LANGER HEINRICH URANIUM (PTY) LTD

NANO-FILTRATION TECHNOLOGY FOR REAGENT RECOVERY

BMS ENGINEERS
Building Membrane Solutions

Langer Heinrich Uranium mine

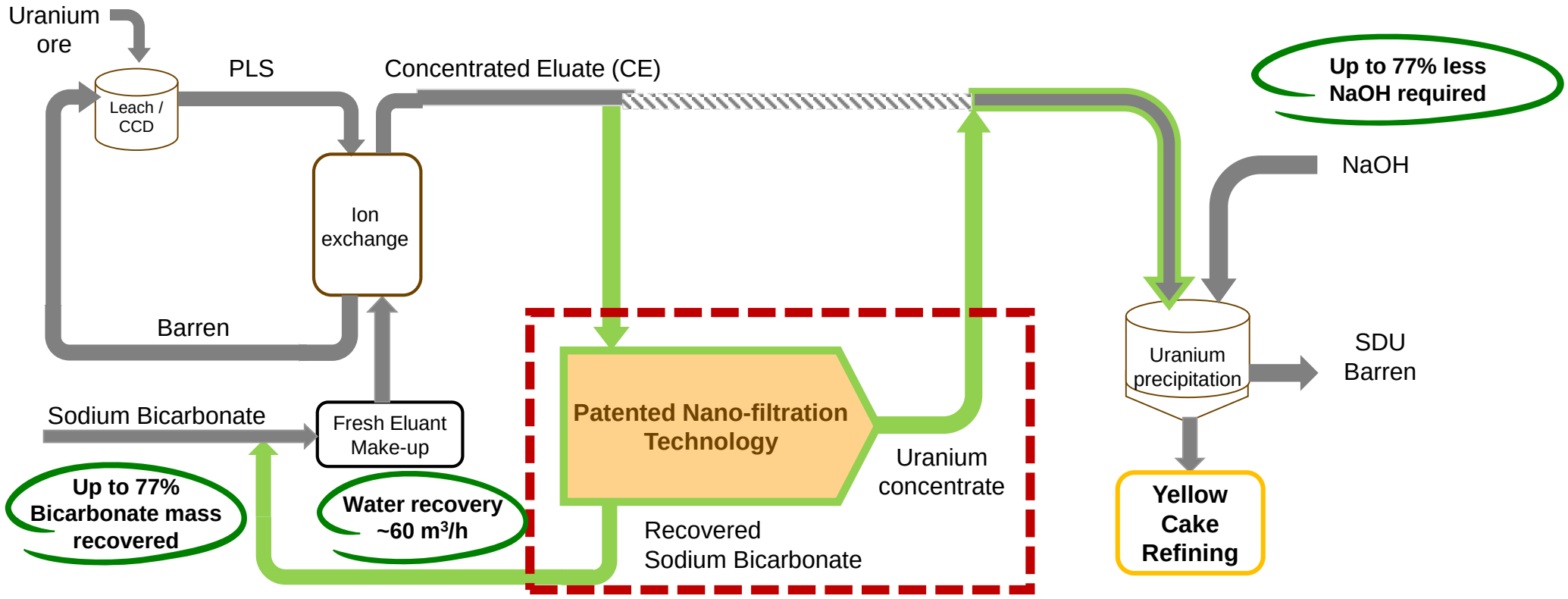
BMS Engineers designed and commissioned the Bicarbonate Recovery Plant (BRP) at the **Langer Heinrich Uranium Mine** for the recovery of Sodium Bicarbonate

Langer Heinrich Uranium Mine

- **Langer Heinrich Mine (LHM)**is located in central coastal Namibia.
- **Langer Heinrich** is owned 75% by **Paladin Energy Limited** and 25% CNNC
- The mine design capacity is 5.1Mlb U_3O_8 per annum
- The carbonate process used at LHM has the Uranium being recovered onto resin, before being eluted with bicarbonate.
- Normally the bicarbonate requires conversion to carbonate in the precipitation process.
- The **Bicarbonate Recovery Project** (BRP) utilises membranes to recover bicarbonate for reuse in elution.

Patented Technology – Reagent Recovery from Uranium Process

Bicarbonate Recovery (BRP)



1 Fresh Eluant

- **Up to 77% of sodium bicarbonate recovered and recycled to Fresh Eluant make-up**
- **Significant sodium bicarbonate savings**

2 Precipitation

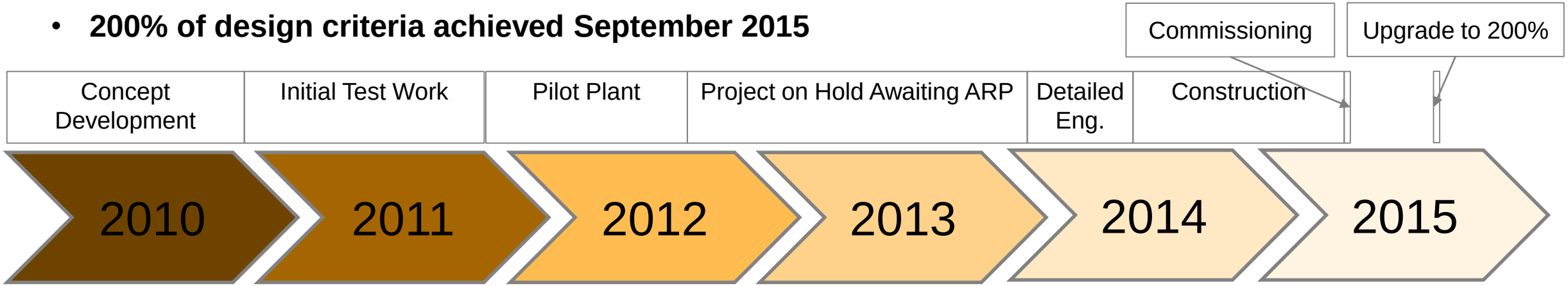
- **Neutralisation reagent savings proportional to recovered sodium bicarbonate**
- **Significant neutralisation reagent cost saving**

3 Fresh Water Input

- **Fresh Eluant make-up water addition reduced by up to 87% (60 m³/h)**

Bicarbonate Recovery Plant (BRP)

- **Concept developed in 2010**
- **Initial testwork in 2011 was encouraging using plant liquors**
- **Pilot plant operated in 2012 and provided confirmation of concept as well as design data**
- **Engineering commenced November 2013 and capital commitment May 2014**
- **Hot commissioning commenced 11th March 2015 and design criteria achieved 12th March 2015**
- **200% of design criteria achieved September 2015**



APPROVAL TO COMPLETION IN 2 YEARS

Bicarbonate Recovery Plant (BRP)

Patented nano-filtration technology applied to the alkali uranium process

BMS commissioned the BRP at Langer Heinrich in March 2015

- **BMS Engineers** have designed and commissioned the world's first Bicarbonate Recovery Plant (BRP), recovering sodium bicarbonate from a uranium concentrated eluate stream using NF membranes.
- The membrane plant was commissioned in March 2015. The plant exceeded its design bicarbonate recovery that has resulted in a significant reduction in reagent demand.
- The BRP has also significantly altered the circuit water balance and facilitated improved process recovery.
- Other consequential benefits have been significant.

Bicarbonate Recovery Plant (BRP)

BMS Engineers successfully undertook:

- **Pilot plant trials for BRP concept**
- **Detailed design**
- **Commissioning**
- **Training of site personnel in BRP operations and maintenance**
- **Ongoing remote technical support**

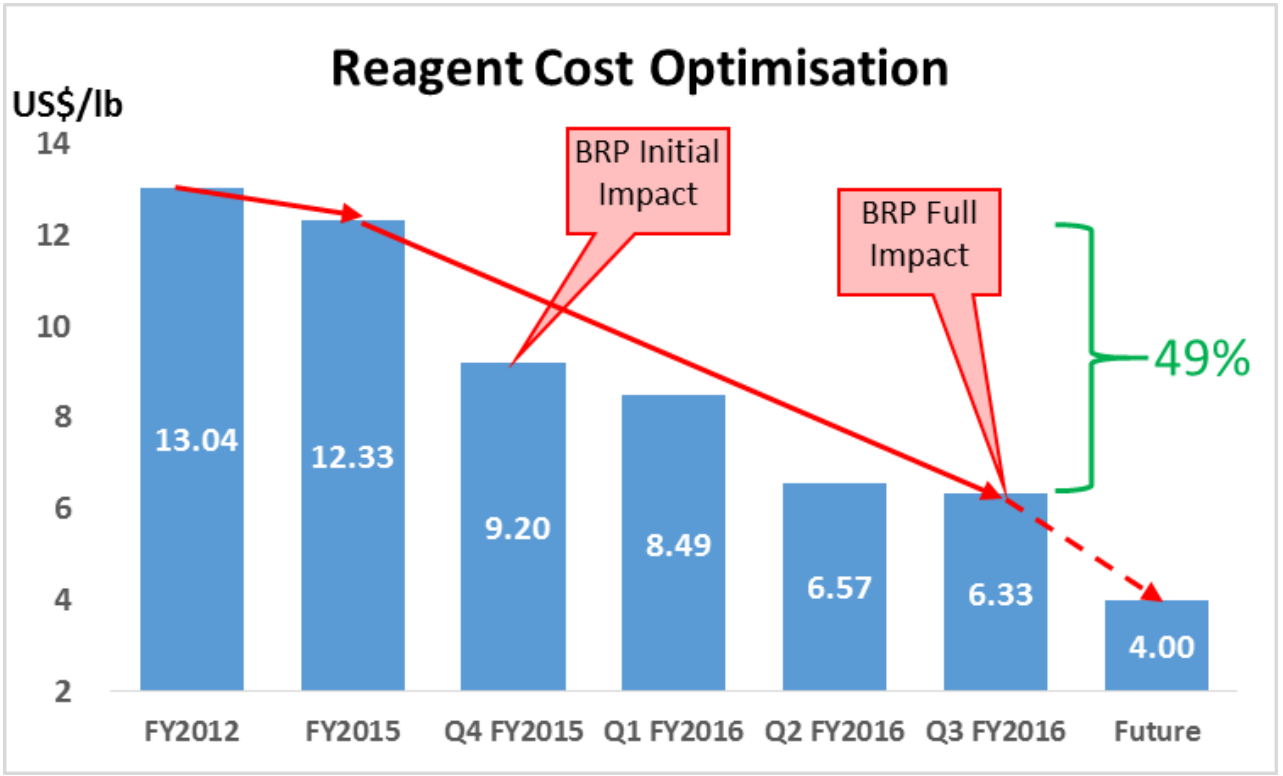
***"...**BRP successfully commissioned in March and operating above design. The extent of this project's success has far-reaching implications for the Langer Heinrich operation now and into the future. BRP is expected to exceed design benefit by up to 100% and establish a new paradigm in carbonate uranium processing..."* ***

*Paladin website Q1 2015 ASX report

Bicarbonate Recovery Plant (BRP)

Based on plant performance, operational improvement (Enhancement 4) was undertaken and improved plant bicarbonate recovery to 200% of nameplate at minimal cost*.

- BRP Enhancement 4 now operational
  - ✓ Capital Cost of additional <US$100k of our original capital cost of US$6.8M
  - ✓ Recovery of sodium bicarbonate now exceeds 200% of design
  - ✓ Total operating cost saving now >US$6/lb (>US$30Mpa)
  - ✓ Additional secondary benefits

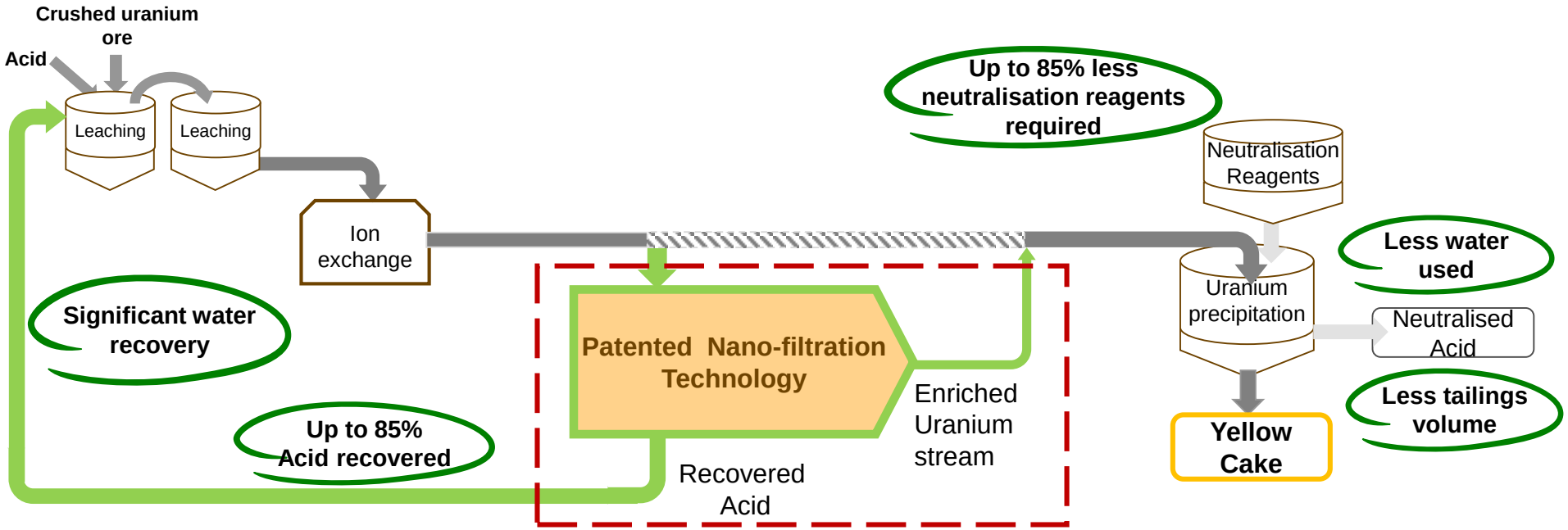


*Paladin 2015 AGM Report

Kayelekera Uranium Mine – First Nano- Filtration Plant

- **Kayelekera** is located in northern Malawi.
- Kayelekera Mine is owned 100% by **Paladin (Africa) Limited (PAL)**, a subsidiary of **Paladin Energy Limited**.
  - The mine design capacity is 3.3Mlb U_3O_8 per annum
  - Acid leach process utilising high pulp density Resin In Pulp (hdRIP) technology.
  - Plant on Care & Maintenance since April 2014 due to market conditions (price)
  - Uranium is precipitated from acidic Concentrated Eluate (CE) which requires the acid to be neutralised at significant cost.

Nanofiltration Technology – Sulphuric Acid Recovery



1 Elution Acid

- Up to 85% of elution acid recovered and reusable
- Significant acid cost reduction
- Acid supply logistics reduced significantly
- Site becomes acid self-sufficient

2 Neutralisation

- Neutralisation reagent proportionate to recovered acid
- Significant neutralisation cost savings

3 Water balance & Tailings

- Elution acid make-up water reduced by up to 85%
- Reduced tailings volume due to reduced acid, other reagents and water addition to circuit

Kayelekera Mine - Project Delivery

- **Plant fabricated in Johannesburg**

- **ARP was built to be fully transportable**
  - 3 containerised skids
  - 5 separate 316SS tanks

- **Complete FAT and Wet Commissioning prior to dispatch**
  - PLC programming fully tested during FAT,
  - All pumps operated,
  - All lines leak tested,
  - CIP skid fully tested.

Plant Performance

Inputs:

- **Feed stream**: Concentrated Eluant (CE) from RIP
- **Design Flowrate**: 30 m^3/hr
- **Composition**: 100 g/l H_2SO_4, 10 g/l U_3O_8

Objectives:

- Recover acid from CE for re-use

Design Outputs:

ARP Produced two streams

- Permeate (*recovered acid*) – 75% of CE volume
- Concentrate (*uranium rich*) – 25% of CE volume

Plant Output Streams:

- Permeate (*recovered acid*) re-used in leach process,
- Concentrate (*uranium rich*) progressed to CE neutralisation and Uranium Precipitation.

Kayelekera's Nano-Filtration Acid Recovery Plant (ARP)

- Recovery of over 40 t/day (equivalent) of 98% sulphuric acid
  - Typical feed flow of 30 m^3/hr @ 1M sulphuric acid
- Equivalent stoichiometric saving of neutralisation reagents.
- Uranium concentration to precipitation circuit increased from ~10 g/l to ~40 g/l
  - Improved refinery performance due to longer residence times
  - Improved final product contaminant removal.
- Project cost of US$5 M
  - Project on time and within budget
  - Net operating cost savings of over US$3 per lb U_3O_8.
  - Cash payback period (including all operating costs) of 7 months on reagent savings alone.
  - Significant other consequential benefits.
- Process now subject to patent and BMS hold commercial rights

Project Findings

- **Uranium concentrations increased 4 fold in concentrate**
  - Can achieve 5 fold
- **Average membrane life**,
  - dependent on acid concentration
  - Achieved significantly longer life than used for project justification
- **No cleaning on NF membranes required**
- **Minimal NF scaling observed**

BMS Piloting

- **Pilot campaigns were undertaken to generate design data, identify membrane life and assess main plant design,**
- **BMS Personnel undertook all membrane site testwork.**

Piloting Process Solutions

- **Multiple membrane types tested:**
  - **Acid “resistant” membranes**
    - **Shorter life**
    - **Excellent uranium rejection**
    - **Low membrane cost**
  - **Acid “proof” membranes**
    - **Longer life**
    - **Lower uranium rejection**
    - **High membrane cost (*~6x acid resistant cost*)**
- **Test housing on main plant**
  - **Enables continuous membrane testing and ongoing optimisation.**

Modified Membranes

- **Improvements based on operational performance and process requirements,**
  - **Greater than 10% flux improvement achieved with modified membranes.**

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Conclusions

- **BMS, Paladin and LHM has completed the development of a truly innovative uranium processing change**
  - **The process is applicable in both acid and alkali environments**
  - **Process has been patented**
  - **The impact on processing costs has been dramatic and creates a new paradigm for uranium hydrometallurgy**
  - **The commissioning periods achieved here (days only) are testament to the level of engineering expertise involved**
  - **BMS hold the commercial exploitation rights to the process and have developed proprietary membranes – knowhow is the key**
- **THERE IS MORE TO COME FROM THIS TECHNOLOGY**

Acknowledgements

- **A number of people have been critical to the very successful development of this process and need to be acknowledged:**

- **BMS Employees:**
  - **Mark Peacock,** Principle Lead Engineer
  - **Shana McDougall,** Principle Process Engineer

- **LHM Employees:**
  - **Simon Donegan,** Metallurgical Superintendent

- **Paladin Employees:**
  - **Darryl Butcher,** EGM – Technical, Project Development
  - **Dr Merrill Ford,** Metallurgy Manager
  - **Paul Boshoff, GM –** Technical, Project Development