Petroleum Engineering

TA3440, Lecture 1, 12 February 2013

Lecturers TA3440 2012-2013

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Schedule TA3440 2012-2013

- Tue 12-2 – JDJ – Reservoir fluids, HSE
- Tue 19-2 – PZ – Drilling and production
- Tue 26-2 – HH – Fluid flow and simulation 1
- Tue 5-3 – DvO – Fluid flow and simulation 2
- Tue 12-3 – WR – Enhanced oil recovery 1
- Tue 19-3 – PZ – Enhanced oil recovery 2
- Tue 26-3 – JDJ – Smart wells & smart fields

Introduction

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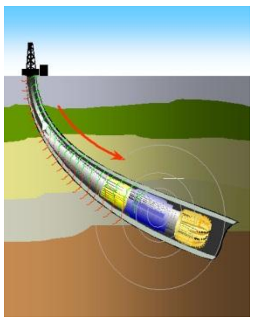
Upstream oil industry

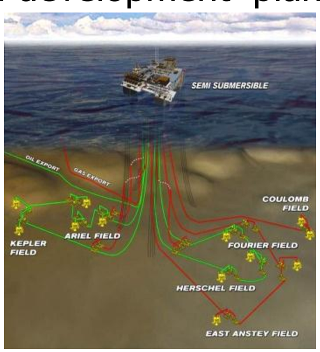
production

seismic imaging

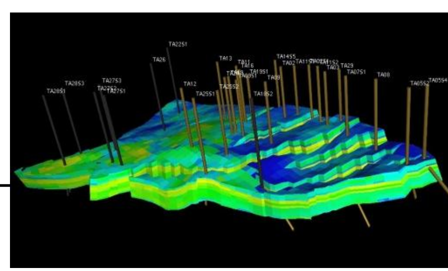


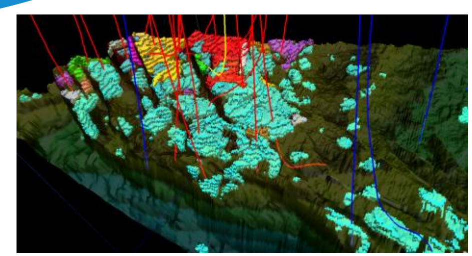
drilling

field development planning



reservoir modeling





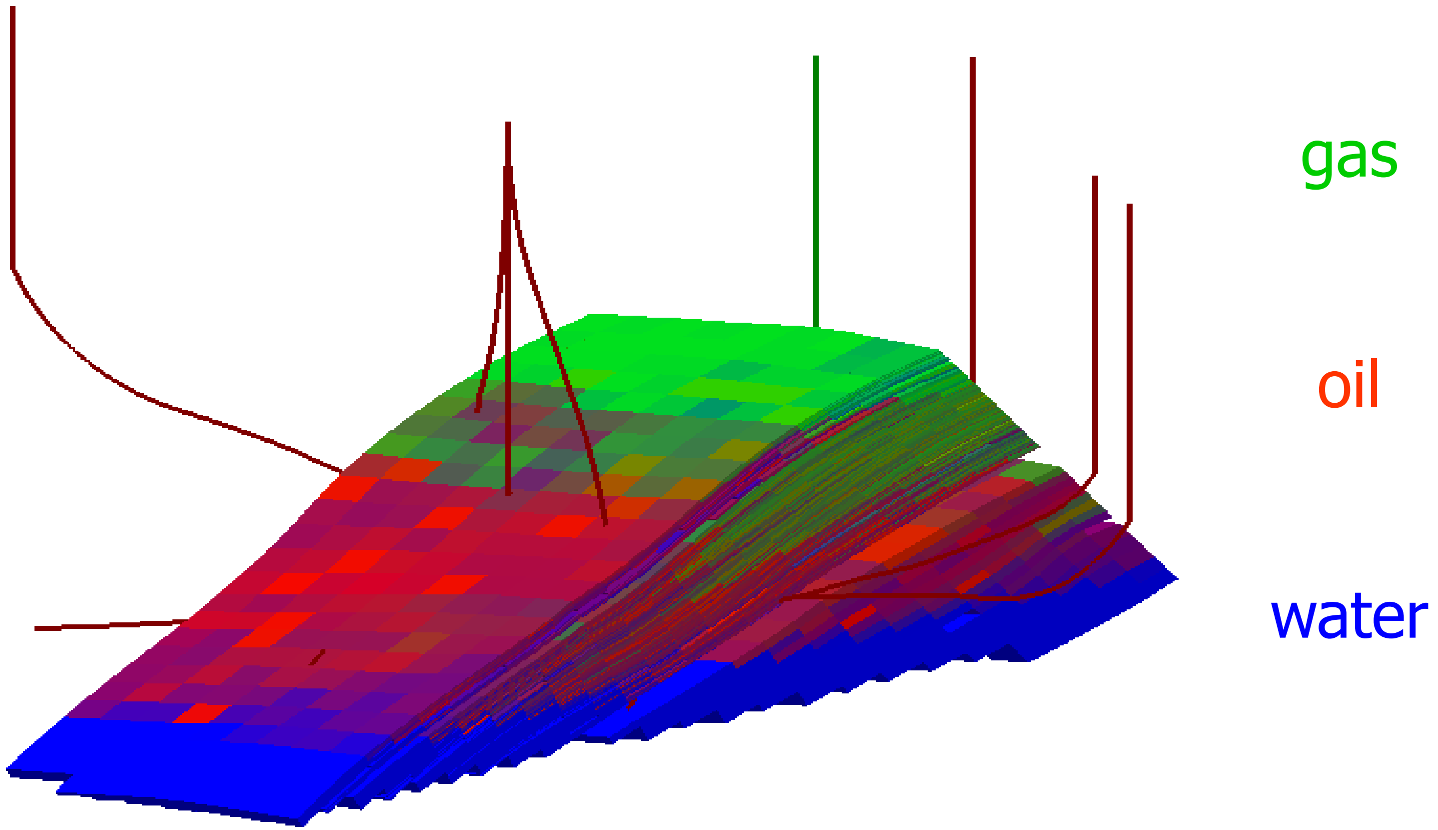
geological modeling

Upstream oil industry characteristics

- Capital intensive
  - well: 1-100*10^6 $
  - field: 0.1-10*10^9 $
- Uncertain
  - geology
  - oil price
  - limited amount of data
- Stretched in time scales
  - production ops.: day – weeks
  - field development: years
  - res. management: decades
- Slow in response
  - production: months
  - reservoir drainage: years
- Discipline oriented
  - geology, geophysics,
  - reservoir engineering,
  - production, drilling
- Remote
  - deserts
  - swamps
  - offshore
- Speeding up!
  - horizontal drilling
  - multi-laterals
  - time lapse seismic
  - smart fields …

Oil & gas reservoirs

Fluids trapped in porous rock below an impermeable 'cap rock'



Oil production mechanisms

- Primary recovery – expansion of rock and fluids, decreasing reservoir pressure

  (depletion drive, compaction drive, 5-40% recovery)

- Secondary recovery – injection of water or gas to maintain reservoir pressure and displace oil actively

  (water flooding, gas flooding, 10-60% recovery)

- Tertiary recovery – injection of steam or chemicals (polymers, surfactants) to change the in-situ physical properties (viscosity, surface tension, wettability)

  (steam flooding, polymer flooding, 20-80% recovery)

R&D drivers

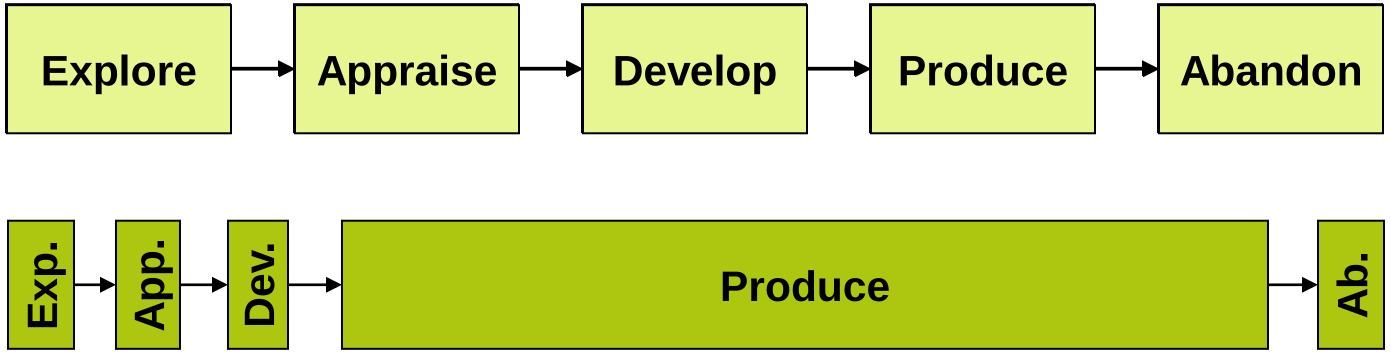
- Lower margins, higher complexity of developments
  - 'easy oil' has been found
  - pressure on cycle times

=> produce more from existing reservoirs => IOR & EOR

- Increasing knowledge- and data intensity
  - more sensors: pressure/temperature/flow, time-lapse seismic, passive seismic, EM, tilt meters, remote sensing, …
  - more control: multi-lateral wells, smart wells, snake wells, dragon wells, remotely controlled chokes, …
  - more modeling capacity: computing power, visualization

=> smart wells & smart fields

Petroleum life cycle



Unit conversions

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Unit conversions

- Still most used: ‘oil field units’: psi, bbl, ft, in, d, etc.
- Increasingly used: ‘allowable SI’: Pa, m^3, m, d, etc.
- Note difference between psia and psig
- Note difference between lbm and lbf
- Note dimensional constant g_c , ft s^{-2} lbm lbf^{-1}

Dimensional constant g_c in field units

$$F = m\frac{d^2x}{dt^2} \qquad \mathrm{N} = \mathrm{kg\,m\,s^{-2}}$$

$$F_{grav} = 1\,\mathrm{kg} \times 9.81\,\mathrm{m\,s^{-2}} = 9.81\,\mathrm{N}$$

$$F_{grav} = \frac{1}{32.2} \times 1\,\mathrm{lbm} \times 32.2\,\mathrm{ft\,s^{-2}} = 1\,\mathrm{lbf}$$

$$g_c$$

$$F = \frac{1}{g_c} m \frac{d^2x}{dt^2} \qquad \mathrm{lbf} = \frac{1}{g_c}\,\mathrm{lbm\,ft\,s^{-2}}$$

Properties of reservoir fluids

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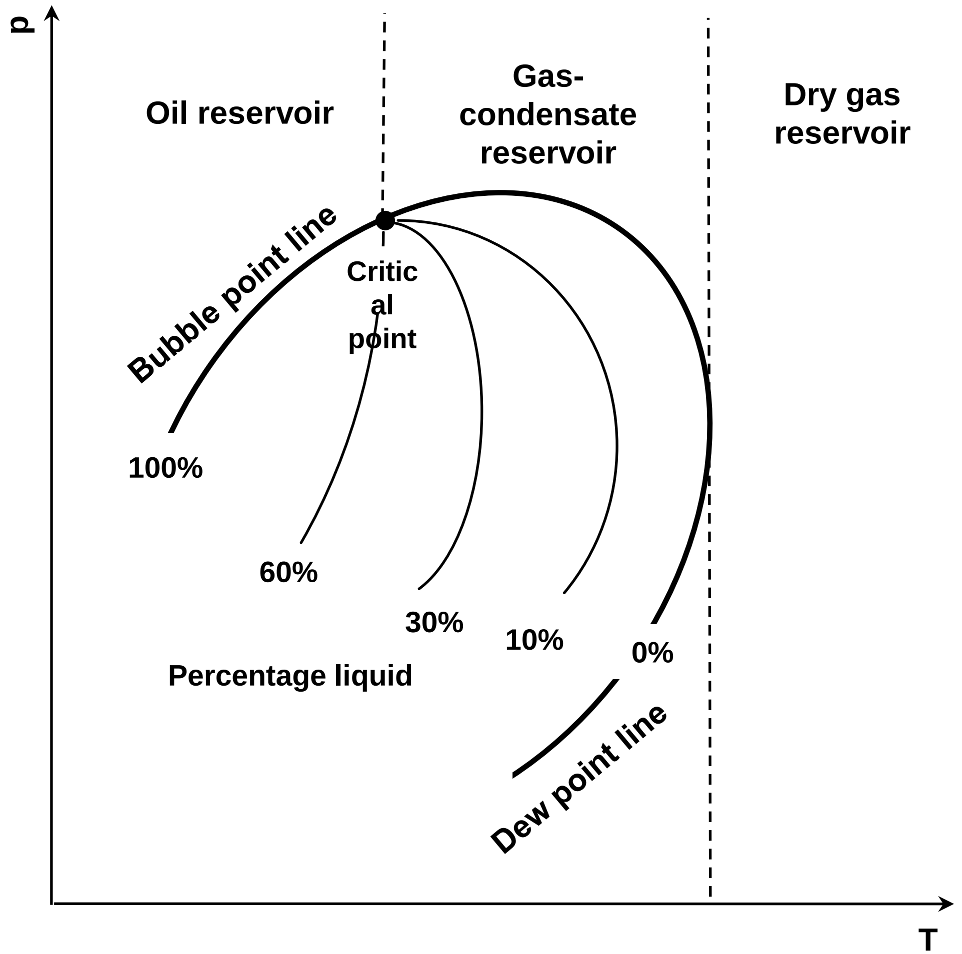
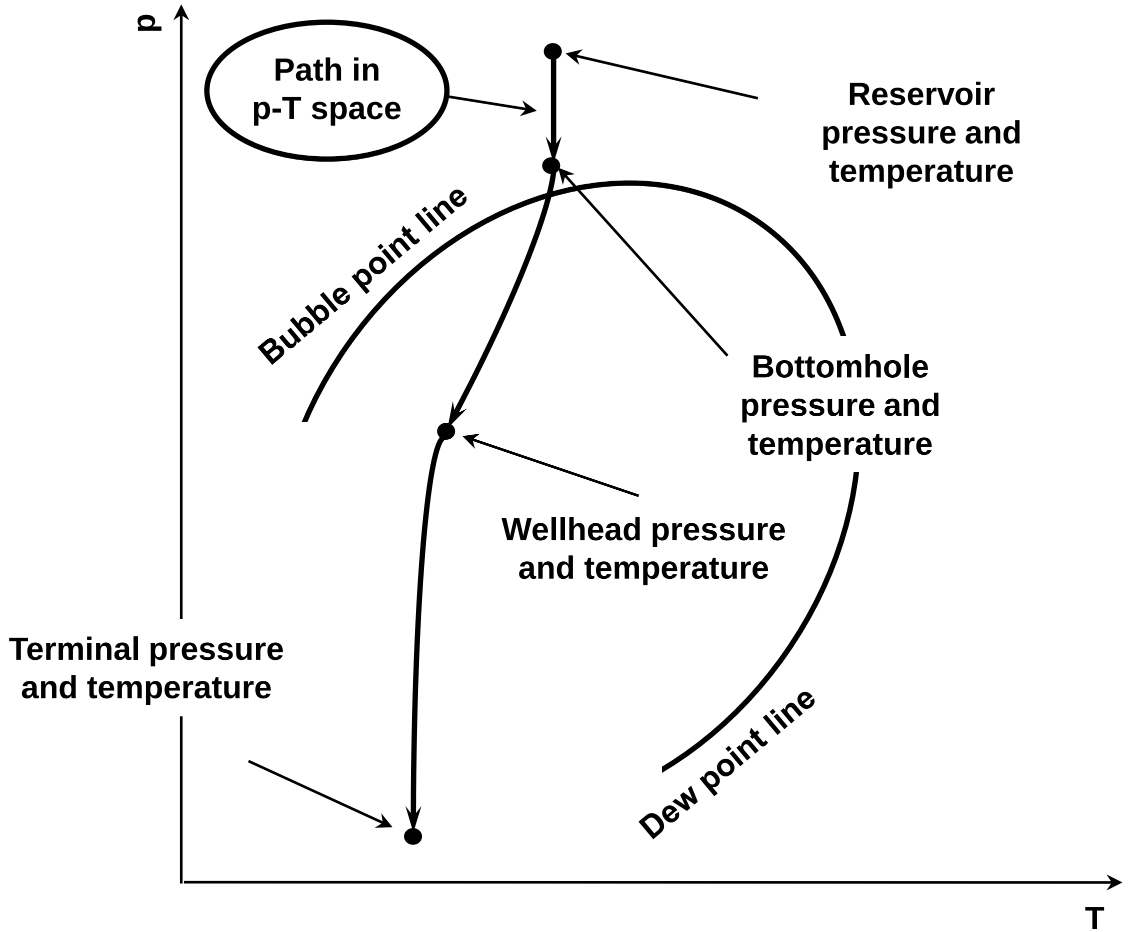
Phase diagram



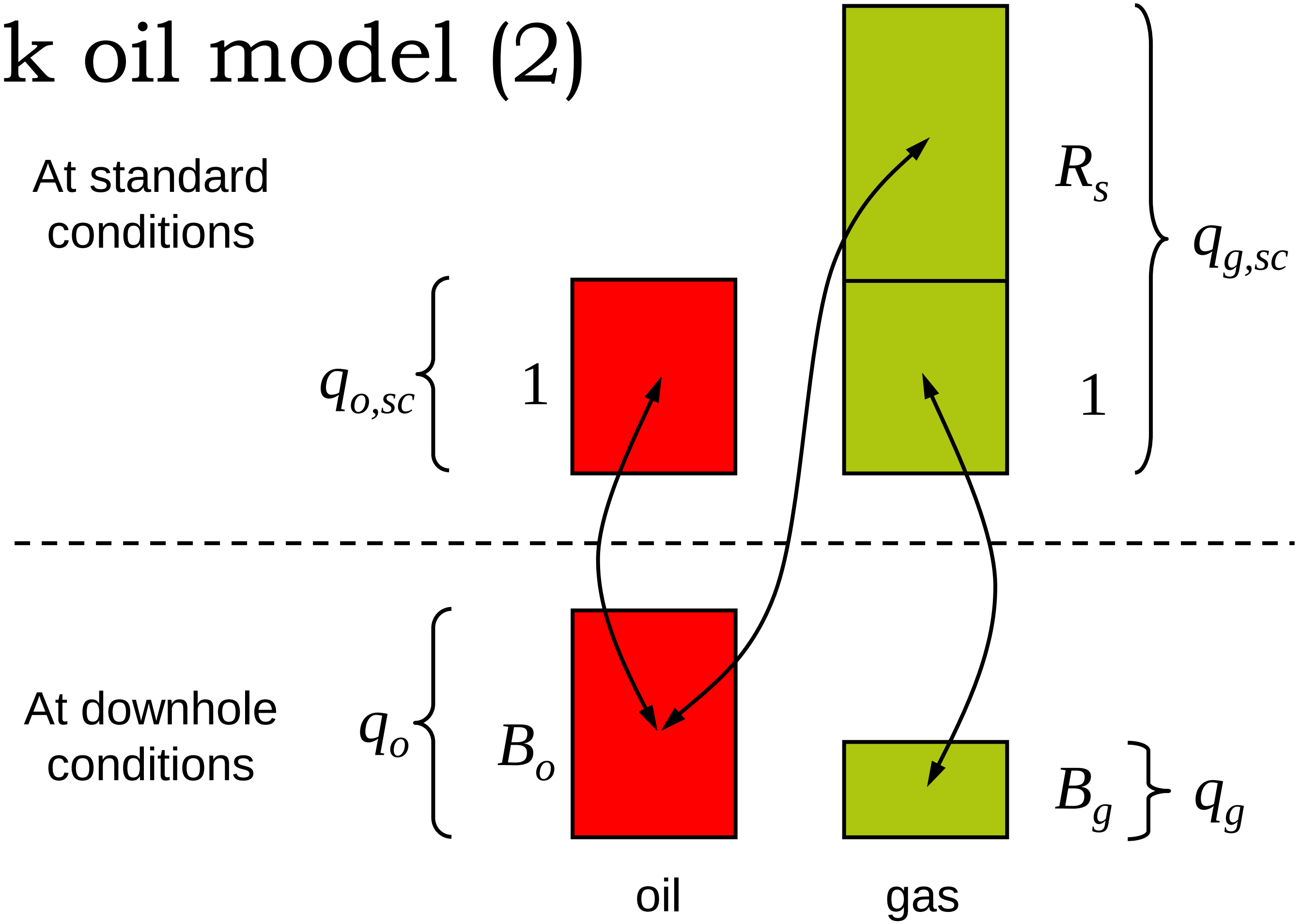
Path in *p*-*T* space



Black oil model (1)

- Volume and density of oil and gas phases under downhole and standard conditions depend on p, T, and composition and properties of HC components
- Black oil model consists of two pseudo components: gas and oil at standard conditions, a.k.a. 'lights' and 'heavies'.
- Properties of pseudo components at standard conditions fully characterized by density: $\rho_{g,sc}$ and $\rho_{o,sc}$
- Composition of pseudo components at standard conditions fully characterized by bubble point GOR R_{sb}
- Volume and density at downhole conditions fully characterized by black oil parameters $B_g(p, T)$, $B_o(p, T)$, $R_s(p, T)$
- Gas dissolves in oil. Gas does not condense in gas.

Black oil model (2)



$$q_o = B_o q_{o,sc} \qquad q_g = B_g q_{g,sc} - B_g R_s q_{o,sc}$$

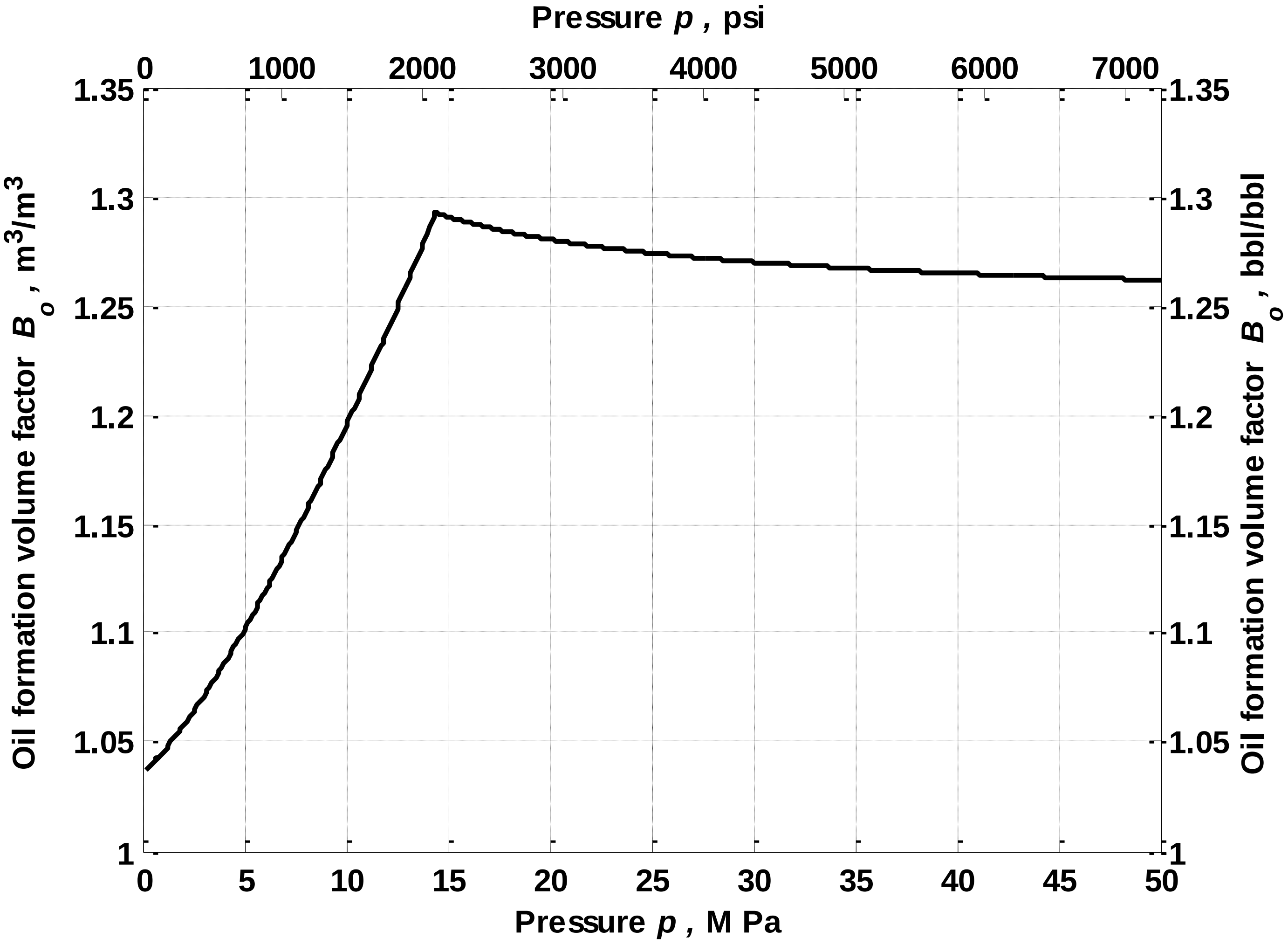
Gas formation volume factor B_g

- B_g m^3 of gas at downhole conditions yields 1 m^3 of stock tank gas, or
- 1 m^3 of gas at downhole conditions yields $1/B_g$ m^3 of stock tank gas
- $B_g < 1$, and therefore $1/B_g > 1$. In other words, the gas expands when it comes to surface
- Quantity $E = 1/B_g$ is known as gas expansion factor

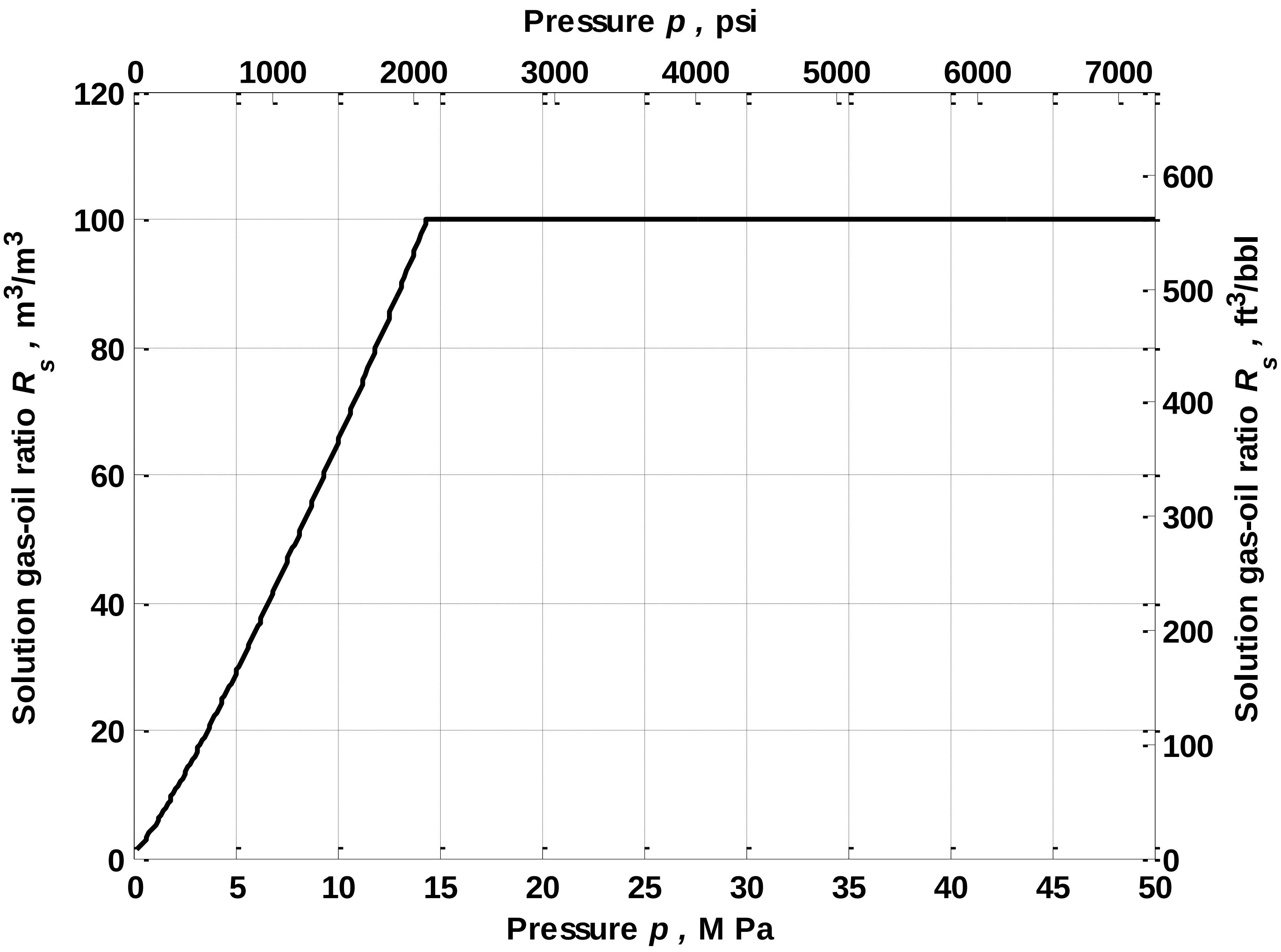
Oil formation volume factor B_o

- B_o m^3 of oil at downhole conditions yields 1 m^3 of stock tank oil and R_s m^3 of stock tank gas, or
- 1 m^3 of oil at downhole conditions yields $1/B_o$ m^3 of stock tank oil and R_s/B_o m^3 of stock tank gas
- $B_o > 1$, and therefore $1/B_o < 1$. In other words, the oil shrinks when it comes to surface
  (oil is compressed but a lot of gas escapes)
- Quantity $1/B_o$ is known as oil shrinkage factor

Oil formation volume factor



Solution gas-oil ratio



Gas compressibility factor Z (1)

- Ideal gas:

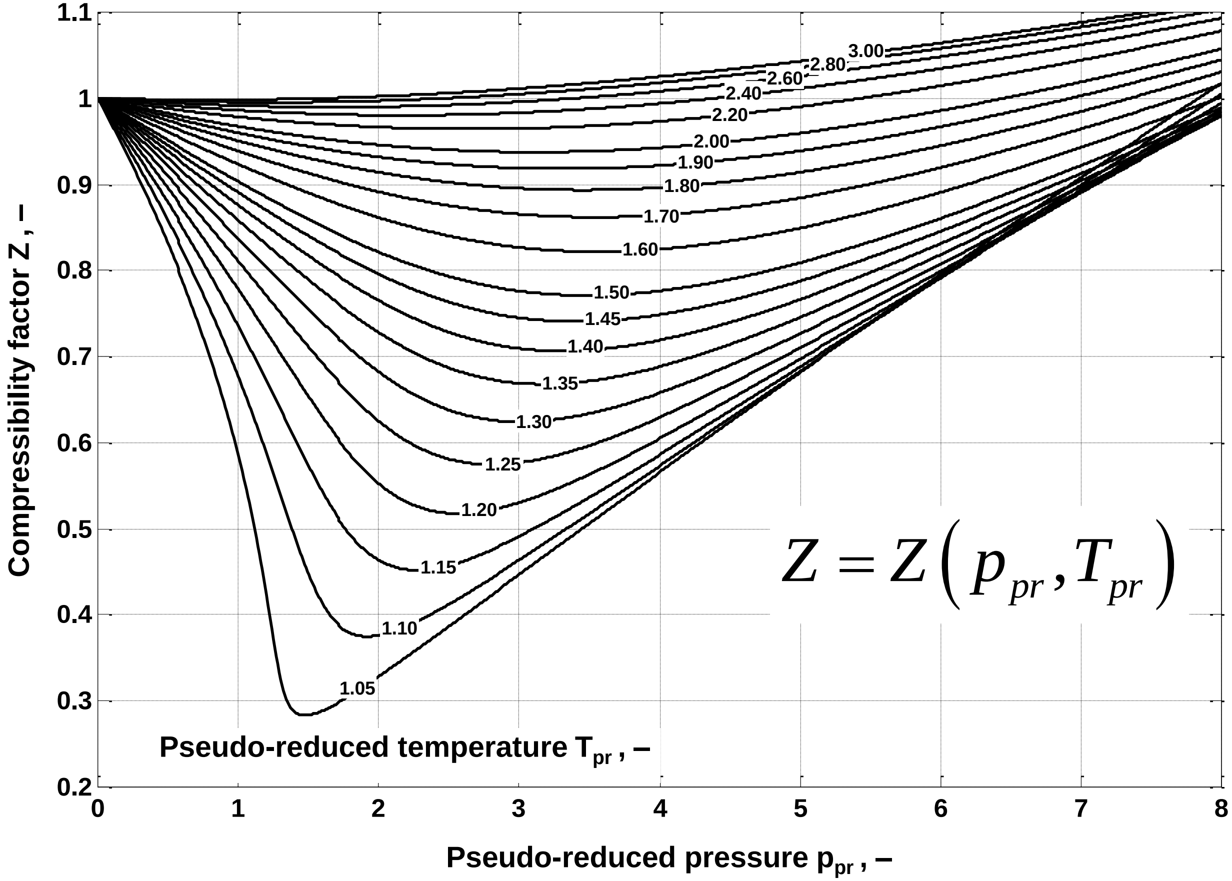
$$pV = nRT_{abs} \quad \text{or} \quad pV = \frac{mRT_{abs}}{M} \quad \text{or} \quad \frac{p}{\rho_g} = \frac{RT_{abs}}{M}$$

- Hydrocarbon mixtures:

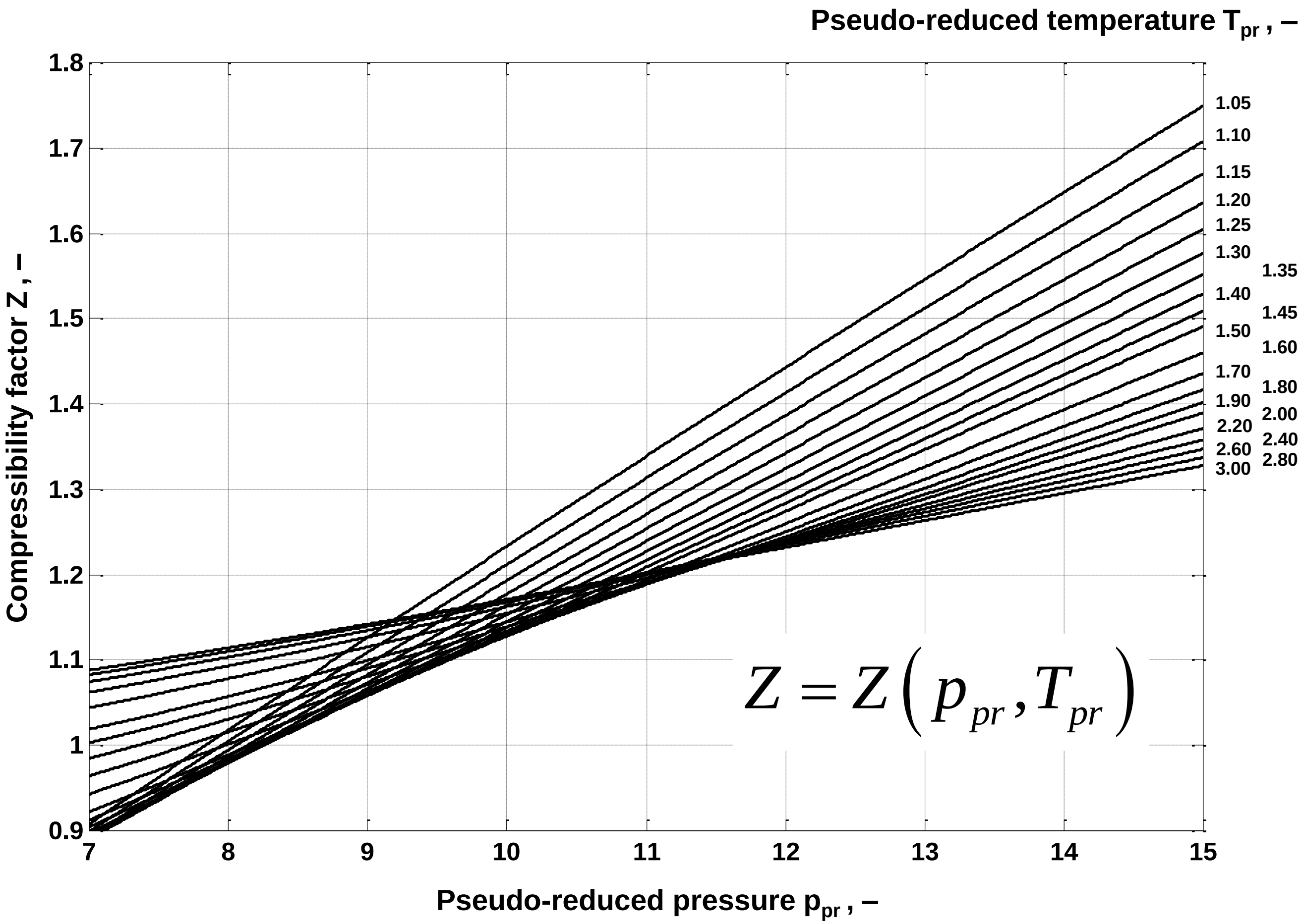
$$pV = nZRT_{abs} \quad \text{or} \quad pV = \frac{mZRT_{abs}}{M} \quad \text{or} \quad \frac{p}{\rho_g} = \frac{ZRT_{abs}}{M}$$

$$Z = Z\left(p_{pr}, T_{pr}\right) \qquad p_{pr} = \frac{p}{p_{pc}} \qquad T_{pr} = \frac{T_{abs}}{T_{pc}}$$

Gas compressibility factor Z (2)



Gas compressibility factor Z (3)



Gas formation volume factor B_g

$$B_g = \frac{V_g}{V_{g,sc}} = \frac{\dfrac{nRT_{abs}}{p}}{\dfrac{nRT_{sc,abs}}{p_{sc}}} = \frac{p_{sc}T_{abs}Z}{pT_{sc,abs}Z_{sc}}$$

Gas expansion factor E

$$E = \frac{1}{B_g} = \frac{V_{g,sc}}{V_g} = \frac{pT_{sc,abs}Z_{sc}}{p_{sc}T_{sc}Z}$$

Gas material balance

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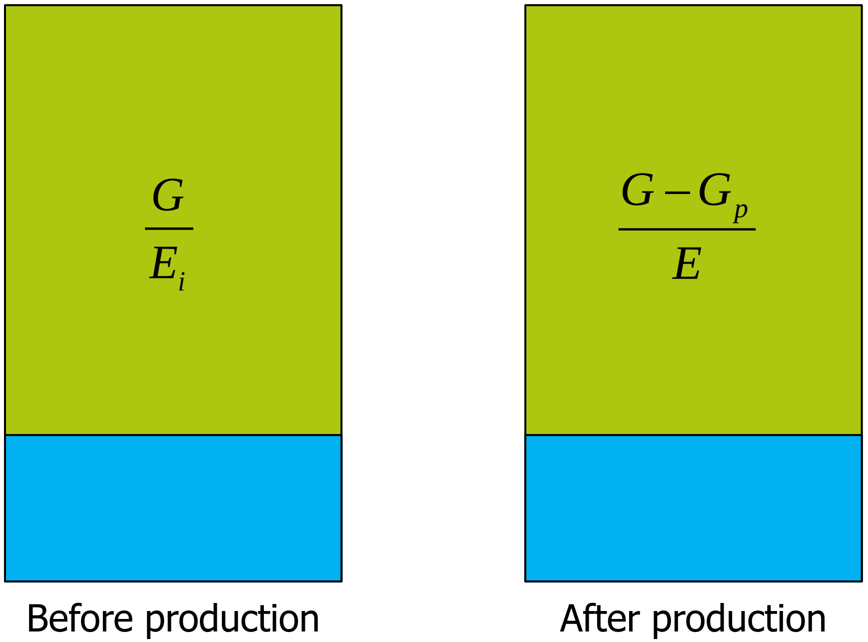
Gas material (volume) balance (1)



Simplest case:
no water influx,
no water production

$$\frac{G}{E_i} = \frac{G-G_p}{E}$$

Gas material (volume) balance (2)

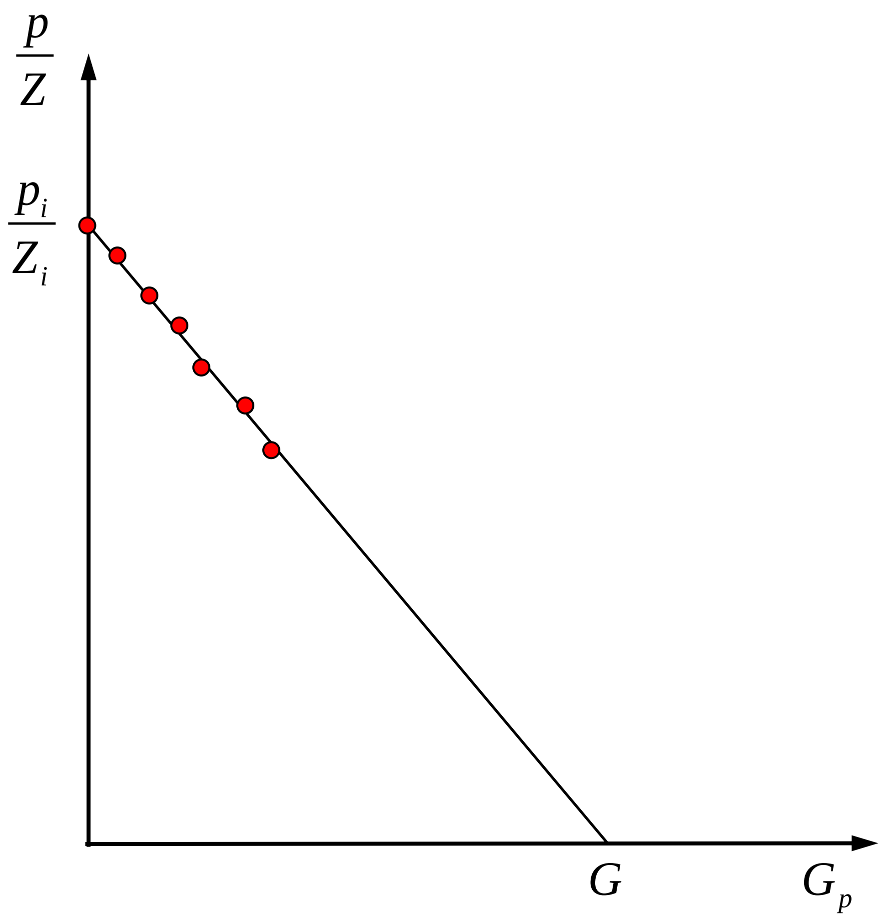
$$\frac{G}{E_i} = \frac{G - G_p}{E}$$

$$E = E_i - \frac{E_i}{G} G_p$$

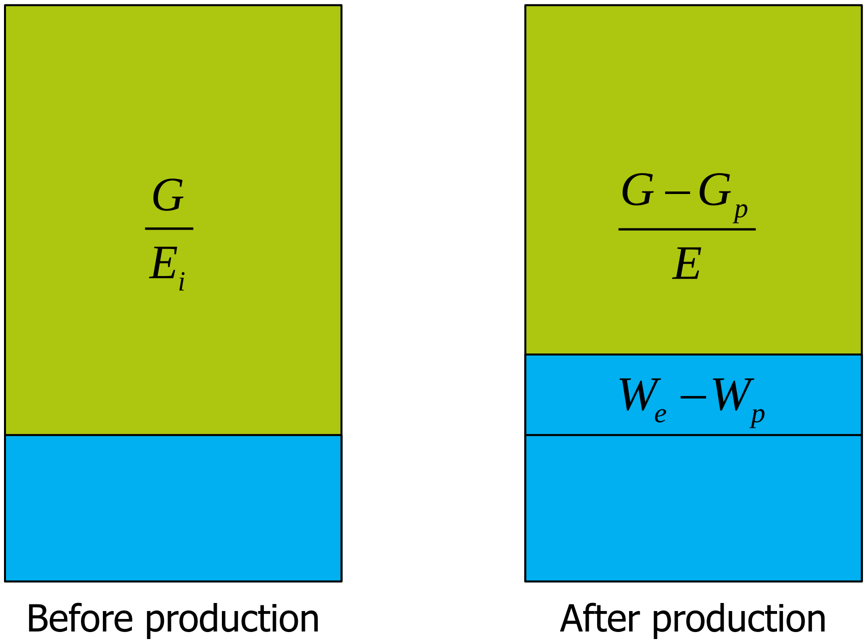
$$E = \frac{p T_{sc,abs} Z_{sc}}{p_{sc} T_{sc} Z}$$

$$\frac{p}{Z} = \frac{p_i}{Z_i} - \frac{p_i}{Z_i G} G_p$$

Gas material (volume) balance (3)



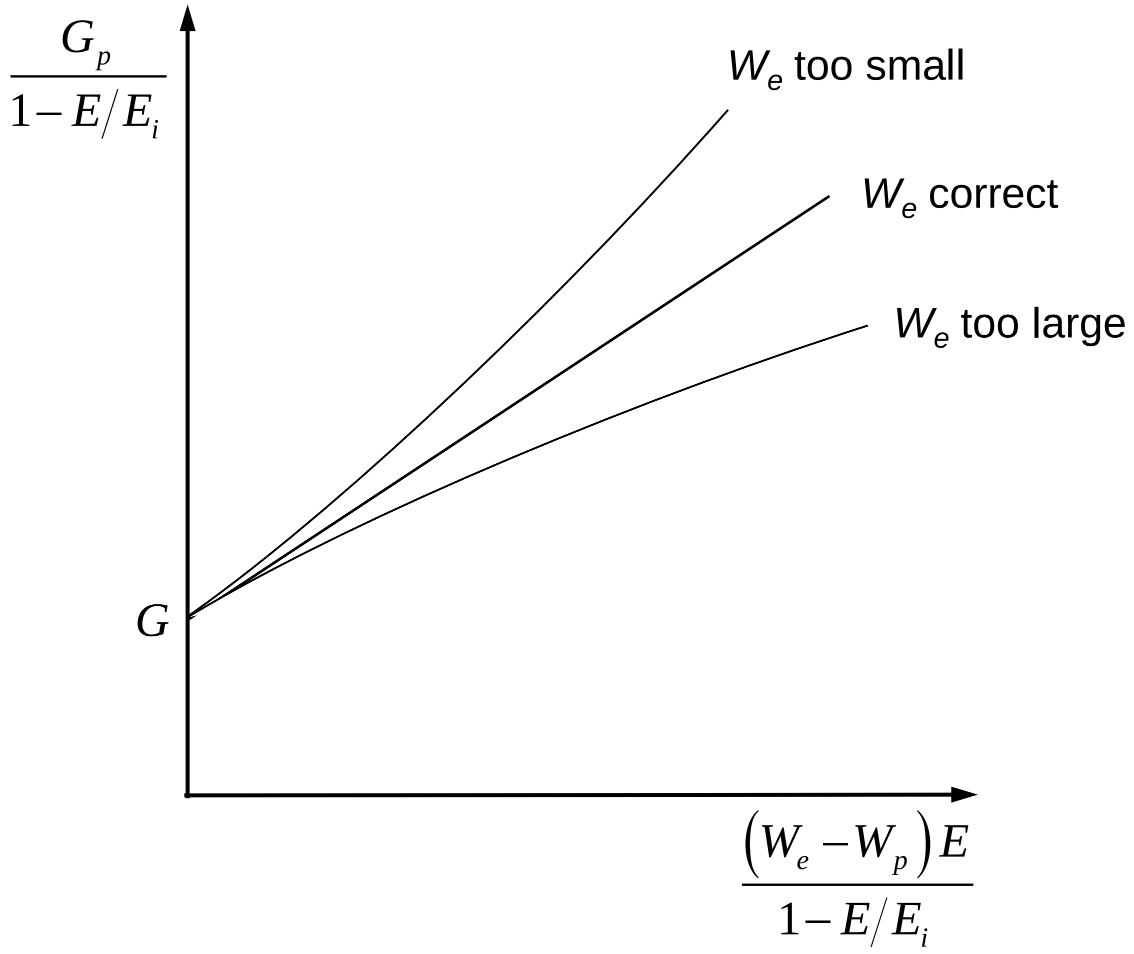
Gas material (volume) balance (4)



With water influx and production

$$\frac{G}{E_i} = \frac{G-G_p}{E} + W_e - W_p$$

Gas material (volume) balance (5)



Gas material (volume) balance (6)

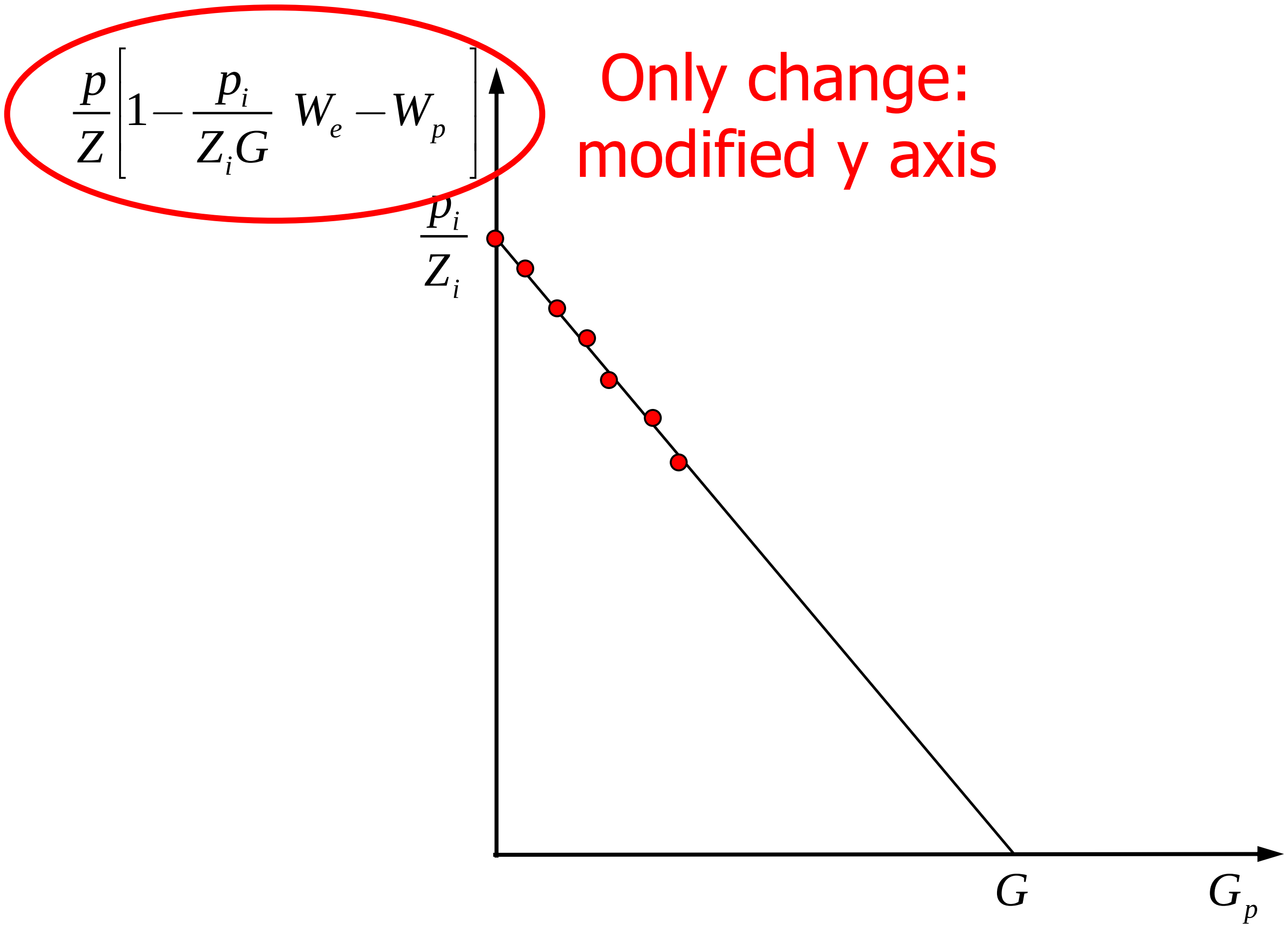
$$\frac{G}{E_i} = \frac{G - G_p}{E} + W_e - W_p$$

$$E = E_i - \frac{E_i}{G} G_p + \frac{E E_i}{G} \left(W_e - W_p \right)$$

$$\frac{p}{Z} = \frac{p_i}{Z_i} - \frac{p_i}{Z_i G} G_p + \frac{p}{Z} \frac{p_i}{Z_i G} \; W_e - W_p$$

$$\frac{p}{Z} \left[1 - \frac{p_i}{Z_i G} \; W_e - W_p \right] = \frac{p_i}{Z_i} - \frac{p_i}{Z_i G} G_p$$

Gas material (volume) balance (7)



Health, safety & environment

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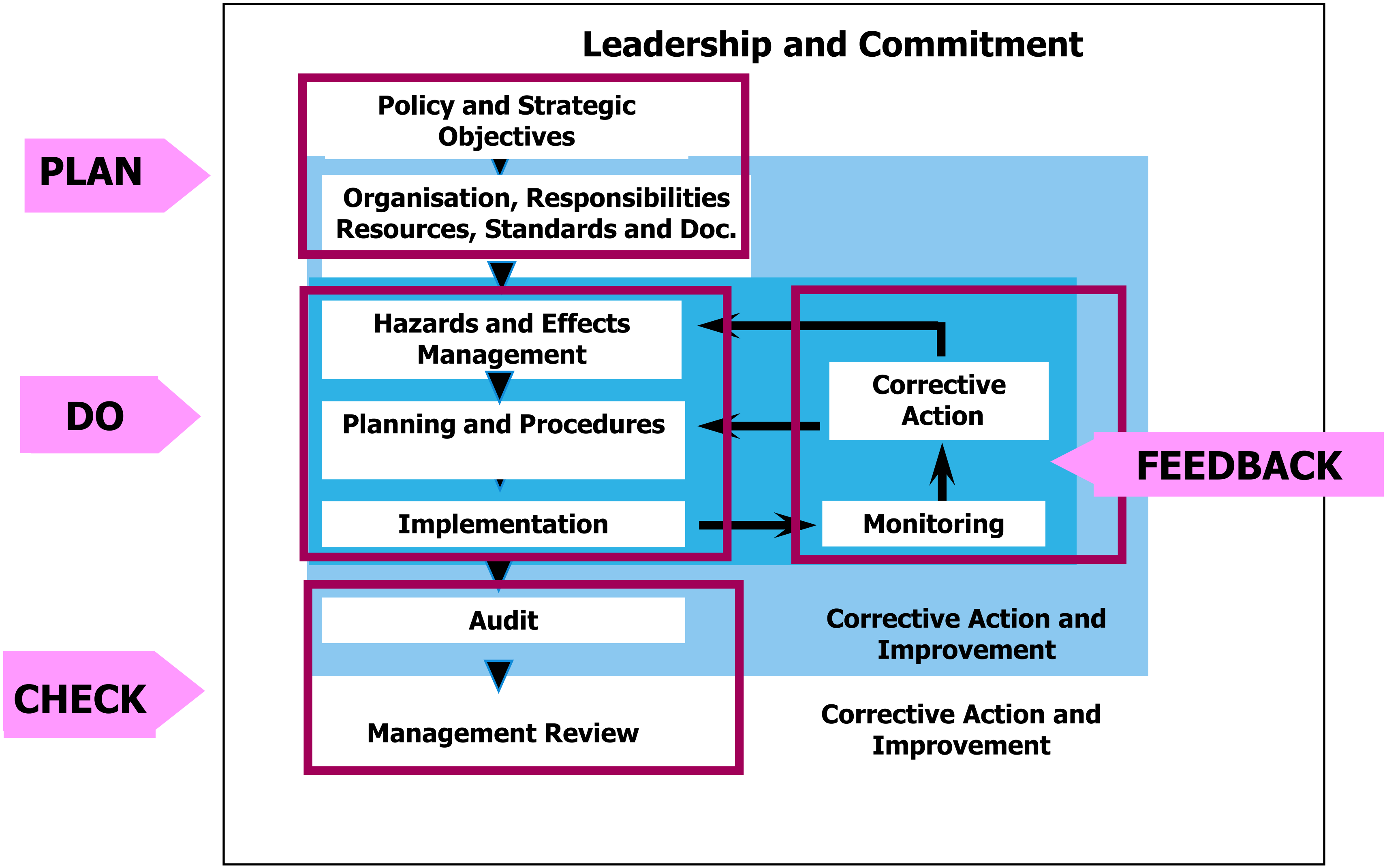
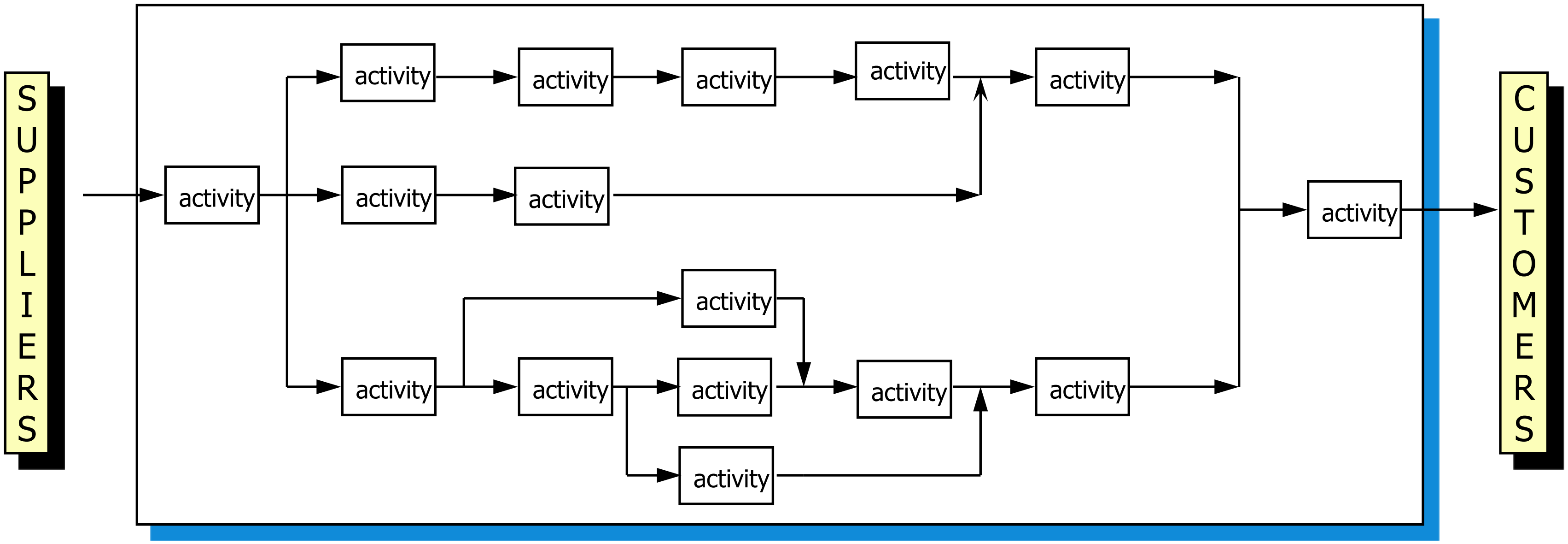
Quality management system



Business process analysis



A business process is characterised by a logical sequence of interrelated activities with specific inputs that produce a set of outputs to meet customer requirements.

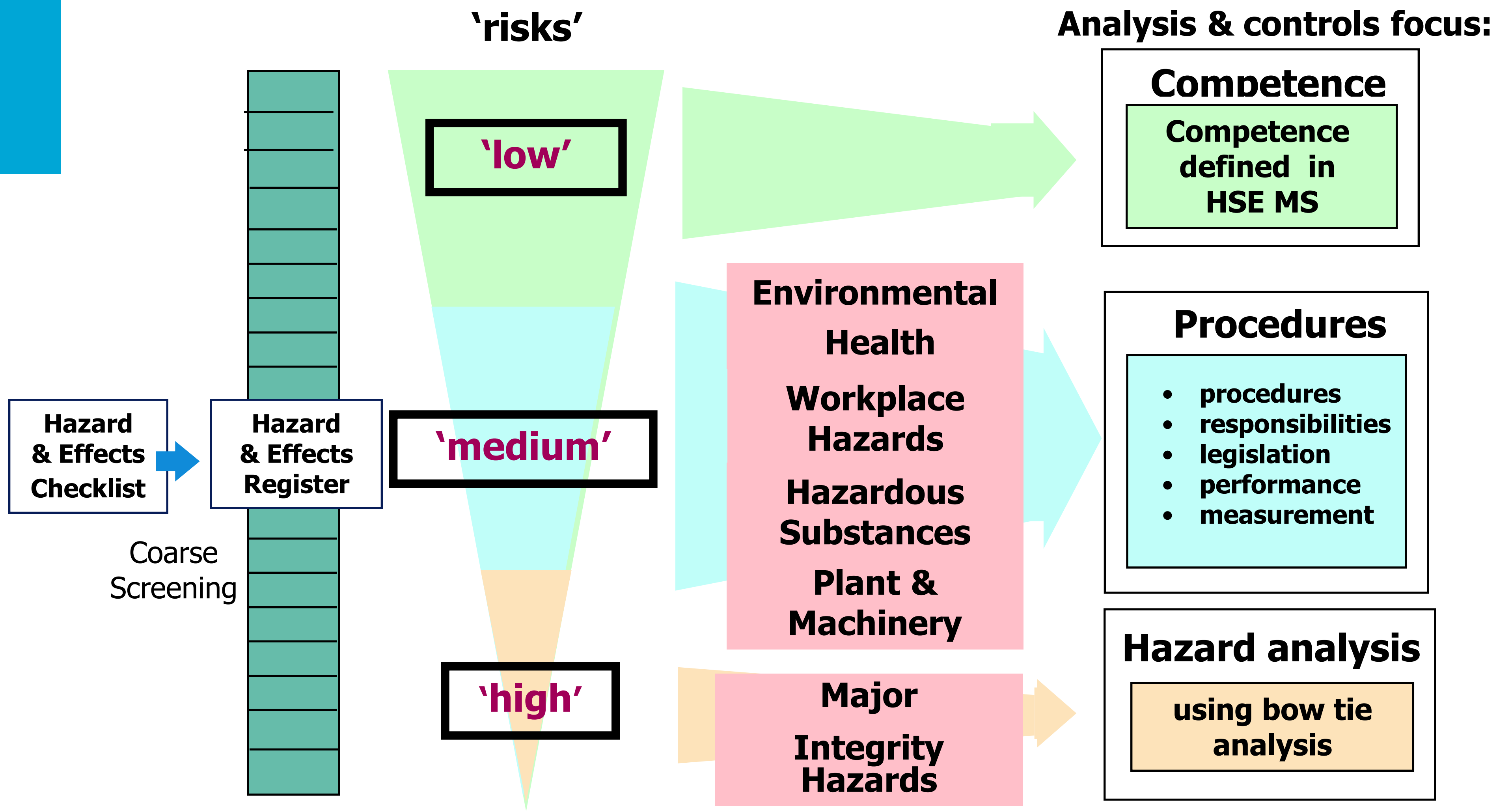
What is risk?

Risk = probability x consequence

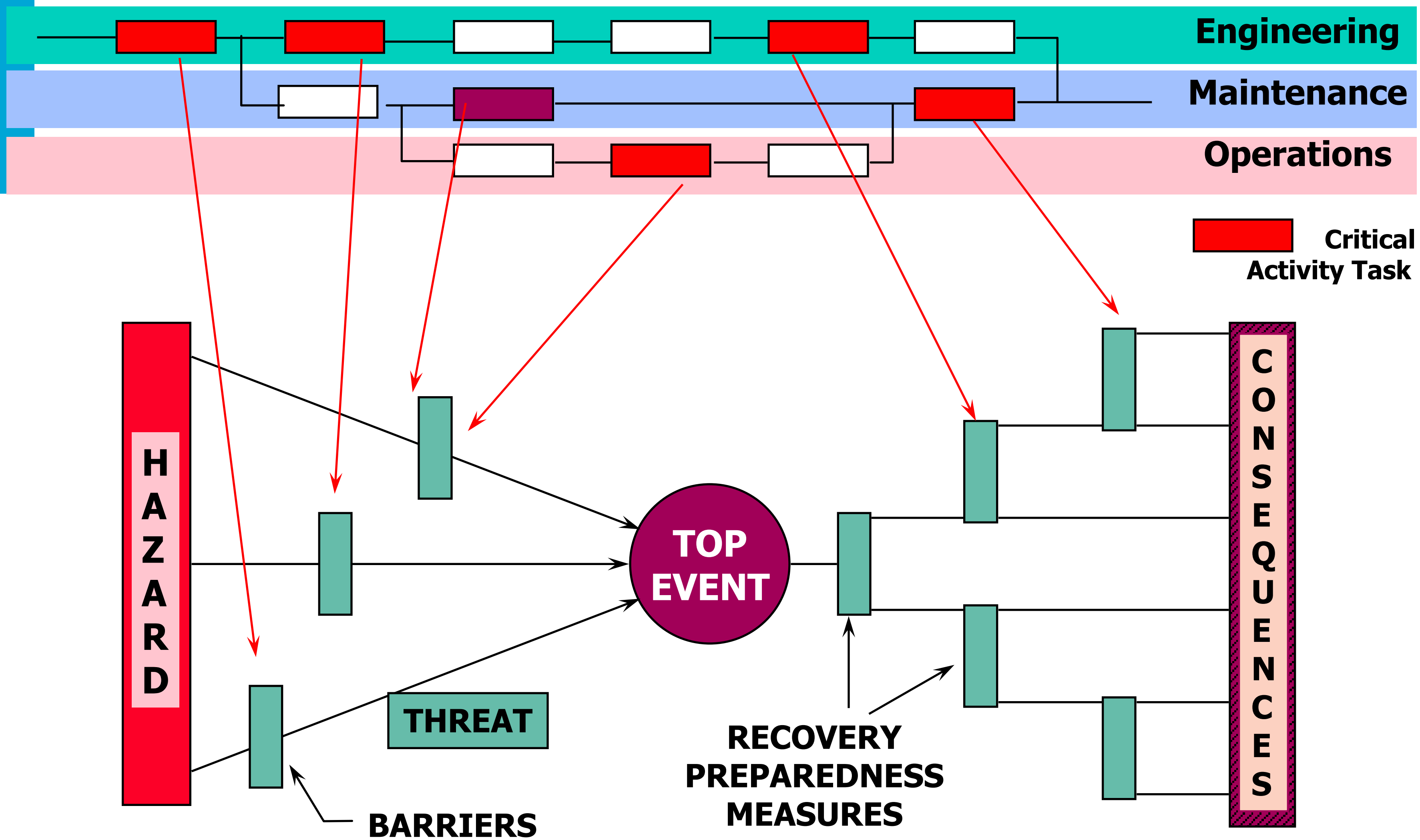
Risk matrix

Severity	Consequence				Probability				
	People	Assets	Environment	Reputation	A	B	C	D	E
					Never heard of in EP industry	Has occurred in EP industry	Has occurred in company	Happens several times per year in company	Happens several times per year in location
0	No injury	No damage	No effect	No impact					
1	Slight injury	Slight damage	Slight effect	Slight impact		low HSE risks			
2	Minor injury	Minor damage	Minor effect	Limited impact					
3	Major injury	Localised damage	Localised effect	Considerable impact					
4	Single fatality	Major damage	Major effect	National impact		medium HSE risks			high HSE risks
5	Multiple fatalities	Extensive damage	Massive effect	International impact					

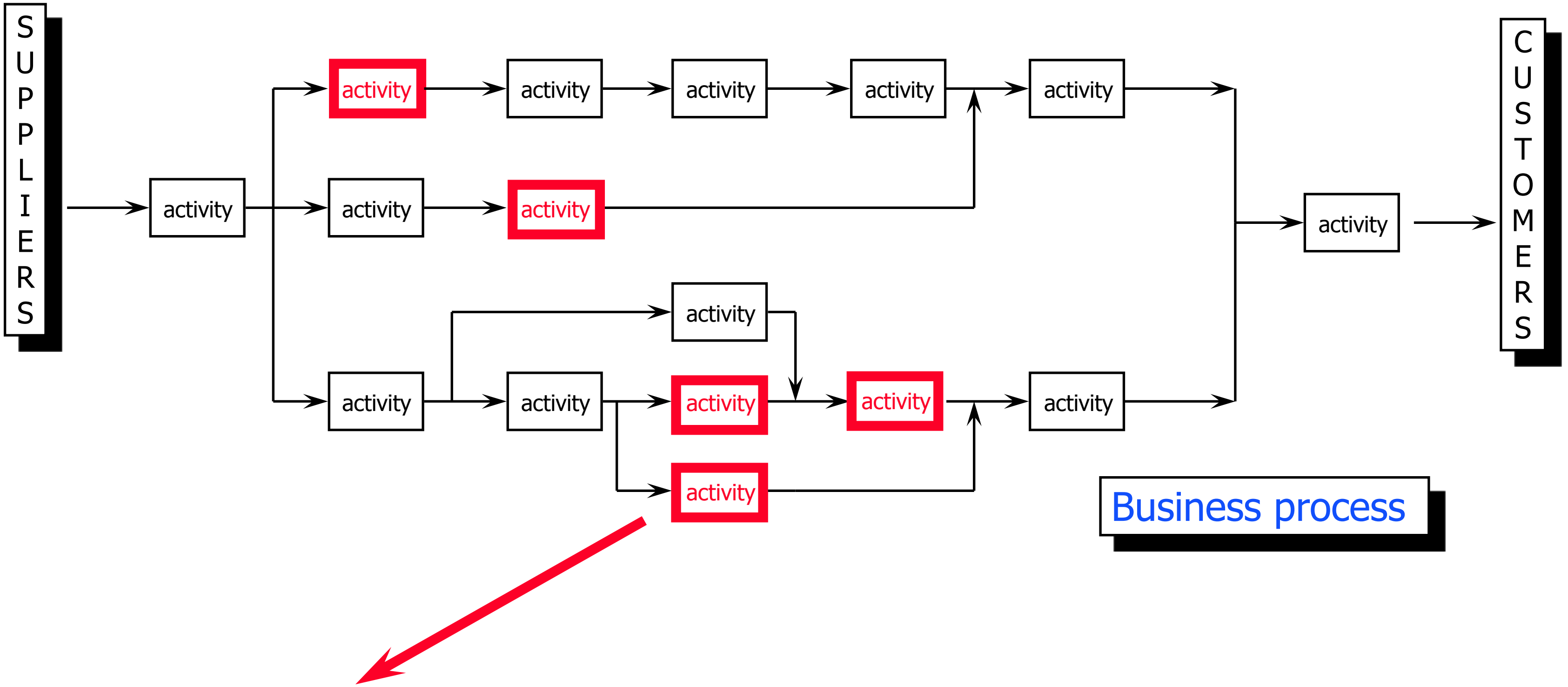
Risk management



Bow tie analysis

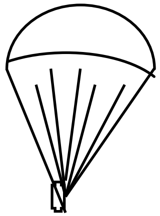


HSE-critical activities



An HSE Management system focuses on the HSE-critical activities in a process

Hazardous vs. HSE-critical activities



A hazardous activity or task is one which exposes the person or persons carrying out the task to hazards

e.g. welding, scaffolding, entry to confined spaces.

HSE-critical activities are activities or tasks necessary to provide or maintain barriers or control and recovery preparedness.

e.g. monitoring alarms, gas detector testing.

These tasks are not necessarily risky in themselves.