DESIGN OVERVIEW OF THE INGULA PUMPED STORAGE SCHEME

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Project Manager (Design Service)

BRAAMHOEK CONSULTANTS JOINT VENTURE
Structure of Presentation

- Concept of Pumped Storage
- Long term planning
- Ingula development initiative
- BCJV Services
- Ingula Project Development and Programme
- Impact of Cost on Pumped Storage
- Health & Safety
- Questions
Conventional Hydro and Pumped Storage

- Conventional Hydro
  - Water passes through a turbine and continues down the river

- Pumped Storage Scheme
  - Cyclical system with water passing through reversible turbines – generally on a weekly cycle
Electricity Demand Curve

Time (h)

System Demand (MW)

Future

Current

0 2 4 6 8 10 12 14 16 18 20 22 24
Electricity Demand Curve

- **System Demand (MW)**
- **Time (h)**

**Base load supply**
- Store energy
- Release energy
The need for the Ingula Pumped Storage Scheme

- Long term planning – Eskom and NER has identified a need for enhanced peak generation capacity to serve:
  - Growth in the industrial sector
  - Successful rural electrification programme

- IPSS selected for design and development ahead of many alternatives considered since the 1980’s
Top 7 Site Locations
In 1998 Ingula Pumped Storage Scheme recommended for study at Feasibility level.

Study undertaken by Eskom’s own Hydro and Water Dept and completed in November 2003.

Feasibility Report suggested an installed capacity of 1000MW, and

After subsequent optimisation studies the installed capacity was increased to 1333MW.

September 2003 interested parties invited to bid to provide consulting services for Detailed Design.
Braamhoek Consultants Joint Venture (BCJV)

- Contract signed for Phase 1 design service in May 2004
- Principal Members
  - Arcus Gibb
  - Knight Piesold
  - Stewart Scott
- Sub Consultants
  - ARQ South Africa (Dams)
  - KP Canada (Transients, Penstocks & Gates)
  - PBP New Zealand (Electrical & Mechanical)
  - NK Japan (Gates and Electrical)
  - SWP United Kingdom (Hydro Power Optimisation)
BCJV Services Provided to Eskom

- Phase 1 – Project Optimisation:
  - Geotechnical Investigations – Surface Works
  - Geotechnical Investigations – Underground Works
  - Exploratory Tunnel

- Phase 2 – Final Design, Tender Documentation:
  - Access and Site Roads
  - Site Infrastructure
  - Upper and Lower Dams
  - Underground Works
  - Hydro-mechanical & Electrical Works (Performance Specification)
BCJV Services Provided to Eskom (2)

- Phase 3 – Construction Stage Design, Monitoring and Sign-off:
  - Verification of Design Assumptions
  - Foundation Interfaces & Design
  - Rock Interface and Site Influenced Design
  - Hydro-mechanical and Electrical Interfaces
  - Construction Drawings
  - Record Drawings
  - Project Sign Off
Ingula Pumped Storage Scheme – Developments to date
<table>
<thead>
<tr>
<th>Scheme Layout Options</th>
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</thead>
</table>

**OPTION 3 - TWIN SYSTEM**

**HEADRACE**
- Intake/Outlet Structure Serving Two Tunnels, 3 shaftings and 2 Emergency Gates
- Two Headrace Tunnels - 6.6m diameter
- Two Pressure Shafts and Tunnels - 3.5m diameter
- Four Penstocks (after Turbines) - 3.0m diameter

**TAILRACE**
- Four Draft tubes - 4.5m diameter
- Four Draft Tube Gates - 2.8m x 4m
- Two Tailrace Tunnels - 6.5m diameter

**OPTION 3**
- In this option two separate hydraulic systems are provided, each serving two units. This offers best security against tunnel failure allowing one system to remain in service whilst the other is de-watered. However, it is the most expensive option.

**OPTION 4 - BARE BONES SYSTEM**

**HEADRACE**
- Single Intake/Outlet Structure and Headrace Tunnel - 3.1m
- Two Bypassing Gates - 4.2m x 6m
- Single Pressure Shafts and Tunnels/Service Shaft - 3.5m diameter
- Four Penstocks (after Turbines) - 3.0m diameter

**TAILRACE**
- Four Draft Tubes - 4.5m diameter
- Four Draft Tube Gates - 2.8m x 4m
- Two Surge Shells Leading into Single Tailrace Tunnel
- Single Tailrace Tunnel - 6.5m diameter

**OPTION 4**
- This system has a single low pressure headrace and tailrace tunnels and single pressure shafts and tunnels. It is the most risky with regards to failure of a high pressure tunnel when the whole station will be out of commission - but it is the most inexpensive.
<table>
<thead>
<tr>
<th>APPROXIMATE DIAMETERS OF TUNNELS AND DIMENSIONS OF GATES</th>
<th>COMMENT</th>
</tr>
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<tbody>
<tr>
<td><strong>OPTION 1 - DRAKENSBURG STYLE</strong></td>
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<tr>
<td><strong>HEADRACE</strong></td>
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<tr>
<td>Inlet/Outlet Structure each with 2 No. Stoplogs and 2 No. Emergency Gates</td>
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<tr>
<td>Two Headrace Tunnels - 9.3m diameter</td>
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<tr>
<td>Four Pressure Shells and 7.7m diameter</td>
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<tr>
<td>Four Penstocks (after Inlet/Outlet) - 3.0m diameter</td>
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<tr>
<td><strong>TAILRACE</strong></td>
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<tr>
<td>Four Draft Tubs - 6.5m diameter</td>
<td>OPTION 1</td>
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<tr>
<td>Four Draft Tubs Gates - 2.5m x 5m</td>
<td>This was the design adopted for the Drakensburg Scheme. The headrace pressure tunnels were considered high risk and separate low pressure headrace tunnels were provided to allow de-watering of one headrace system whilst the other headrace remained in service.</td>
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<tr>
<td>Two Barge Chambers, leading into Single Tailrace Tunnel</td>
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<tr>
<td>Single Tailrace Tunnel - 6.3m diameter</td>
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| **OPTION 2 - MODIFIED DRAKENSBURG STYLE**               |         |
| **HEADRACE**                                           |         |
| Single Inlet/Outlet Structure and Headrace Tunnel - 9.4m diameter |         |
| Two Pressure Shells and 7.7m diameter                   |         |
| Four Penstocks (after Inlet/Outlet) - 3.0m diameter      |         |
| **TAILRACE**                                           | OPTION 2 |
| Four Draft Tubs - 6.5m diameter                         | This is similar to the Drakensburg Scheme layout, but a single low pressure headrace tunnel has been adopted as this is low risk. No part of the headrace can be isolated so repairs to any part of the headrace will mean closing down the whole scheme. |
| Four Draft Tubs Gates - 2.5m x 5m                      |         |
| Two Barge Shells Leading Into Single Tailrace Tunnel    |         |
| Single Tailrace Tunnel - 6.3m diameter                  |         |
Scheme Optimisation

- Scheme Optimisation Considerations
  - Cost
  - Risk
  - Response Time
  - Operational Flexibility
  - Construction Time
Waterways
Underground Powerhouse Complex
Geotechnical Investigations

- Drilling commenced in early 2005, completed early 2007
- Test work consisted of:
  - In-situ testing in selected boreholes
  - Testing of selected core samples in off-site laboratories

- Conclusion of Investigations:
  - Geology more complex than might have been expected in a typical Karoo Supergroup sedimentary sequence, making interpolation between boreholes difficult
  - Mudrocks intersected over the height of and below the powerhouse caverns are less competent than originally expected but the rockmass is relatively unjointed
Exploratory Tunnel

- Construction commenced 2nd quarter of 2005
- Completed June 2007
- Purpose:
  - Further geotechnical investigations (Plate Bearing)
  - Immediate access to excavate top heading of the Machine Hall (Programme benefit)
Access Roads

ALTERNATIVE 2 – DE BEERS-ESCARPMENT

Kiesbeen
Skeurklip
Bedford
Van Reenen
Braamhoek
Besters
Swinburne
R103
N3
N

ALTERNATIVE 2
Main Access Tunnel

- Construction commenced 2nd quarter of 2007
- Expected completion date – early 2009
- Progress to date:
  - Approach cut complete
  - Mining portal complete
  - Tunnel @ chainage 380m
<table>
<thead>
<tr>
<th>Task Name</th>
<th>2007</th>
<th>2008</th>
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<th>2010</th>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<td>Spirals</td>
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<td>Draft Tube</td>
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<td>Spiral Casing and Embedded Pipes</td>
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<td>Pump Turbine Assembly</td>
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<td>Concrete</td>
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<tr>
<td>Generator Motor Assembly</td>
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<tr>
<td>Test and Commission</td>
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Electro-Mechanical Data

- **Motor Generator**
  - (Generation mode: Max output 4 x 333MW @ flow of 348m$^3$.s$^{-1}$)

- **Pump Turbine**
  - (Pump mode: Max output 4 x 291MW @ flow of 241m$^3$.s$^{-1}$)
Impact of Project Costs on Pumped Storage

- Market movement over and above INPUT cost:
  - Increased profit margin opportunities
  - Increased risk due to resource shortages
  - Opportunity costs of taking on risky projects

- Opinions of industry experts and commentators:
  - Bureau of Economic Research (BER)
  - South African Federation of Engineering Contractors (Safcec)
  - Industry Insight – a construction management information service and commentator
Tendering Competition
Growth in Profitability
Health and Safety - Design

- Determination of rock mass parameters:
  - Initially from borehole information
  - Enhanced by excavation of ET
  - Further boreholes within the ET
  - On-going

- All designs compliant with SANS and international standards

- Modelling with state of the art numerical programs
  - 2D numerical modelling using FLAC2D and Phase2, 3D numerical modelling FLAC3D
  - Complex joint structures using UDEC
  - Unstable rock wedges using UNWEDGE
Health and Safety - Construction

- Compliance with Department of Minerals and Energy
- Compliance with Mines Health and Safety Act
- Provision of comprehensive method statements
- Review of method statements for safety and compliance with explosives, Mines and Works Acts
- Compliance with particular site procedures detailed in specifications
Thank you