

Tailoring Process Selection to Uranium Mineralogy and Ore Type

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Overview

- Uranium
- Major Process Routes
- Flow Sheet Building Blocks
- Key Cost Components
- Influence of Mineralogy
- Influence of Ore Types
- Summary



Uranium

What is Uranium?

- **Most common Isotopes**

- U-238 (99.2%)
- U-235 (0.7%)

- **Half life is**

- U-238 (4.47 billion yrs)
- U-235 (704 million yrs)

		Metals																Non-Metals					Noble Gases	
1	1 H 1.01																	2 He 4.003						
2	3 Li 6.94	4 Be 9.01																	5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
3	11 Na 22.99	12 Mg 24.31	Transition Elements										13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.06	17 Cl 35.45	18 Ar 39.95						
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.90	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.7	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80						
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc 98.91	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3						
6	55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (210)	85 At (210)	86 Rn (222)						
7	87 Fr (223)	88 Ra 226.0	89 Ac (227)	104 Unq (261)	105 Unp (262)	106 Unh (263)	107 Uns (262)	108 Uno (265)	109 Une (266)															
		Inner Transition Elements																						
Lanthanide Series		58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (145)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0									
Actinide Series		90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np 237.0	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)									

Uranium

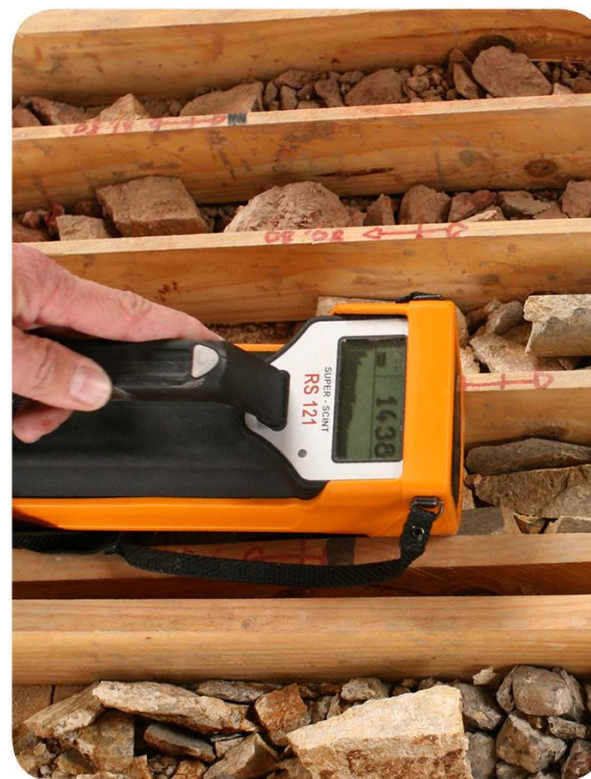
Uses

- Nuclear Energy Rods
- Nuclear Weapons
- Nuclear Medicine
- Depleted Uranium Bullets
- Shielding material in radioactive material containers
- Counterweights for aircraft and inertial guidance gyroscopic compasses
- Smoke Detectors
- Radioactive Tracers (detect leaks in piping and medical imaging)
- Uranium Glass (vacuum capacitors / UV “Glowing” glassware)

Uranium

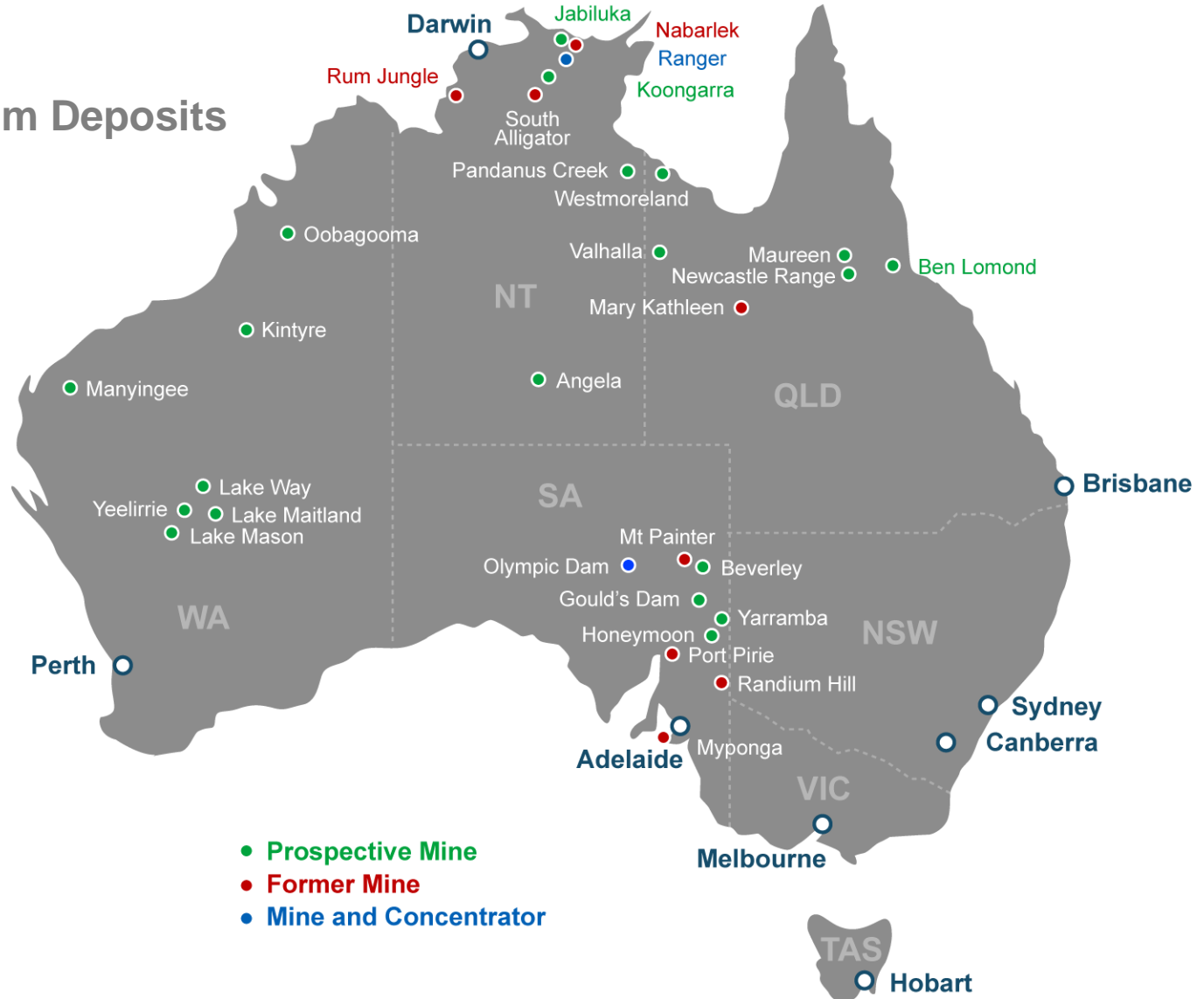
2008 Production

Country	kt U ₃ O ₈	Market Share
Canada	10.6	20.4%
Kazakhstan	10.0	19.4%
Australia	9.9	19.2%
Namibia	5.2	10.0%
Russia	4.2	8.0%
Niger	3.5	6.8%
Uzbekistan	2.8	5.3%
USA	1.7	3.1%
Ukraine	1.0	1.8%
Others	3.0	5.9%
Total	52.0	100.0%



Uranium

Australian Uranium Deposits



Major Process Options

CONVENTIONAL AGITATION LEACH

- Low Technical Risk
- Larger Number of Process Options

RECOVERY AS BY-PRODUCT

- Cost Offset Against Main Process
 - Uranium from Phosphoric Acid
 - Uranium from Gold or Copper Tails

HEAP LEACH

- Rapid Development period
- Trade off Recovery
- Relatively Long Commissioning Ramp-Up

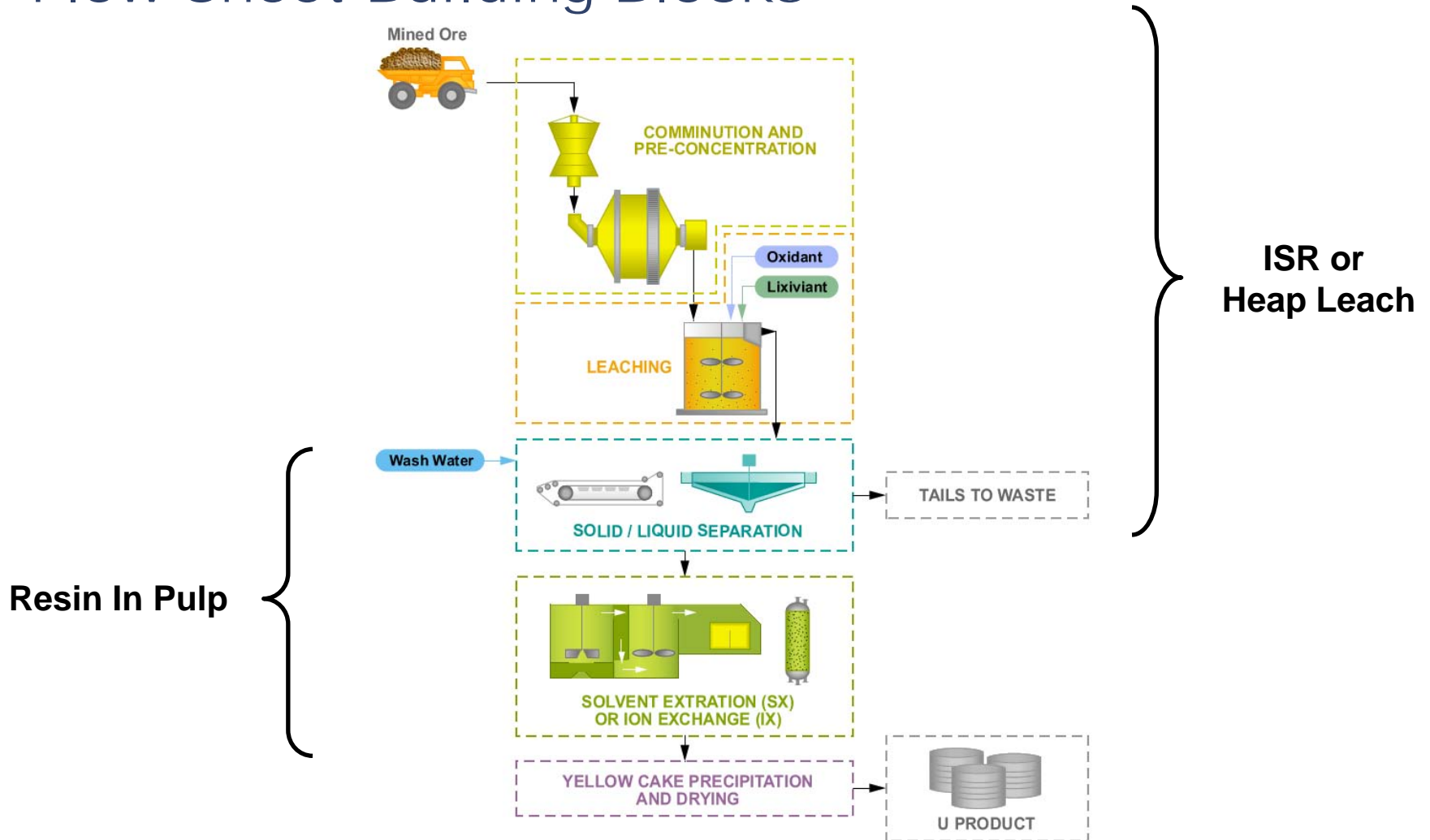
IN-SITU RECOVERY

- Rapid Development period
- Simplicity of Operation
- Require Specific Geological Setting



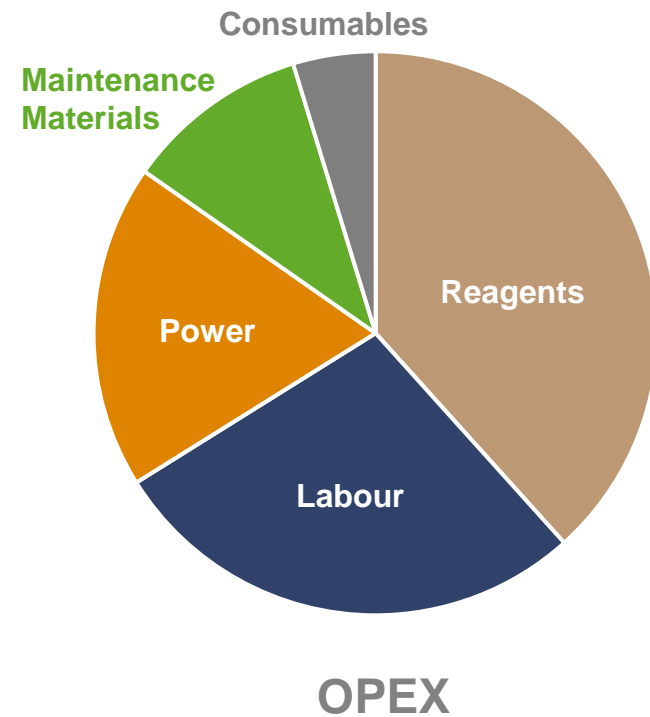
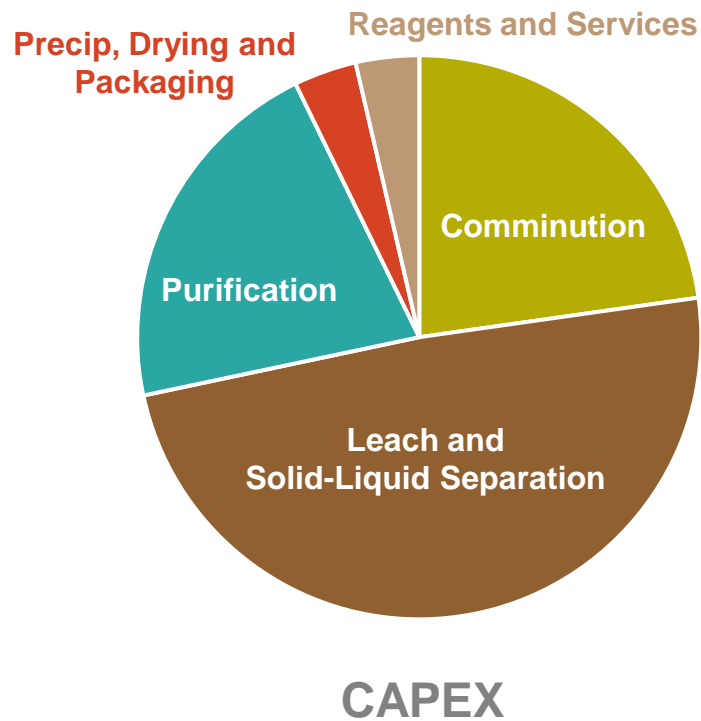
CAPITAL AND OPERATING COSTS

Flow Sheet Building Blocks



Major Process Options

Key Capital and Operating Cost Elements - Conventional Acid Leach



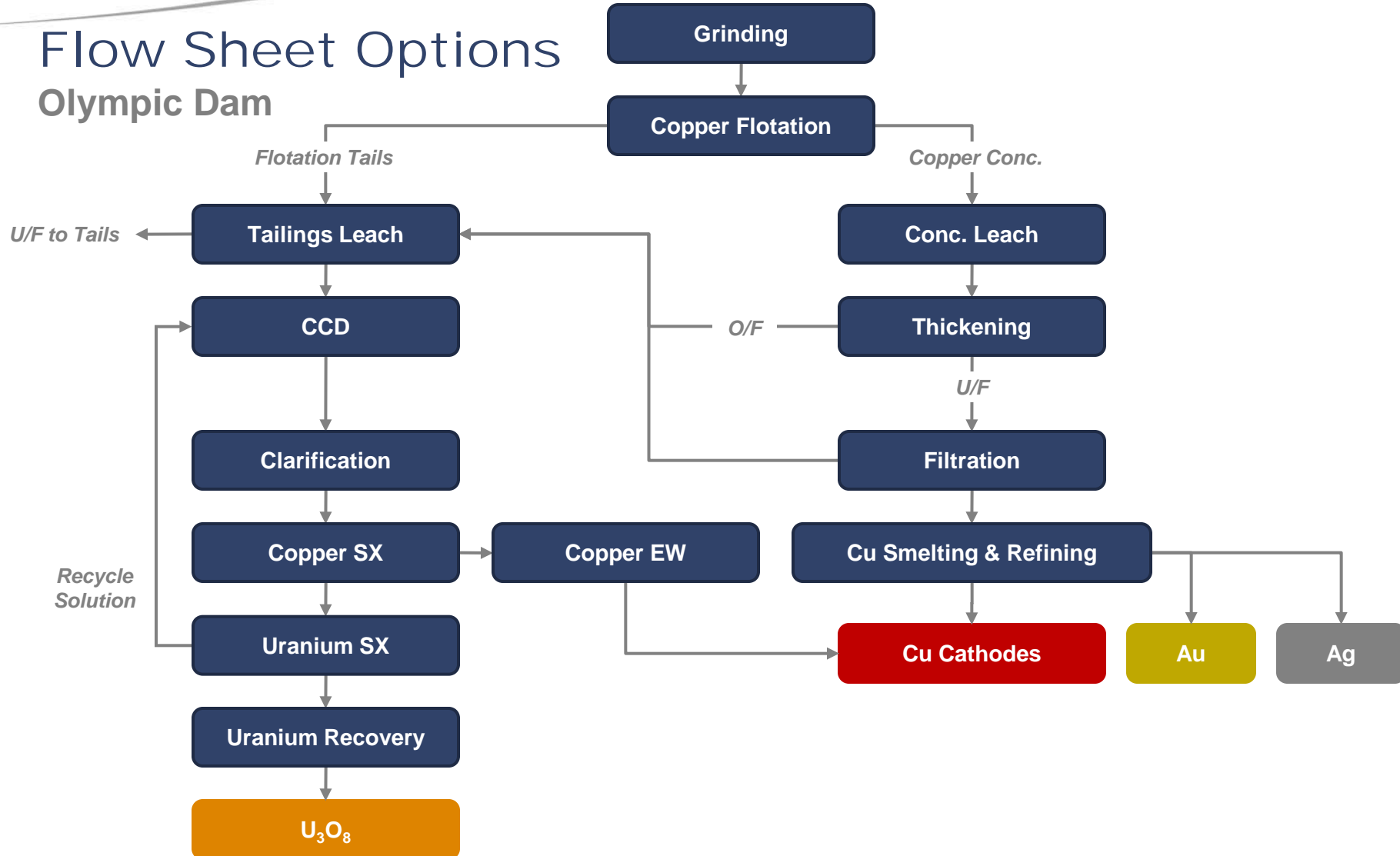
Flow Sheet Options

Conventional Leaching

- **Size reduction - Comminution**
- **Beneficiation / Pre-concentration**
 - Radiometric, gravimetric, size
 - CAPEX and OPEX savings
- **Leaching**
 - Acidic (sulphuric acid)
 - Alkaline (carbonate)
- **Solid / Liquid separation**
- **Purification**
 - Solvent Extraction (SX)
 - Solid Ion Exchange (IX)
 - Resin in Pulp (RIP)
- **Precipitation**
 - Ammonia or Hydrogen Peroxide
- **Drying / Calcining**
 - Uranium oxide product

Flow Sheet Options

Olympic Dam



Flow Sheet Options

Heap Leaching

- Heap leaching operation is normally restricted to low grade ores
- Low CAPEX and OPEX - debatable
- Recoveries are low around 50 - 80%

Flow Sheet Options

In Situ Recovery

- Huge reductions in CAPEX and OPEX due to no mining, crushing, and grinding
- Low recoveries 60 - 80% and only applicable for special deposits:
 - Far from any water supplies for human or livestock consumption
 - Ore must be permeable
 - The surrounding rock must be impermeable
 - Operates typically in shallow areas ~300 m
- Less environmental impacts if decommissioning conducted correctly
- Acidic or alkaline leaching solutions are passed through the uranium deposit
- A pressurised water flow returns the laden solution to recovery well for IX or SX in the processing plant

Influence of Mineralogy Tetravalent Uranium

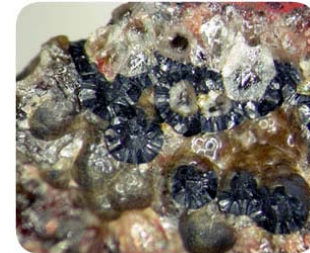
- Low solubility
- Oxidants are essential
- Relatively easily leached
- Can be oxide or silicates
- Can be associated with carbonates

Uraninite



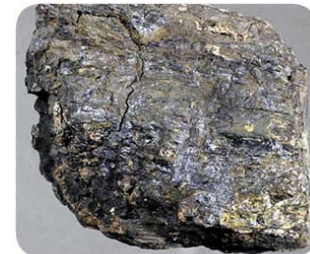
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Pitchblende



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Coffinite



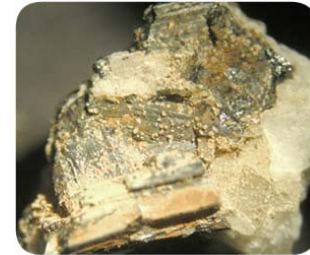
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Influence of Mineralogy

Complex Oxides

- Low solubility
- Often refractory
- Fine grinding
- High temperature
- Associated with Sn, Ta, Ti, Nb

Brannerite



© Van King

Davidite



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Influence of Mineralogy

Hexavalent

- Less common
- Secondary origin
- Associated with weathered ore
- No oxidant required

Carnotite



© Antonio Borrelli

Autunite



© Keith Compton

Influence of Mineralogy

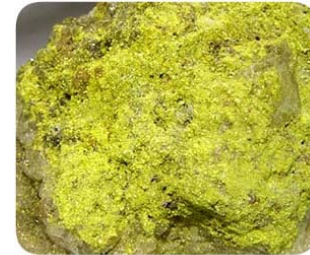
Phosphates

- Associated with apatite
- Dissolves in the Wet Process Phosphoric Acid
- Generally a by-product
- SX from Phosphoric Acid

Influence of Mineralogy Carbon

- Fossil organic matter
- Very low grade
- Easy to leach with fine grinding
- Organics give problems downstream

Tyuyamunite



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Uranocircite



© Peter Haas

Influence of Mineralogy Impurities

- Chlorides
- Iron
- Vanadium
- Molybdenum

Influence of Mineralogy

Acid or Alkaline Leach

	Acid Systems	Alkaline Systems
Calcite in the Ore	< 7 - 8%	> 7 - 8%
Leach Kinetics	Fast	Slow
Leachant	Single Contact	Recirculated
Material of Construction	Stainless / RL / FRP	Mild Steel
Selectivity	Low	High
Purification Techniques	SX / IX / Selective Precipitation	IX / Selective Precipitation
Final Product	ADU / Uranyl Peroxide	Uranyl Peroxide

~ 80 - 120kg Acid/t Ore



Influence of Ore Type

Ore Type	Characteristics	Treatment	Example Projects
Unconformity	<ul style="list-style-type: none"> • Concentrated in faulting • Typically higher grades 	<ul style="list-style-type: none"> • Pre-concentration • Acid leaching • SX or IX 	<ul style="list-style-type: none"> • Ranger - Northern Territory • Rabbit Lake - Canada
Alaskite	<ul style="list-style-type: none"> • Comminution costs • U liberated at coarse size • Solid-liquid separation relatively easy • Moderate grade / high throughput 	<ul style="list-style-type: none"> • Pre-concentration • Acid leaching • SX or IX 	<ul style="list-style-type: none"> • Rössing, Etango, Rössing South, Valencia - Namibia
Vein Type	<ul style="list-style-type: none"> • U Hosted in Veins • High Work Index 	<ul style="list-style-type: none"> • Pre-concentration • Acid leaching • SX or IX 	<ul style="list-style-type: none"> • Kintyre - Western Australia

Influence of Ore Type (Contd.)

Ore Type	Characteristics	Treatment	Example Projects
Calcrete Hosted	<ul style="list-style-type: none"> • Soft, friable and clayey • Solid-liquid separation issues 	<ul style="list-style-type: none"> • Pre-concentration • Alkaline leaching • IX or direct precipitation 	<ul style="list-style-type: none"> • Langer Heinrich, Trekkopje - Namibia • Lake Way, Yeelirrie - Western Australia
Sandstone Hosted	<ul style="list-style-type: none"> • Low energy for size reduction 	<ul style="list-style-type: none"> • ISL depending on geology • Coarse grind • Heap Leach • Acid Leach • IX/SX 	<ul style="list-style-type: none"> • Beverley - South Australia • Colorado region - USA
Collapse Breccia Complex	<ul style="list-style-type: none"> • Associated with base metals 	<ul style="list-style-type: none"> • Flotation • Acid Leach • SX 	<ul style="list-style-type: none"> • Olympic Dam - South Australia

Summary

- Process flow sheet selection should be based on
 - U mineralogy
 - Ore type
- Opportunities to reduce Capital and Operating Costs
 - Beneficiation
 - Resin In Pulp
 - Selection of leachant and oxidant
- Important - downstream purification to eliminate deleterious elements