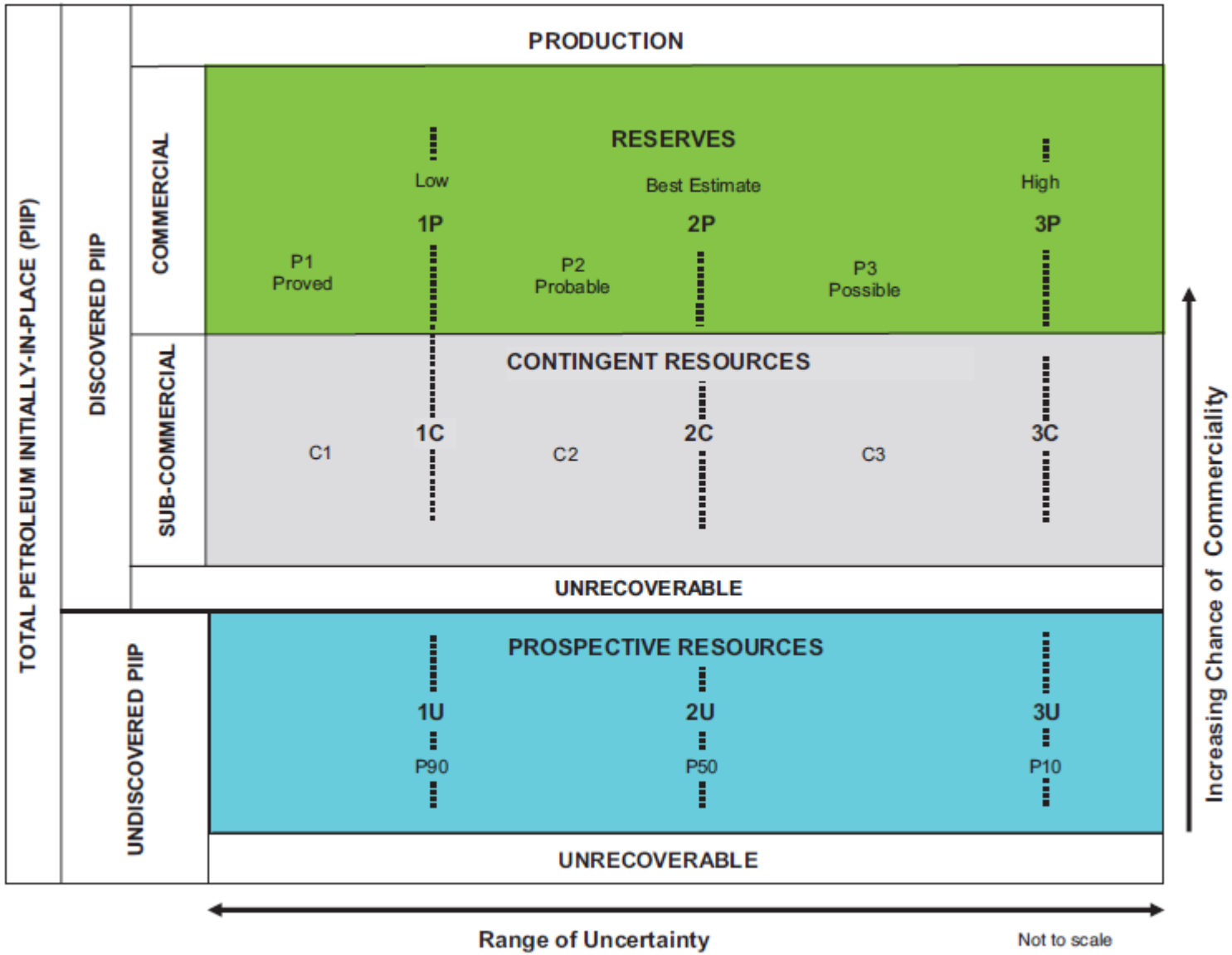
- A ‘Chance of Development’ applies to these projects

Prospective Resources

What are PROSPECTIVE RESOURCES ?

- This is exploration – it's essential to drill a well to discover hydrocarbons
- A successful exploration well will confirm the presence of oil or gas
  - Volumes become Contingent Resources and possibly Reserves in future
- BUT there is a risk there may not be a discovery at all
  - Prospects each have a Chance of Geological 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 Resources. 1C/2C/3C volumes
Needs an investment decision, market, etc

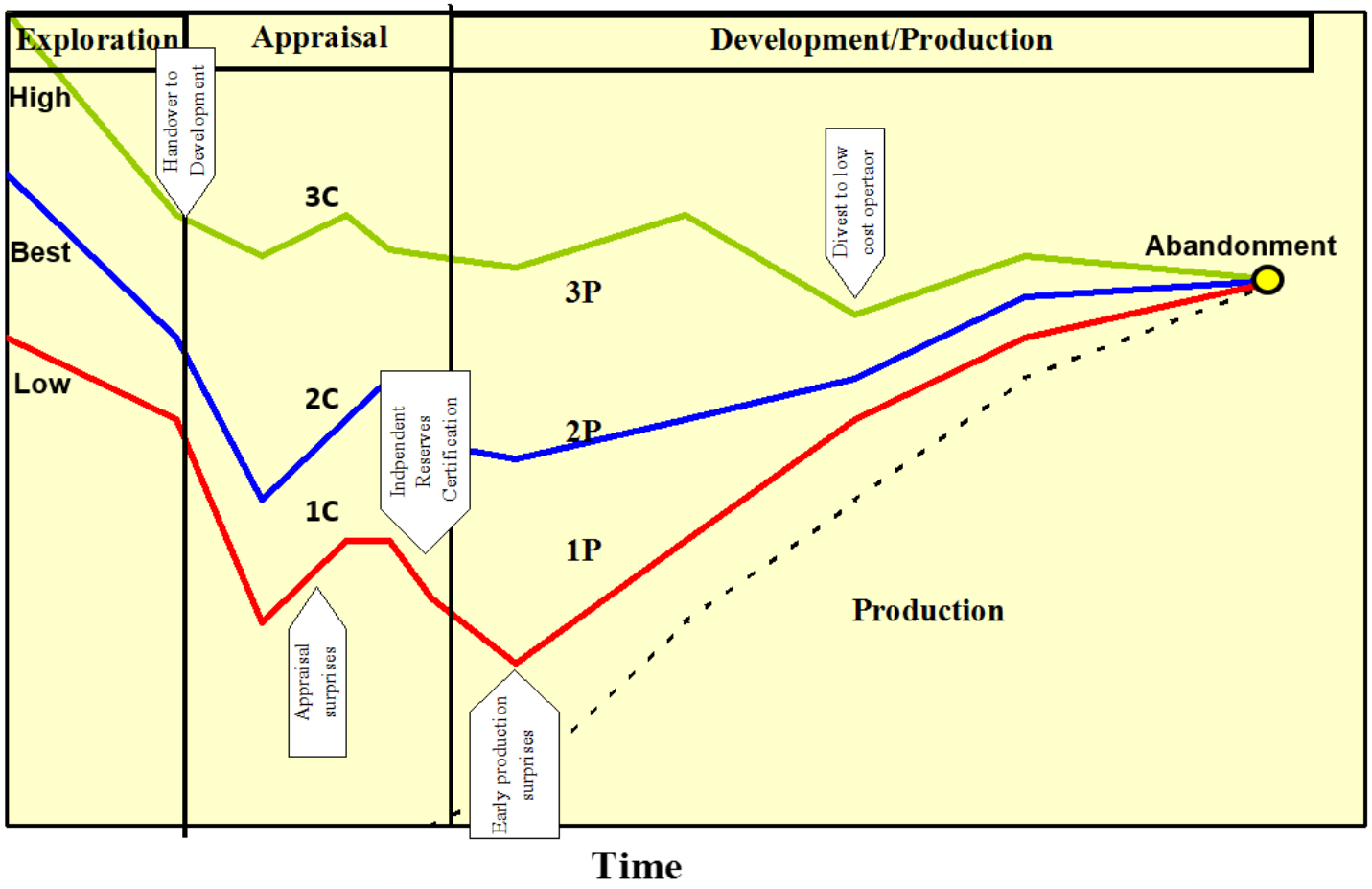
Prospective Resources. 1U/2U/3U volumes
Needs an exploration well

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 goes through Abandonment, Decommissioning and Restoration.



References and Further Reading

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Petroleum Resources Management System

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