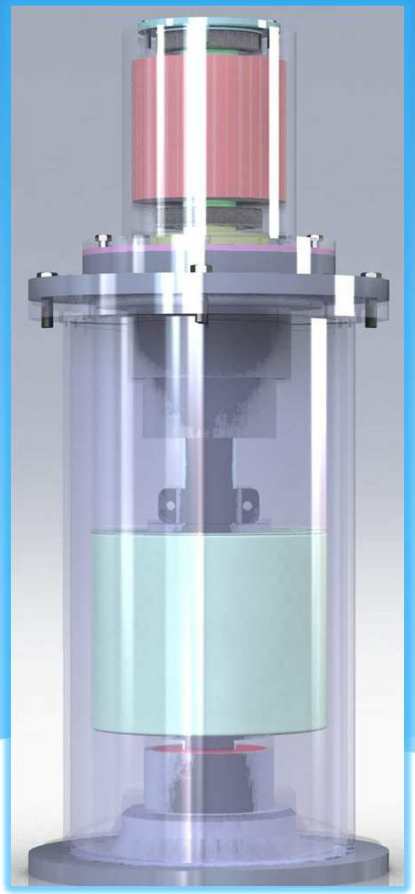
The Concept Design of a Kinetic Energy Storage Device



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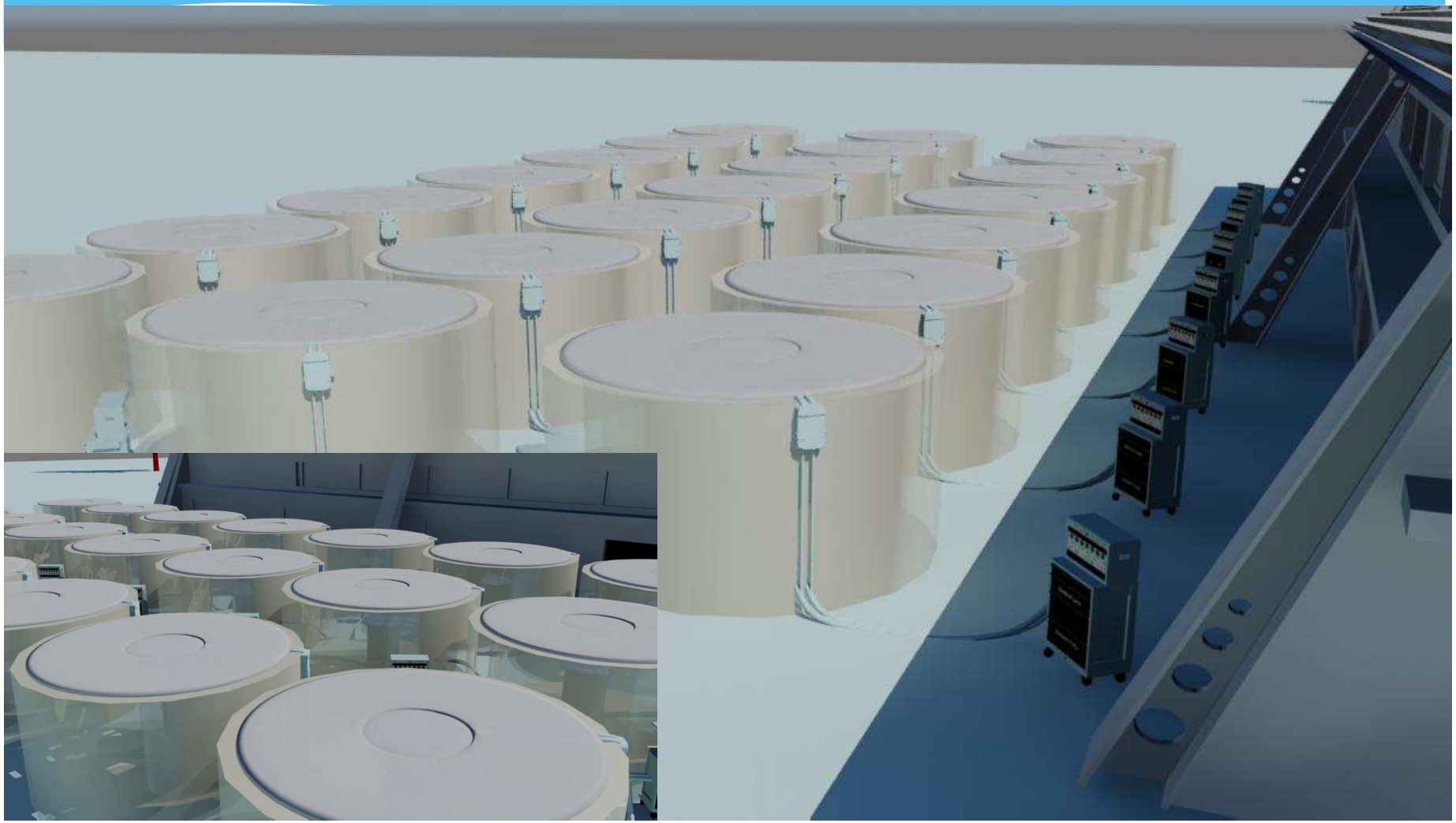
Anthony Johnson

Visualisation of the

Kinetic Energy Storage Device

Kinetic Energy Storage Device
Industrial Application



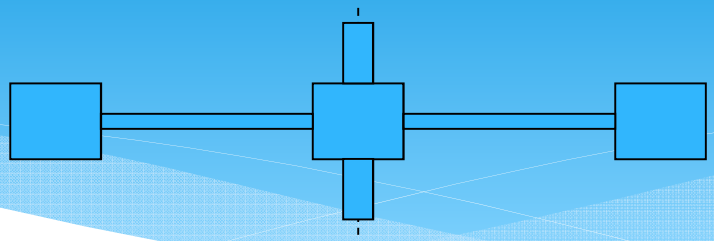
Target Design Specification

Envelope size:	1m³ approx
Power rating:	20 to 50kWh
Efficiency:	> 75%
Power degradation over 24hrs:	< 10%
Calendar life:	10 years
Max sound power level:	63dBA
Low speed:	approx 20k rev/min

Flywheel Design Exploration

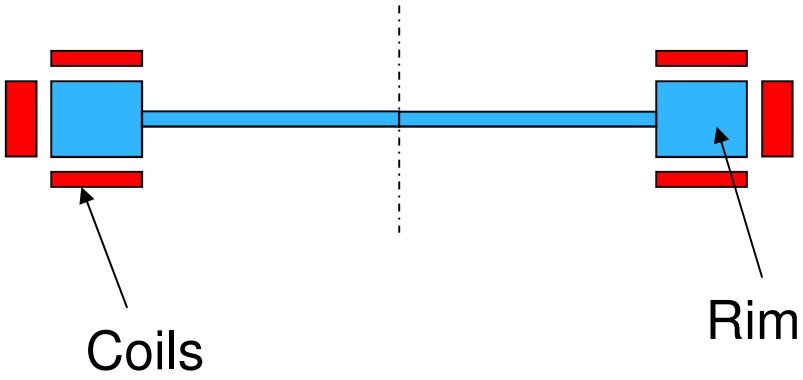
Flywheel Styles

1. Rim Type



2. Rim Type: Toroidal rotor with mag-lev bearings and motor/generator on outer rim.

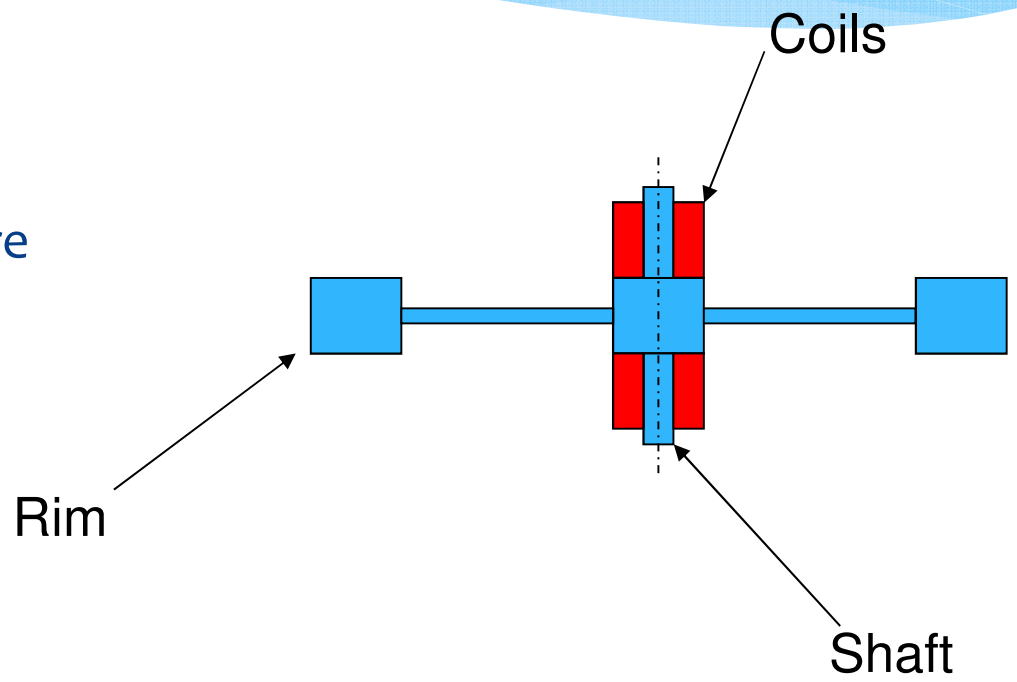
- Uses Eddy currents
- 70% efficient
- Large diameter coils
- Difficult to control
- Surface speeds at coils awkward to handle



Flywheel Design Exploration

3. Rim Type: with magnetic levitation bearings and motor/gen set on shaft.

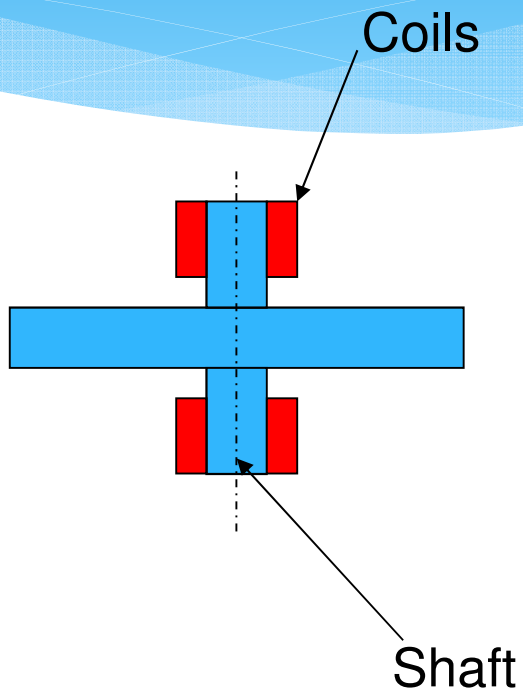
* Uses Stator and Rotor Technology
* 90% efficient
* Small diameter coils
* Easy to control
* Coils easy to manufacture
* Surface speed at shaft within workable bounds



Flywheel Design Exploration

Disc Type: with magnetic levitation bearings and motor/gen set on shaft.

* Uses Stator and Rotor Technology
* 90% efficient
* Small diameter coils
* Easy to control
* Coils easy to manufacture
* Surface speed at shaft within workable bounds



Design Approach Overview

* Standard mechanical engineering techniques
* Use known technology approach where possible
* Use standard materials where possible
* Keep development to a minimum

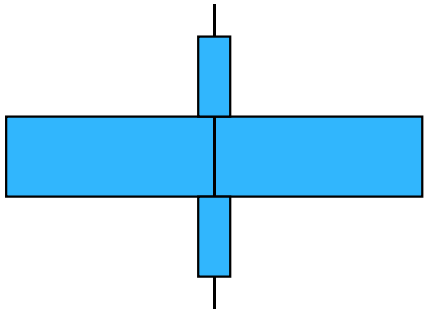
Design Approach: Practical

Options

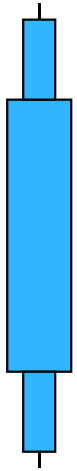
* Small – High Speed
* Large Low Speed

Disc Type

* Large diameter – axially thin



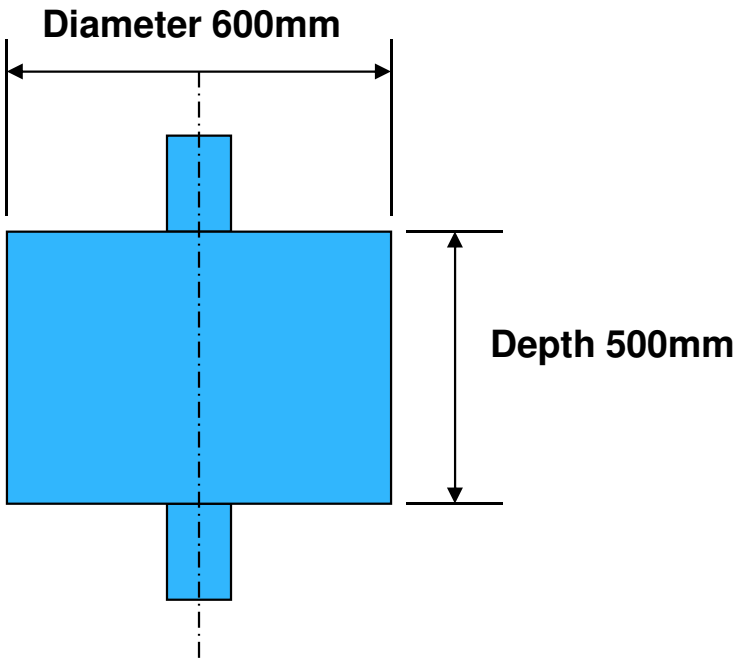
* Small diameter – axially long



Design Approach Disc Type Flywheel

Typical parameters were manipulated and iterated to reveal the **optimum solution** shown below:

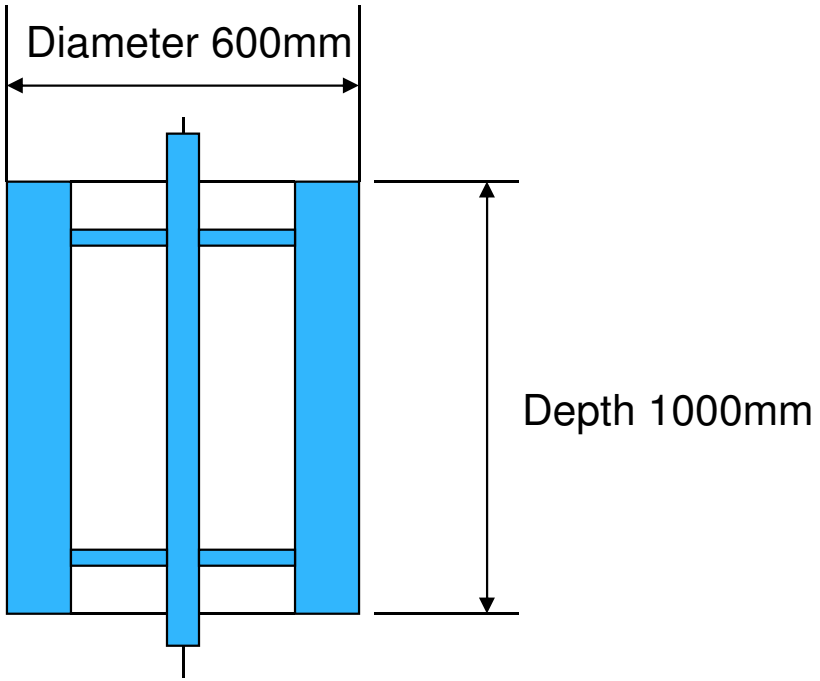
Dia	Depth	mass	Ang Vel	Surface	KE	KE	Power	1 tonne	Rim
m	m	kg	RPM	Speed	MJ	KWh	KW	Mass lift	Stress
				M/s				m	MN/m^2
0.60	0.50	1060	18000	566	318	24	6.6	8151	13



Design Approach Rim Type Flywheel

Typical parameters were manipulated and iterated to reveal the **optimum solution** shown below:

Outer Dia (m)	Inner Dia (m)	Depth (m)	mass (kg)	Ang Vel (Rev/min)	Surface Speed (m/s)	Energy (MJ)	KE (KWh)	Power (KW)	1 tonne Mass Lift (m)	Rim Stress (MN/m^2)
0.6	0.45	1	928	18000	566	74.2	20.6	5.7	8151	13.1

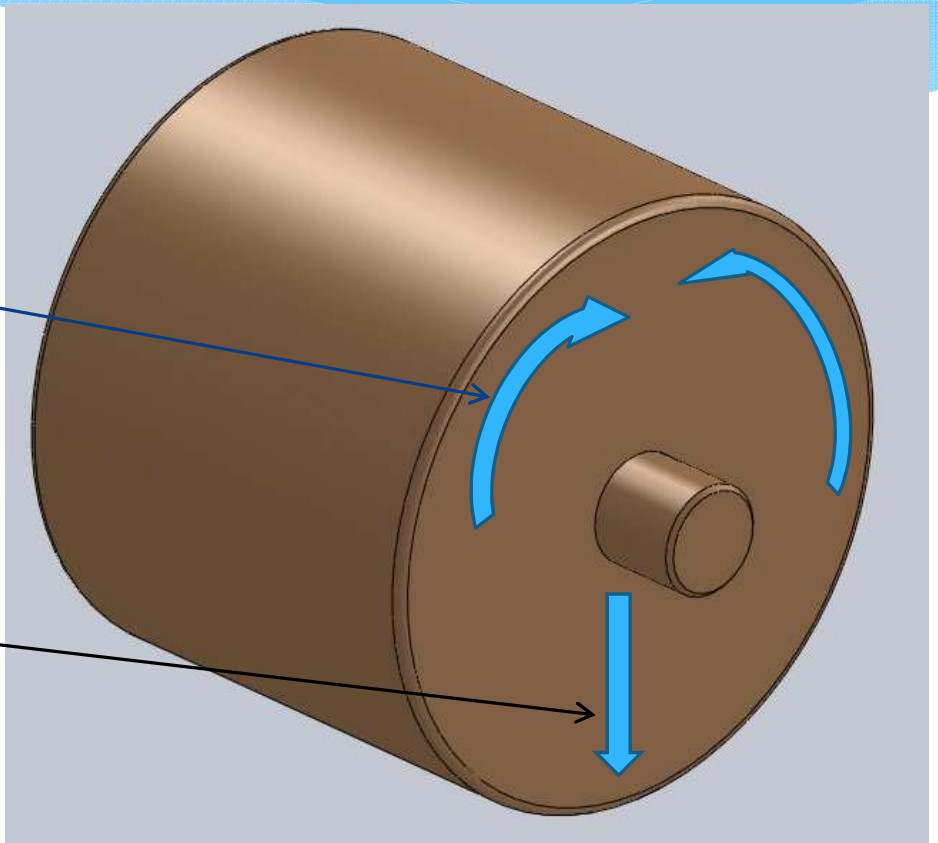


Design Elements and Decisions

Disc-Type Flywheel (Solid)

Careful analysis required to account for

* Radial Stresses
* Hoop tresses



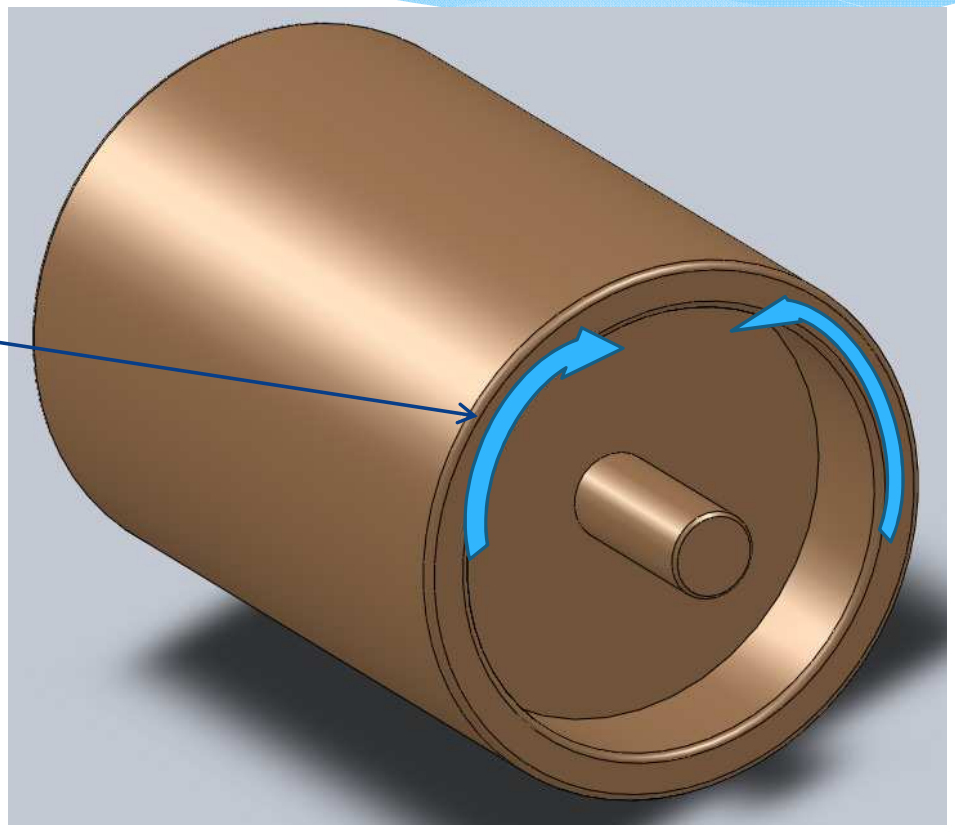
Design Elements and Decisions

Rim-Type Flywheel (Cylindrical)

Careful analysis required to account for

* Hoop tresses

HOOP STRESSES



Design Elements and Decisions

* **Surface speed 566m/s:** 1.6 x speed of sound

  Reduction of air turbulence drag and noise generation achieved by installing the rotor in a **Vacuum Chamber**

* **Reduction of frictional resistance:**

  Apply Magnetic Levitation Bearings

  * Axial Bearings
  * Radial

SKF Magnetic
Levitation Bearing

Design Elements and Decisions

Back-up Bearings

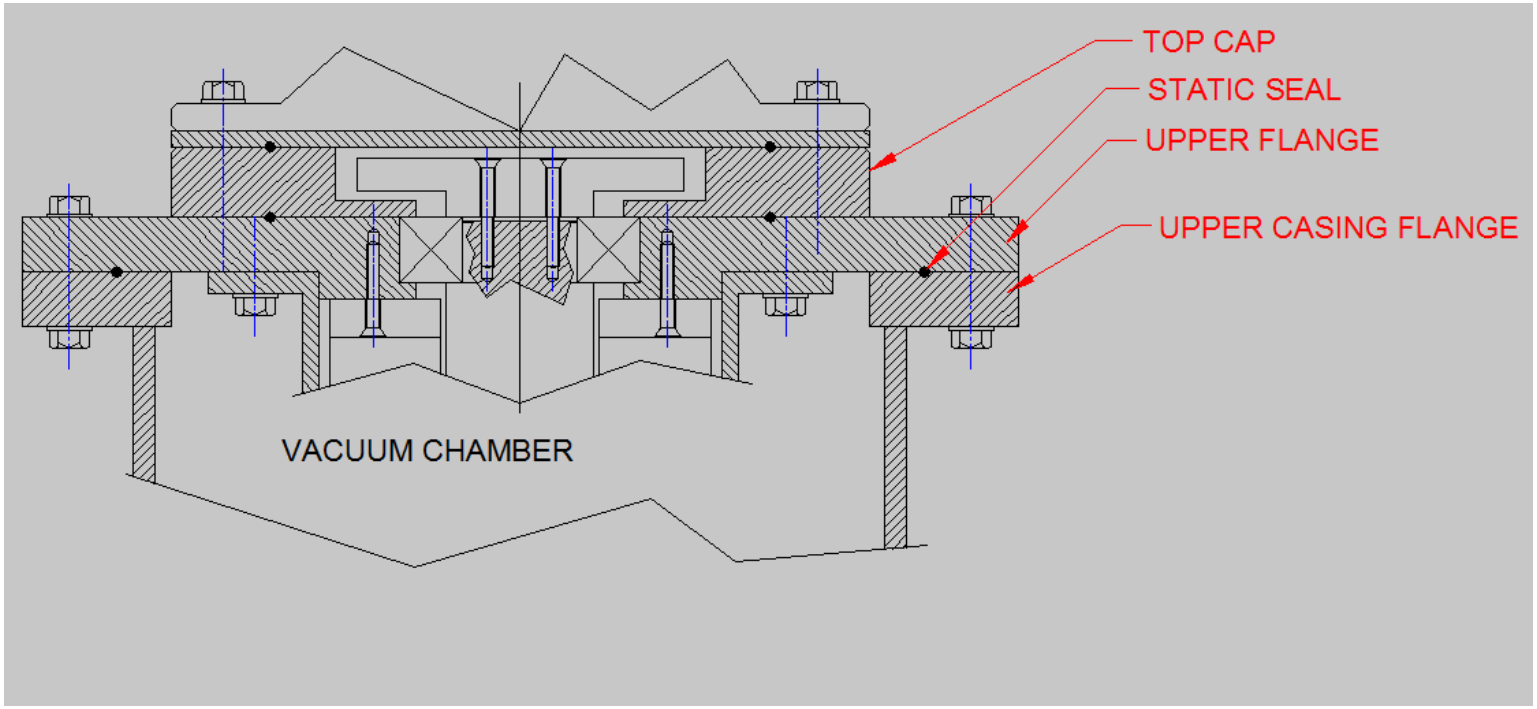
Should power fail to the magnetic levitation bearings a back-up set of **Rolling Element Bearings** will be applied.

Specialist Ceramic Bearings
Supplied by SKF

Design Elements and Decisions

Vacuum Chamber

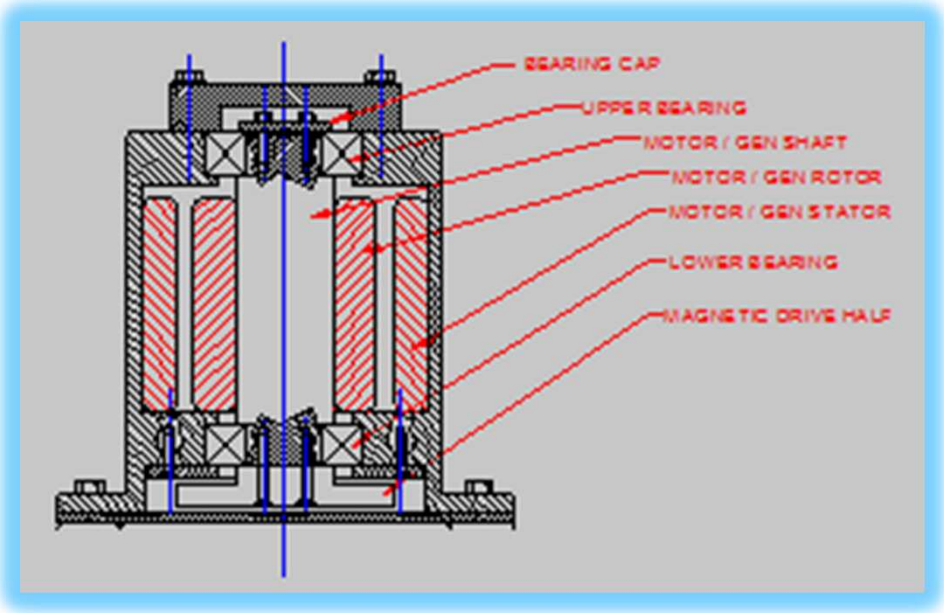
* Encloses the flywheel rotor
* Contains the vacuum
* Uses only static seals (reduces frictional resistance)

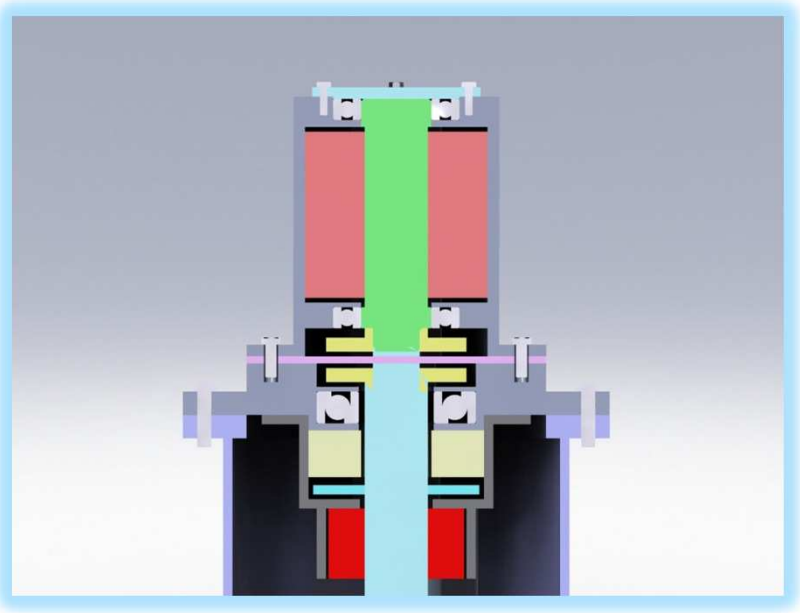


Design Elements and Decisions

Motor / Generator

* External to main flywheel and vacuum chamber
* Modular unit can be changed easily

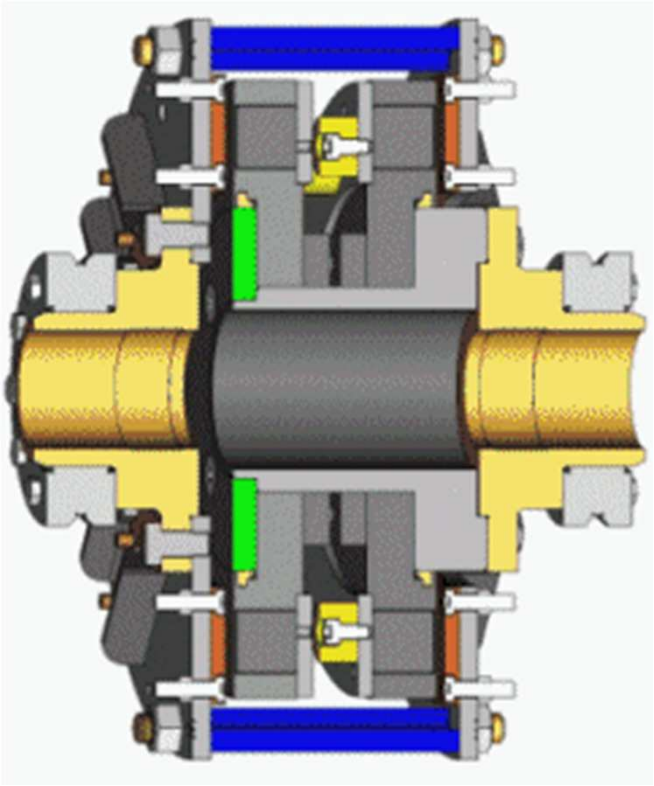




Design Elements and Decisions

Flywheel / Motor-Gen Coupling

* Flywheel Housing separate to Motor–Gen Housing
* Drive system needs to function across the sealed membrane.
* Apply magnetic coupling



Magna Drive Magnetic Coupling

Design Elements and Decisions

Containment Considerations

* Energy enough to lift a 1 tonne mass 8km vertically
* Dangers of burst are very real
  - 85MJ equivalent energy to 18kg (40 Lbs) of TNT

Two Containment Options:

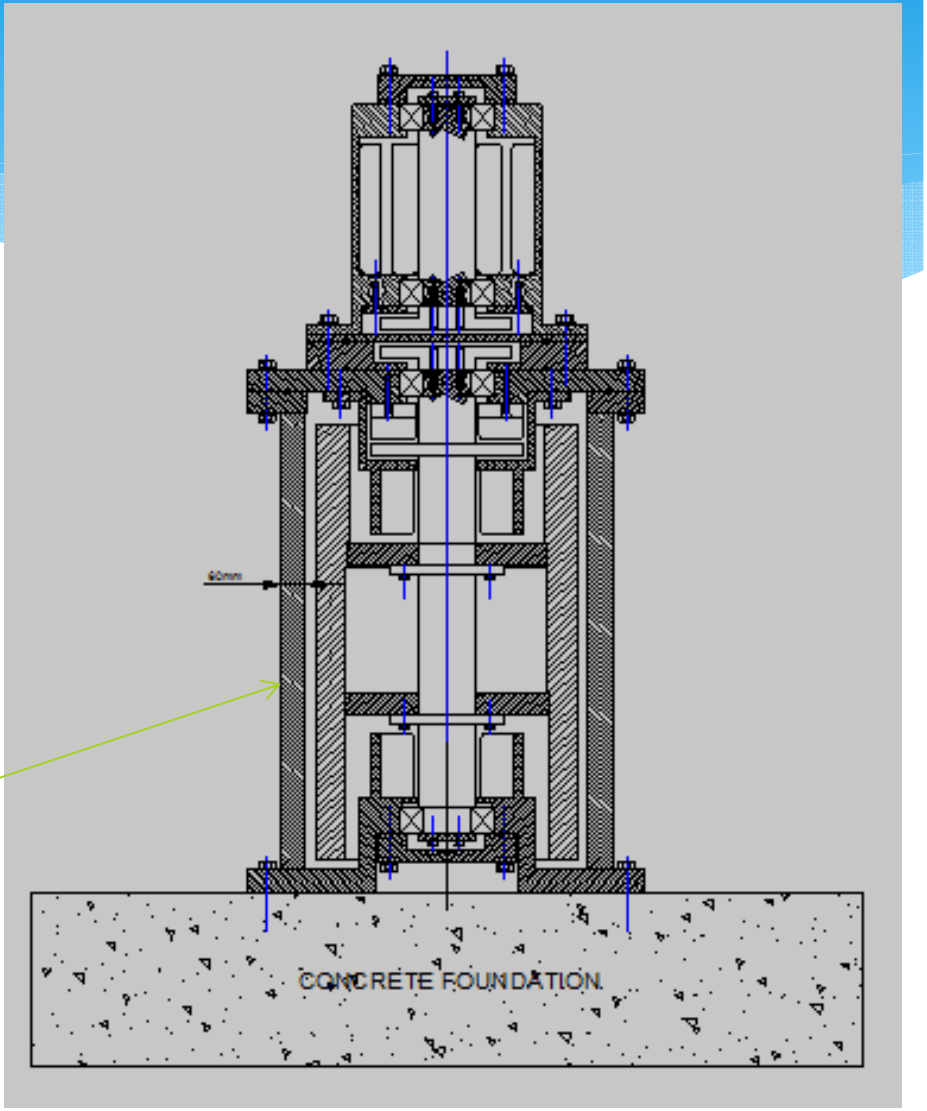
- Heavy containment cylinder on a heavy foundation
- Light weight vacuum chamber encased in a concrete casing.

Design Elements and Decisions

Containment Option One

- Heavy Steel Containment
- Heavy Concrete Foundation

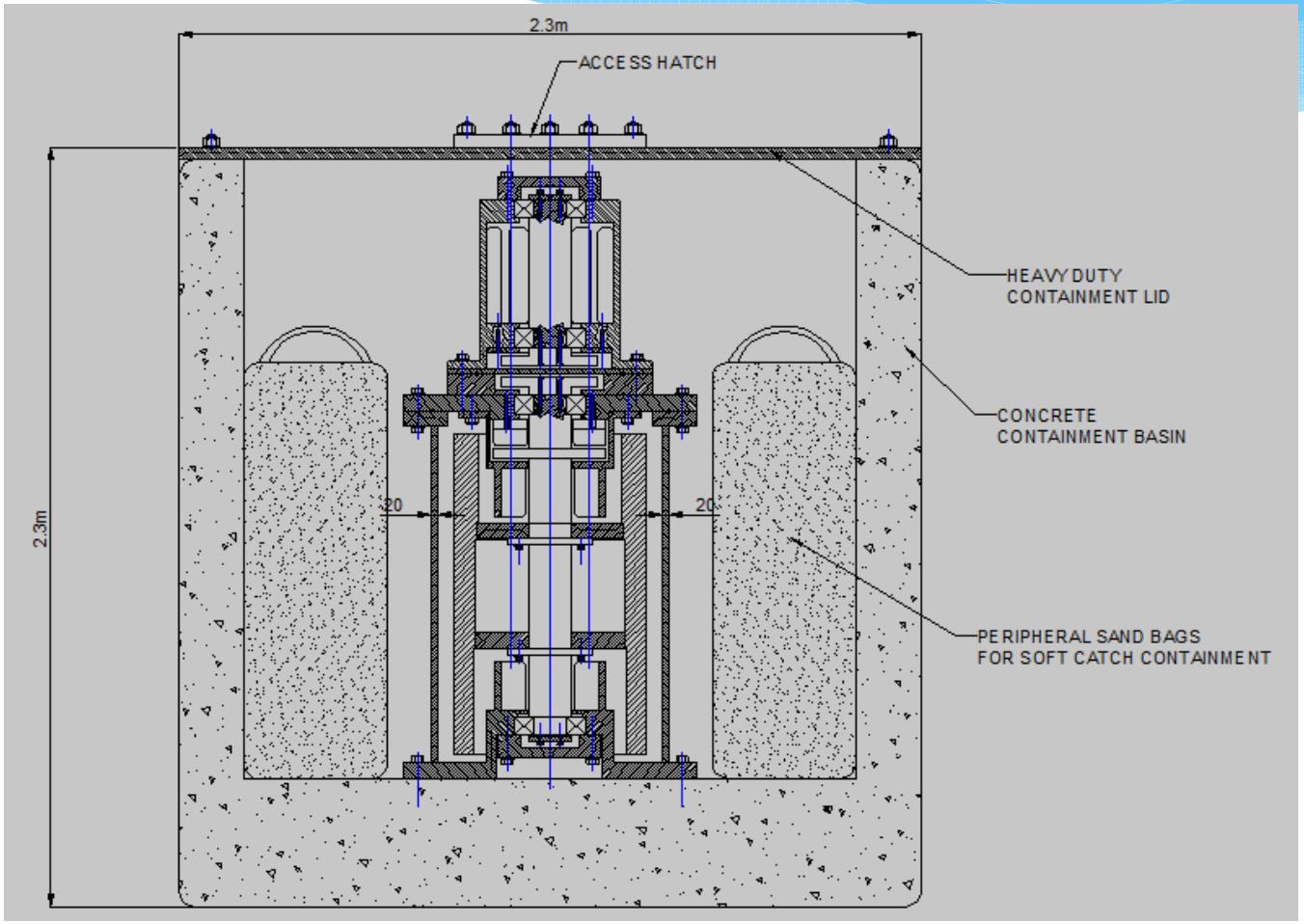
Heavy
Casing



Design Elements and Decisions

Containment Option Two:

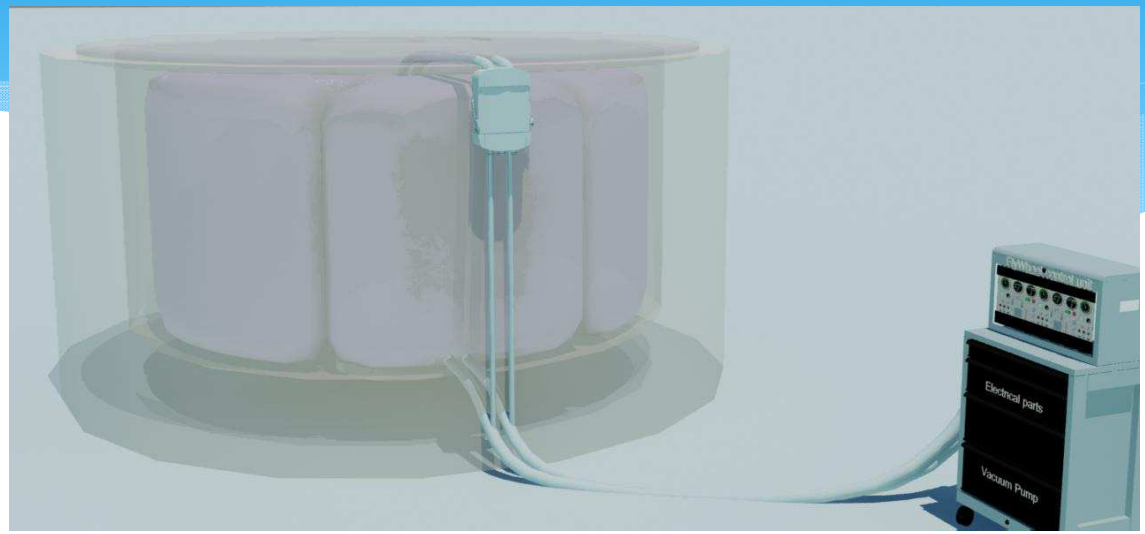
- Lightweight vacuum chamber encased in a concrete casing
- Includes sand bags radially mounted to act as a soft catch

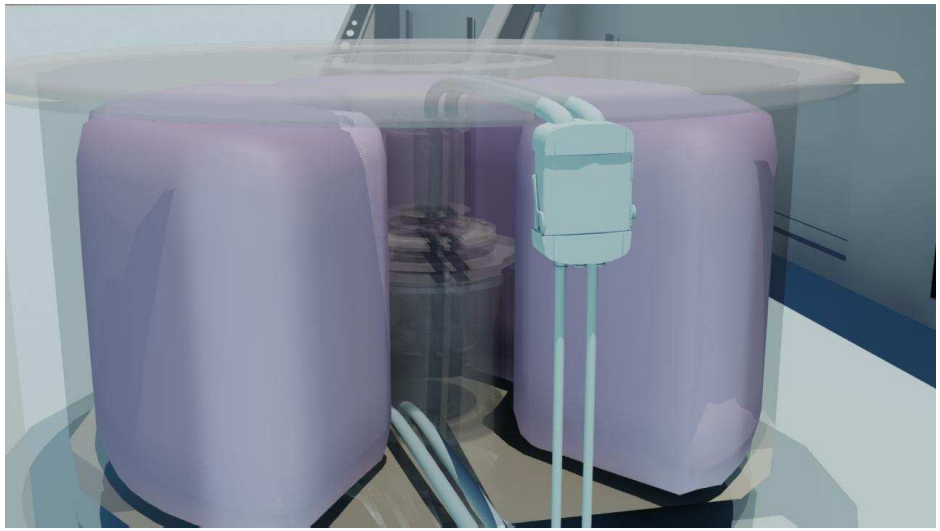


Design Elements and Decisions

Containment Option Two: Concrete Basin with Sand Bag Soft-Catch

Containment with sand bag segments





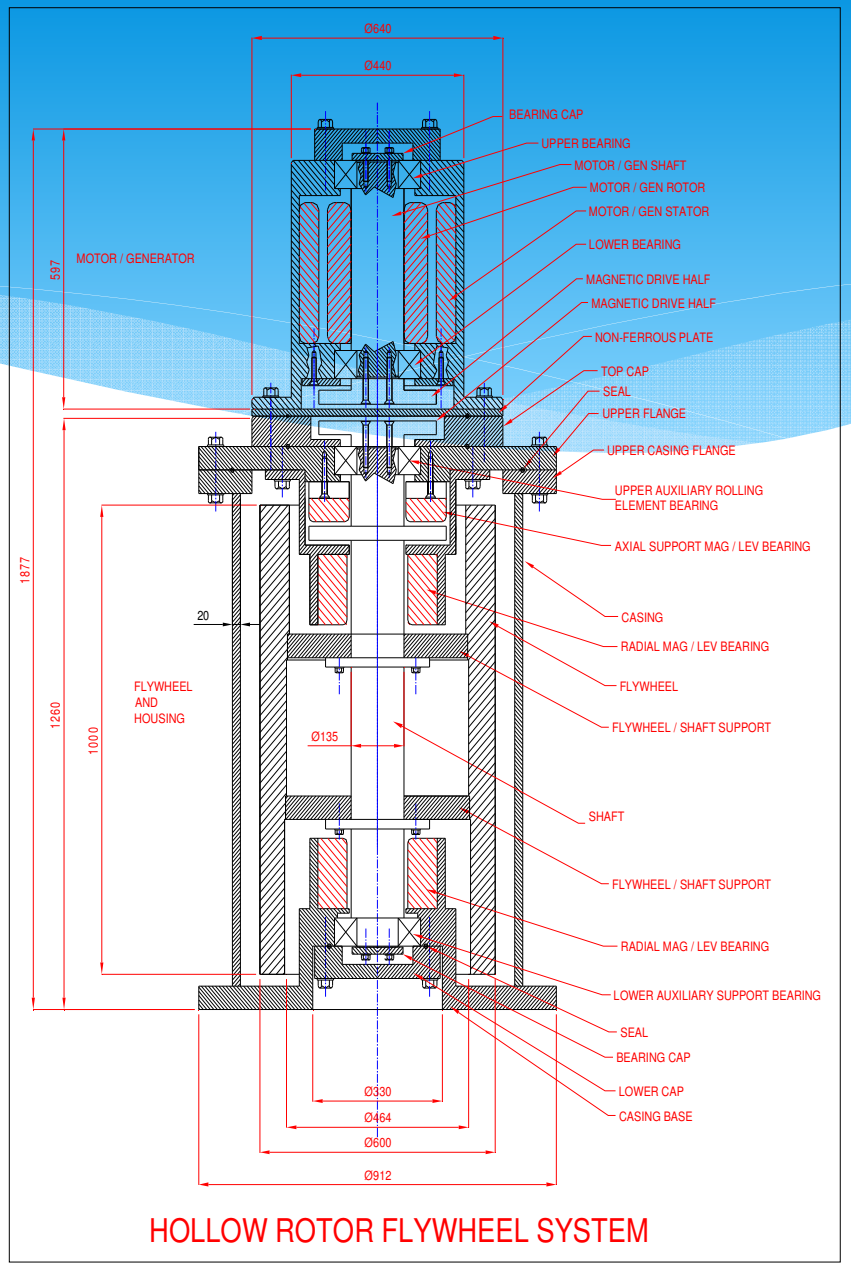
Containment with sand bag segments showing internal arrangement

Concept Outlines

Concept One

Rim Type Flywheel

* Takes the form of a cylinder
* Diameter 600mm
* Length 1000mm
* Mass 930kg



Concept Outlines

Rim Type Flywheel

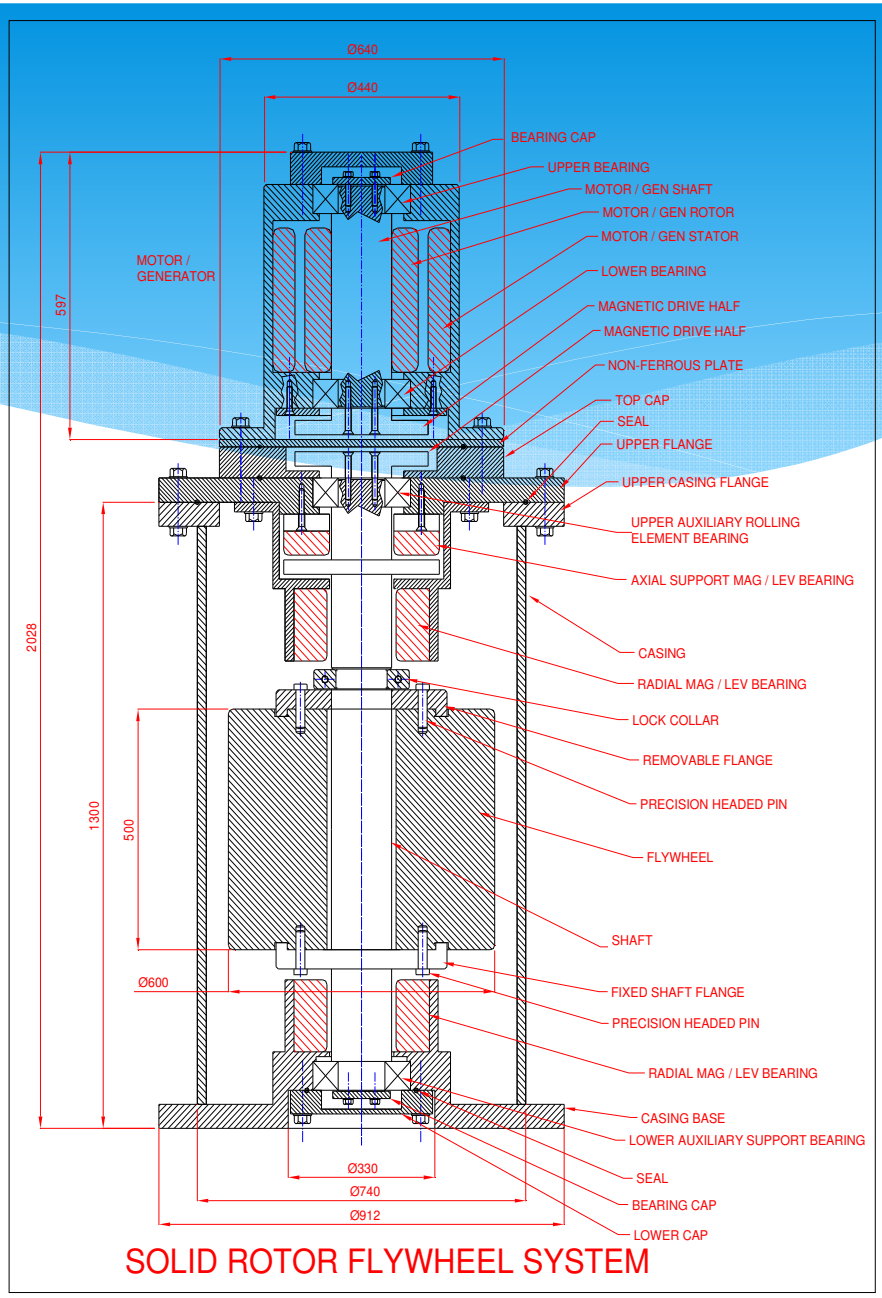
• **Style**		Hollow cylinder
• **Outer diameter (mm)**		600
• **Inner diameter (mm)**		450
• **Rotor depth (mm)**	1000	
• **Material**		steel
• **Density (kg/m^3)**		7500
• **Rotor mass (kg)**		930
• **Angular velocity (Rev/min)**		18000
• **Surface speed (m/s)**		565
• **Energy (Joules)**		74,200,000
• **Energy (kWh)**		20.61
• **Power (kW)**		5.73
• **1 Tonne mass lift (m)**		8150
• **Containment (Primary)**		Steel casing
• **Containment (Secondary)**		Concrete lined Pit
• **Bearing system radial**		Magnetic Levitation
• **Bearing System (secondary)**	Rolling element Brgs	
• **Motor-Generator Drive Coupling**		Magnetic
• **Chamber Type**		Vacuum

Concept Outlines

Concept Two

Disc-Type Flywheel

* Takes the form of a solid rotor
* Diameter 600mm
* Length 500mm
* Mass 1060kg



Concept Outlines

Disc Type Rotor

- **Style** Solid cylinder
- **Outer Diameter (mm)** 600
- **Inner diameter (mm)** n/a
- **Rotor depth (mm)** 500
- **Material** Steel
- **Density (kg/m^3)** 7500
- **Rotor mass (kg)** 1060
- **Angular velocity (Rev/min)** 18000
- **Surface speed (m/s)** 565
- **Energy (Joules)** 84,800,000
- **Energy (KWh)** 23.55
- **Power (KW)** 6.54
- **1 Tonne mass lift (m)** 8,152
- **Containment (Primary)** Steel casing
- **Containment (Secondary)** Concrete lined Pit
- **Bearing system radial** Magnetic Levitation
- **Bearing System (secondary)** Rolling element Brgs
- **Motor Generator Drive coupling** Magnetic
- **Chamber Type** Vacuum

Selection of Concept

Rim Type

- Lower mass 930kg
- Height overall 1877mm
- Energy 20.61 kWh
- Power 5.73 kW
- Stresses in rim only
  (Less prone to burst)

Disc Type

- Higher mass 1060kg
- Overall height 2028mm
- Energy 23.55 kWh
- Power 6.54 kW
- Radial and Hoop stresses present

* Design and manufacturing will present a similar level of difficulty
* Balancing relatively easier with the rim-type flywheel
* Cost implications will be similar for each type

Overall Concept

Modular construction allows:

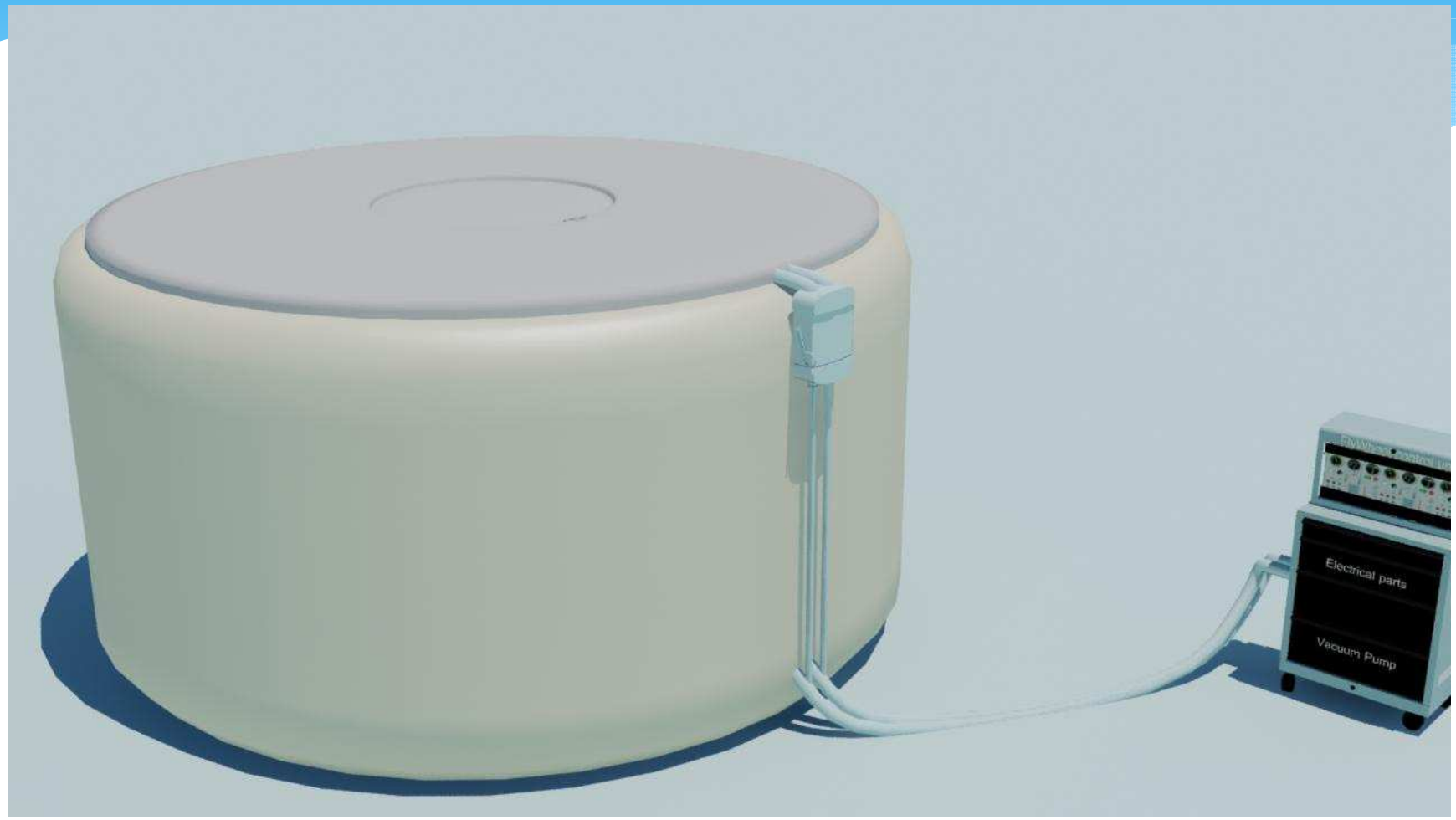
- Ease of Maintenance
- Ease of Assembly
- Standardised Components

Concrete containment can be:

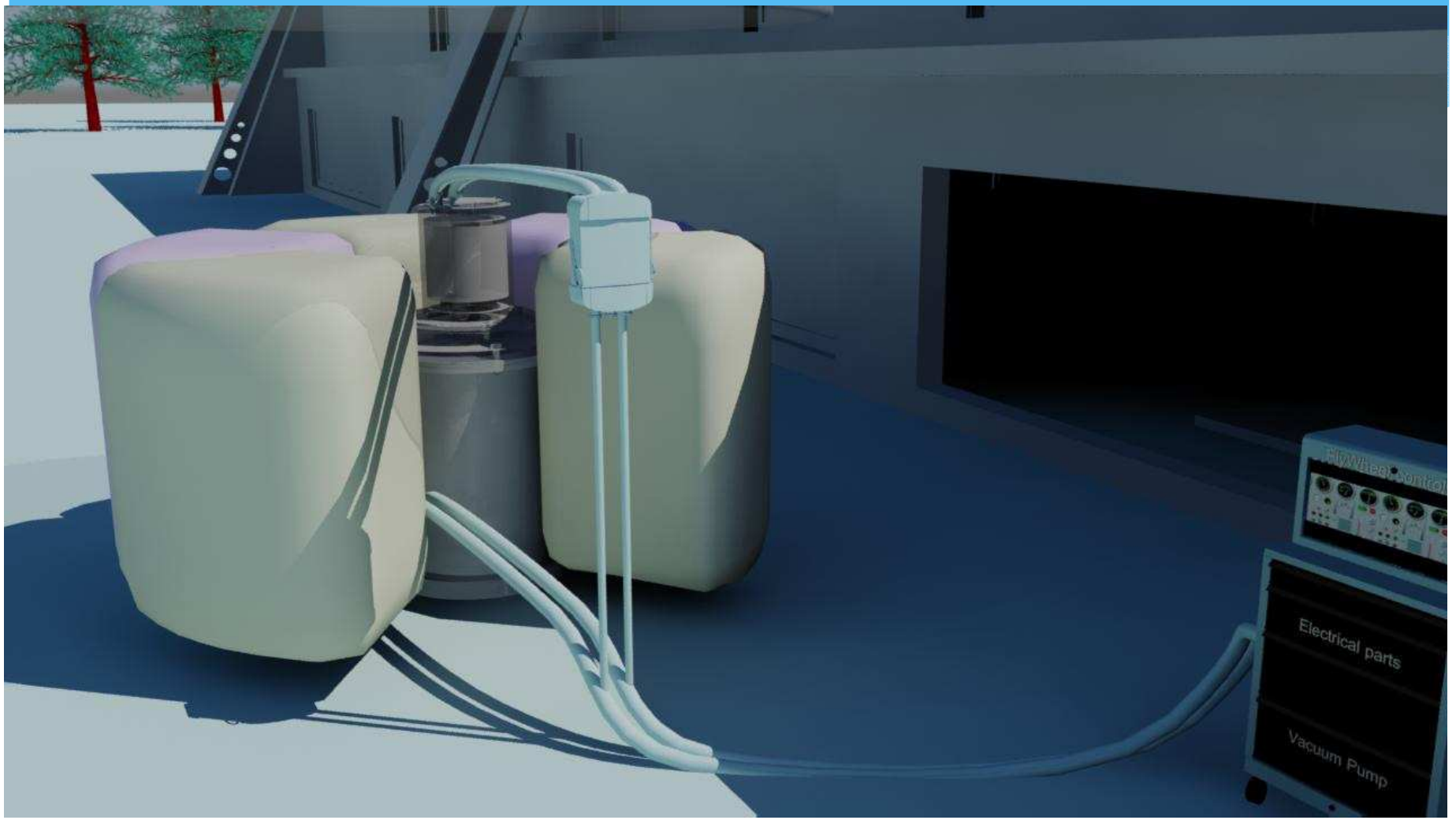
- Free Standing
- Buried

Overall Concept

Single Concrete Containment Basing showing Lid and Control System



6 x sand bags in case of failure



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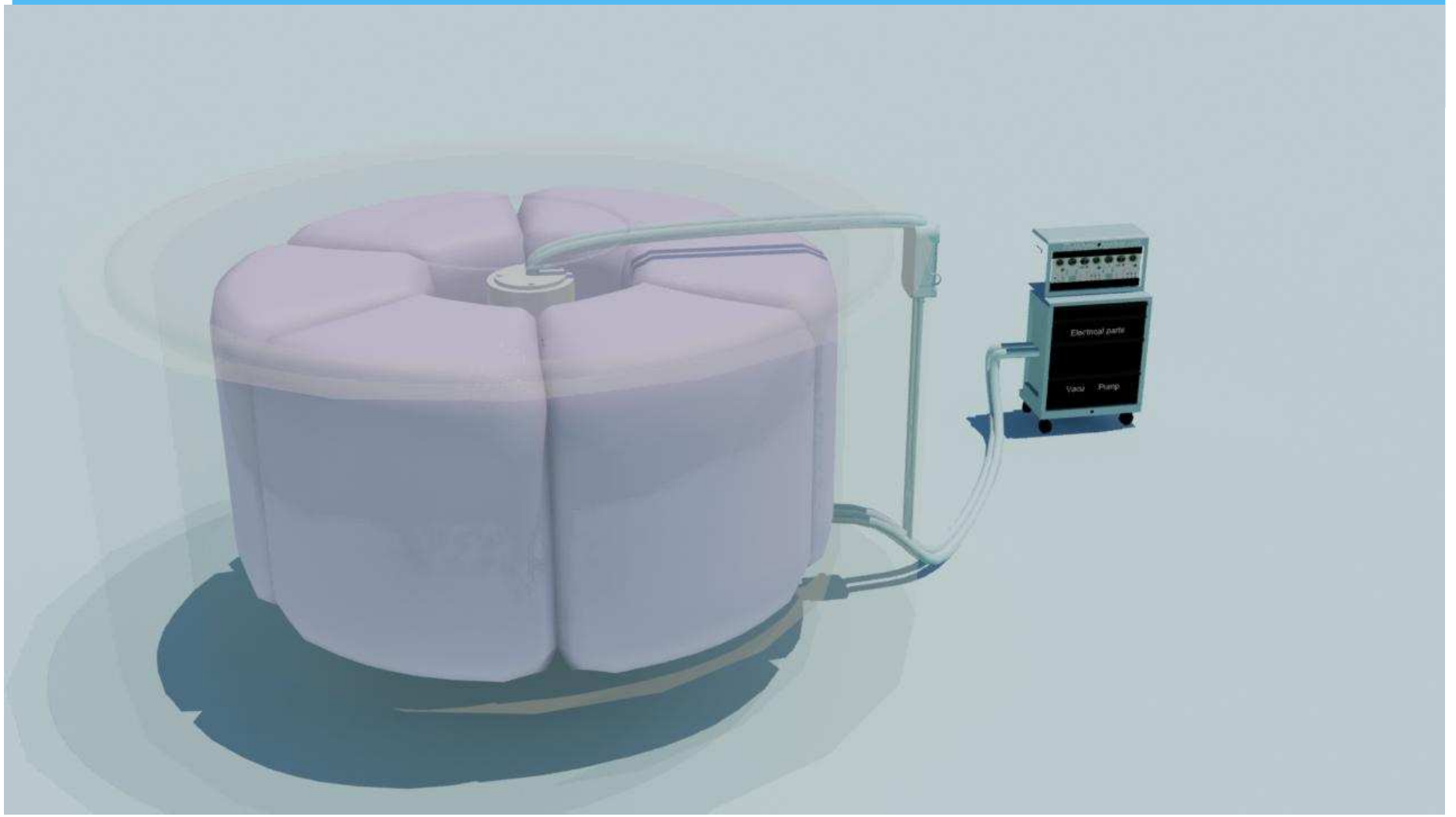
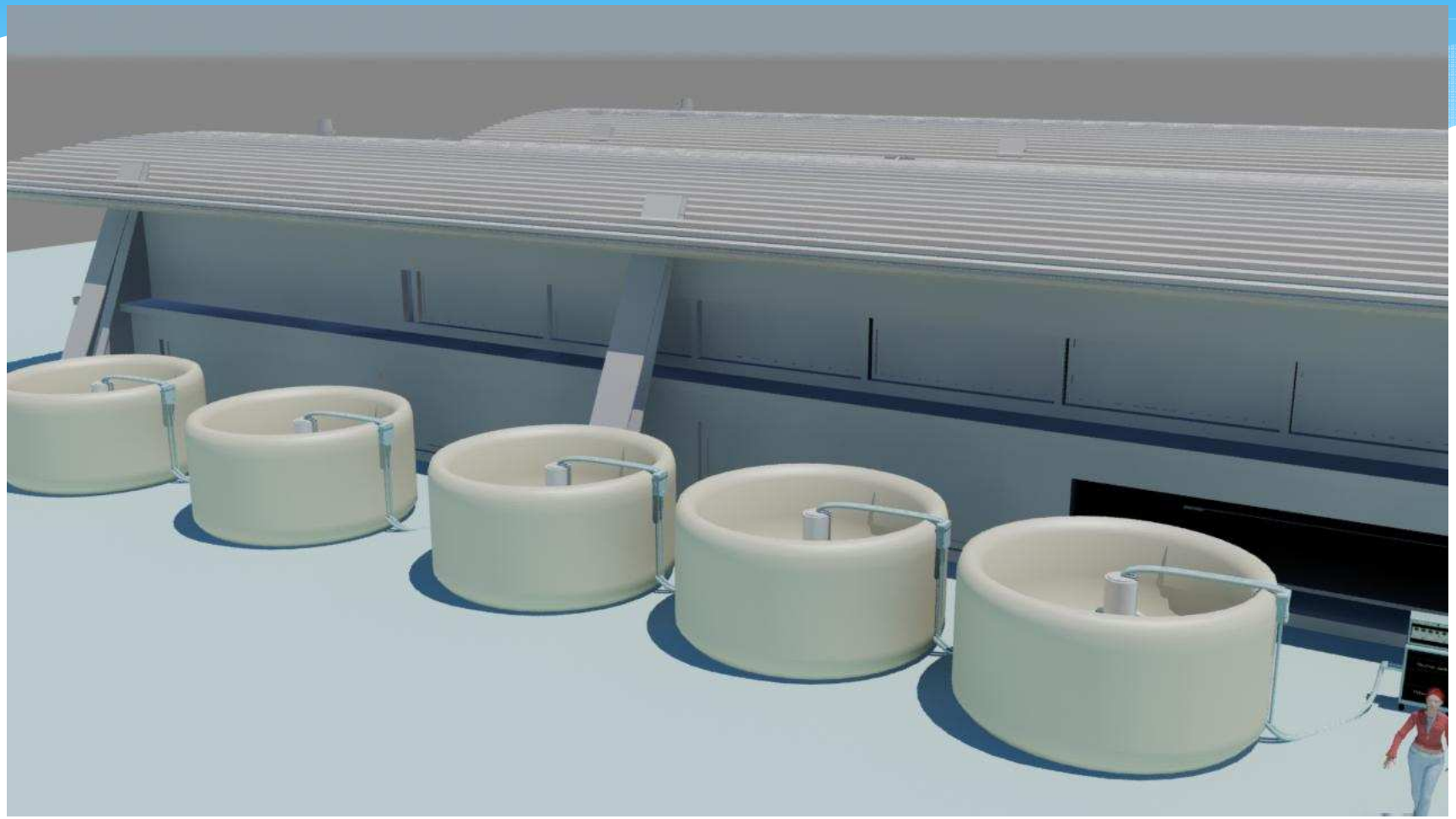


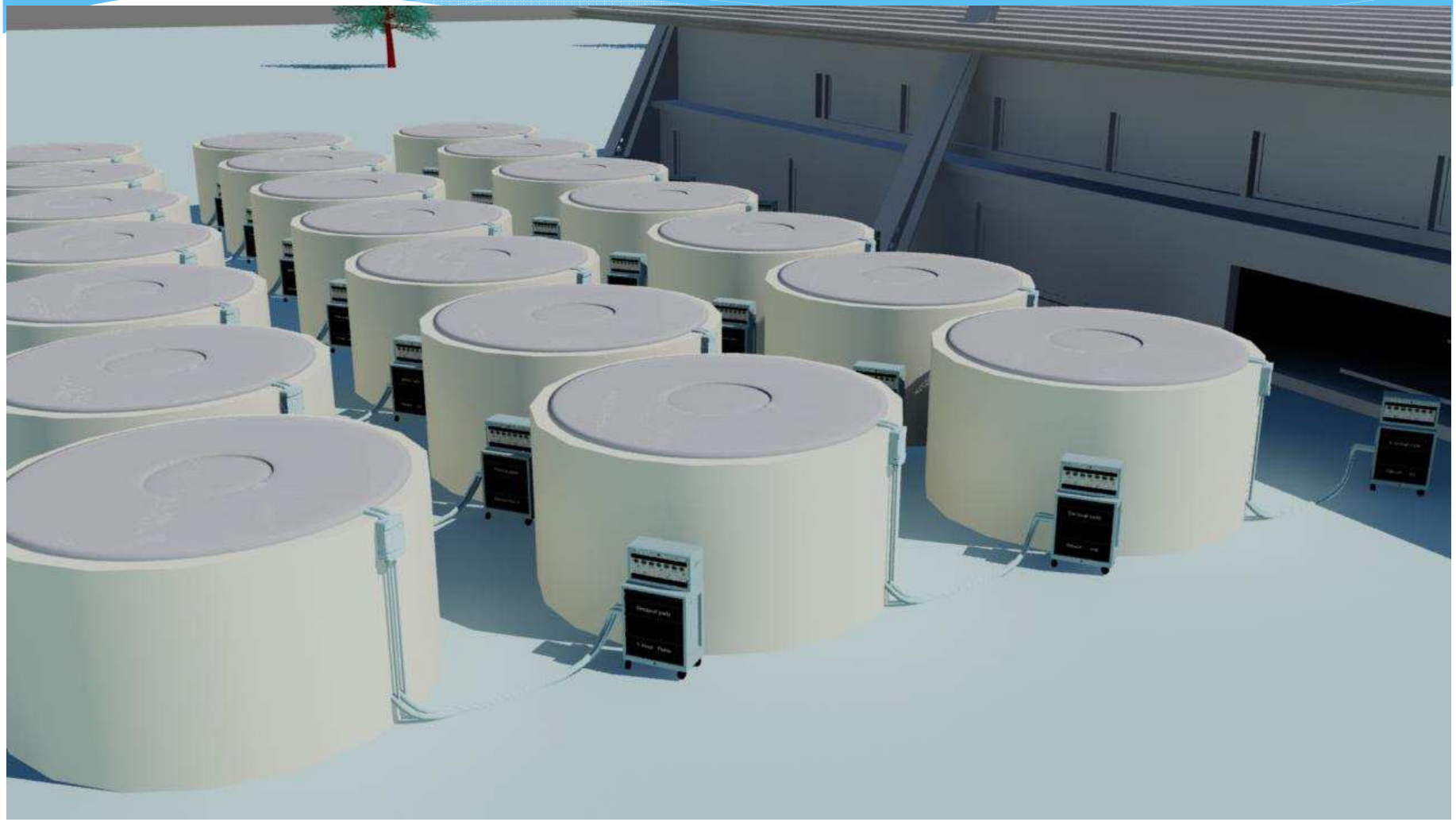
Overall Concept

Envisaged Industrial Application (lead removed)



Overall Concept

Envisaged Industrial Application (lead removed)



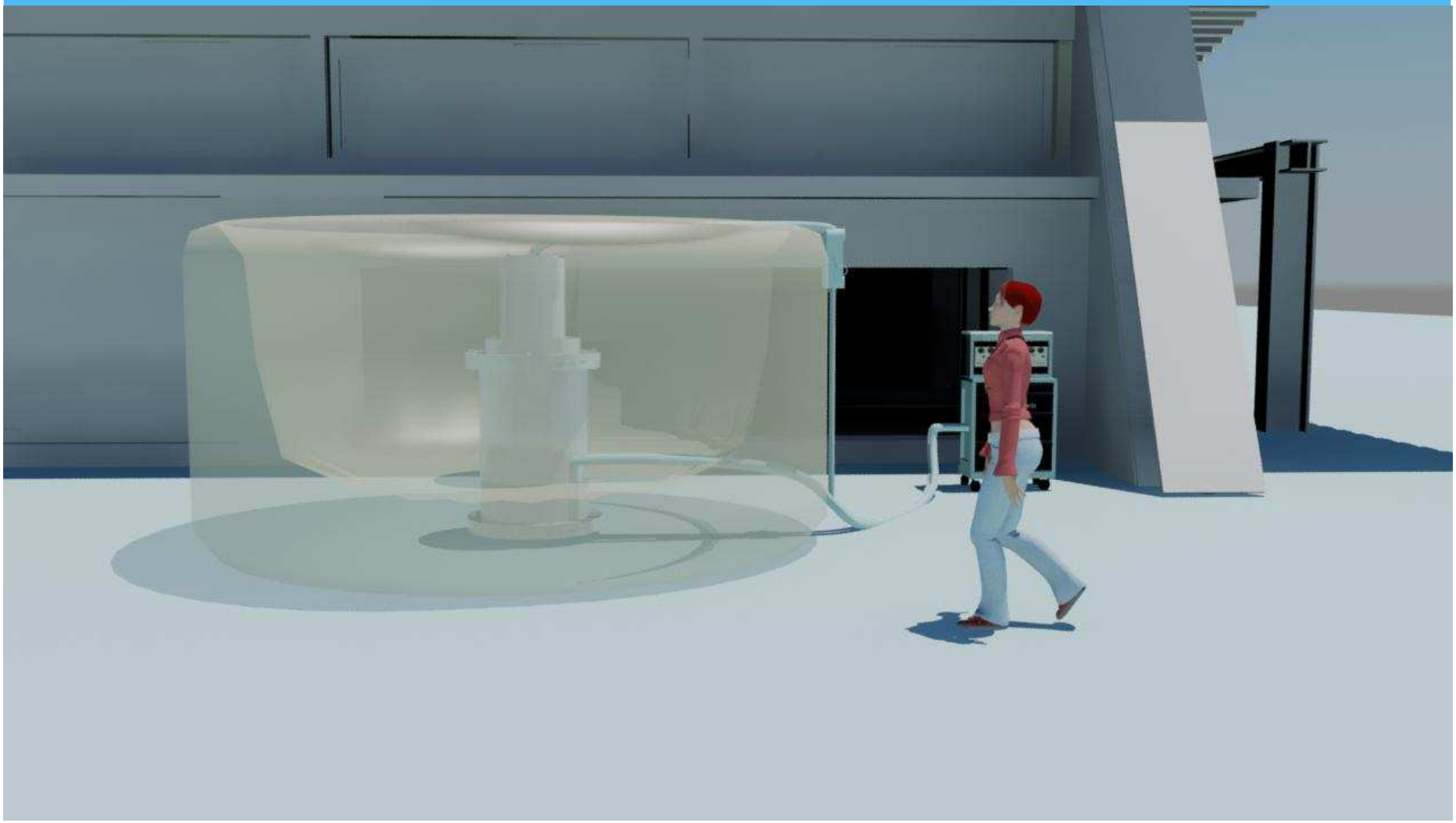
Overall Concept

Envisaged Industrial Application (lead removed)

Overall Concept

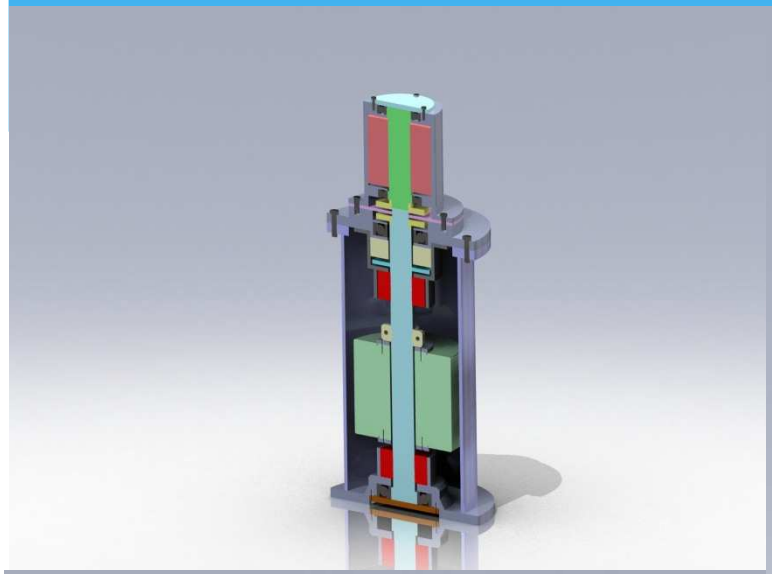
General Scale Visualisation

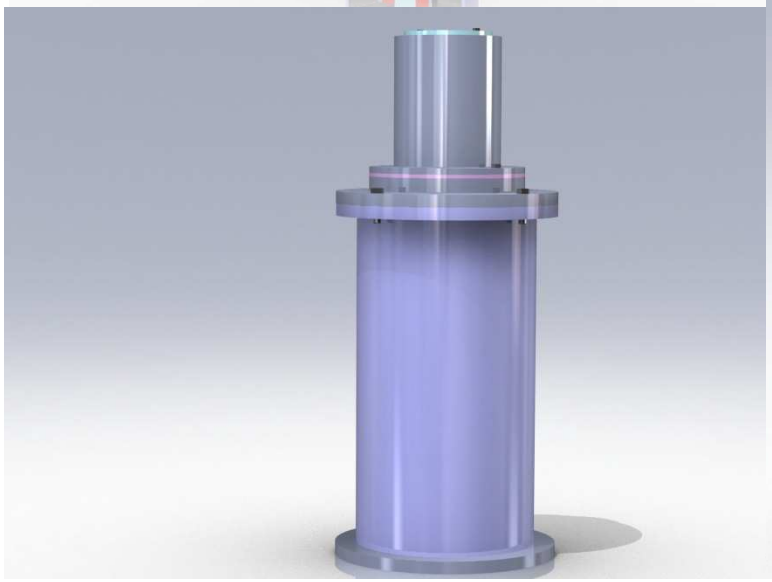
Overall Concept: Industrial

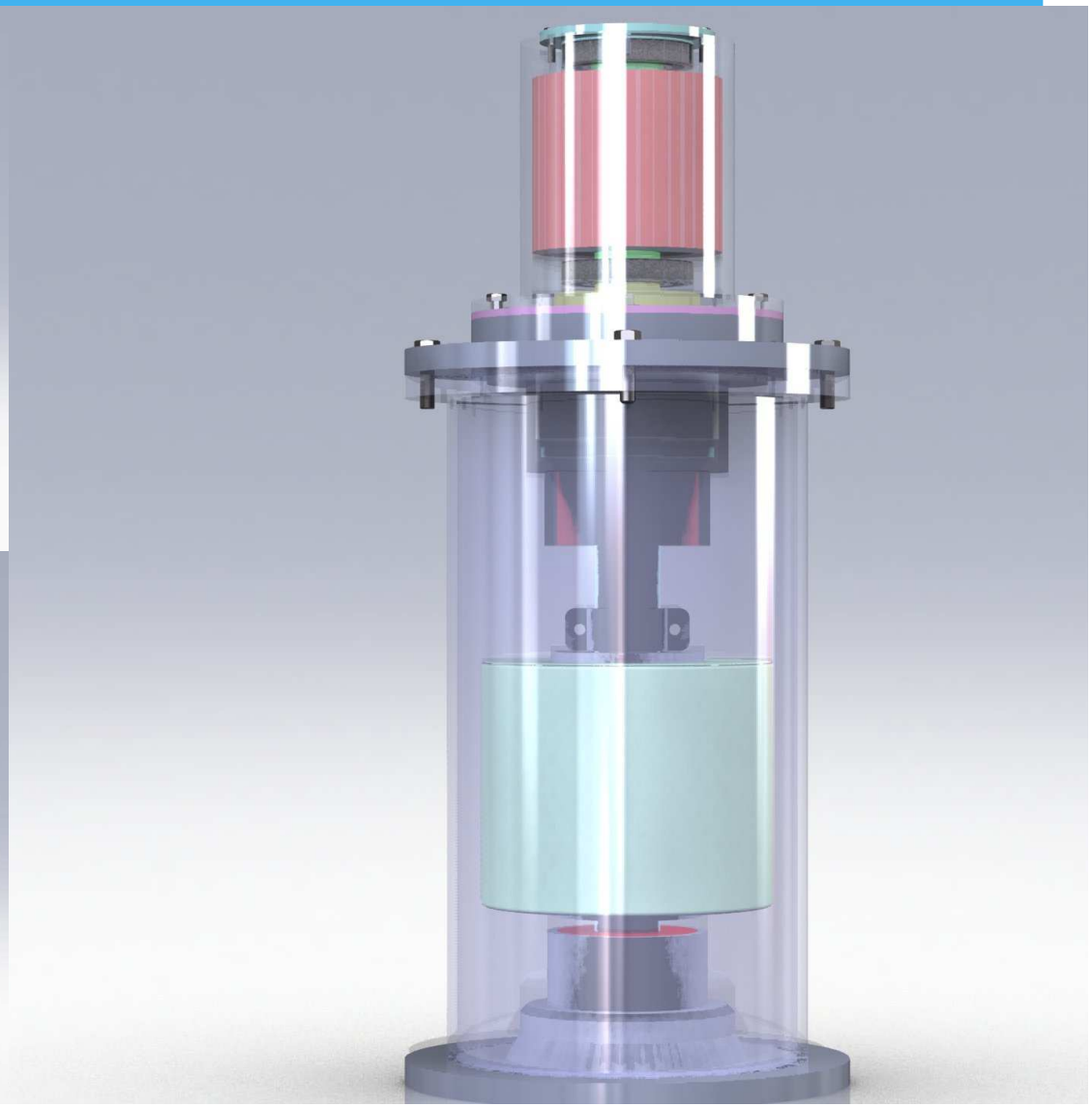


Overall Concept – Solid

Visualisation of the Kinetic Energy Storage Device

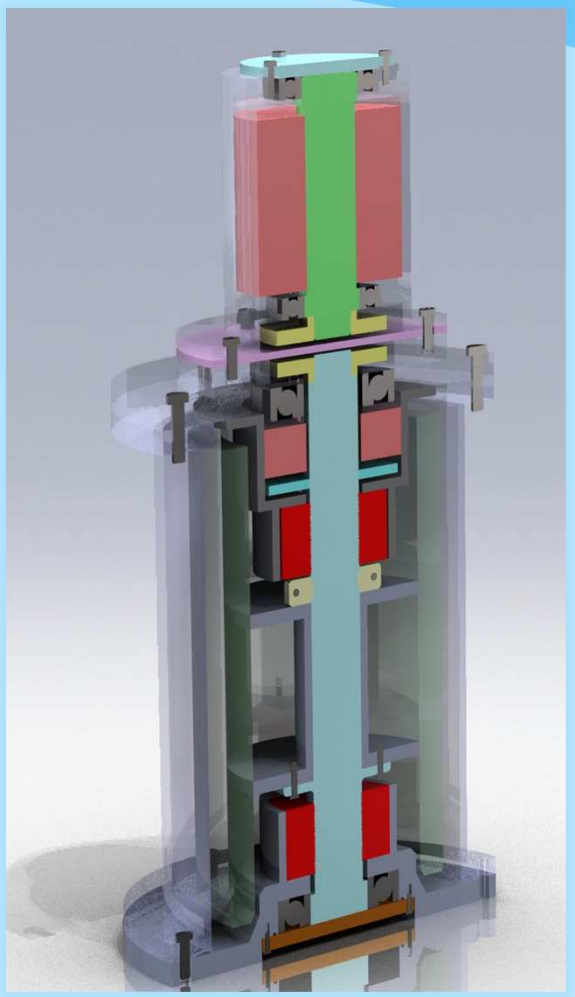






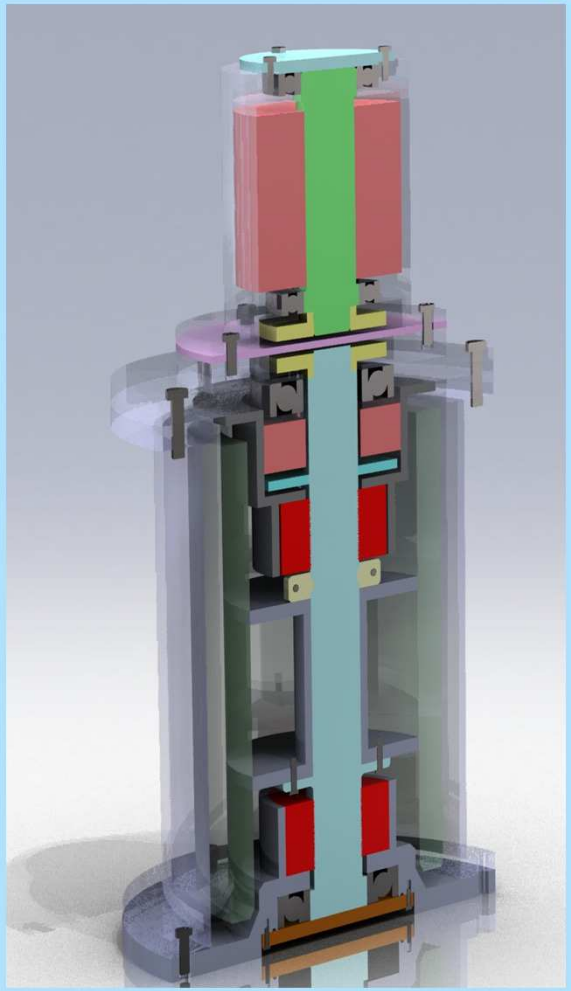
Overall Concept - Hollow

Visualisation of the Kinetic Energy Storage Device



Overall Concept

Visualisation of the Kinetic Energy Storage Device



Work Required to Progress the Project

* Finite element stress analysis vacuum chamber
* Mag/Lev radial bearing design
* Mag/Lev axial bearing design
* Control system for magnetic levitation bearings
* Machine monitoring system
* Design and manufacture of motor / generator set
* Control system for the motor / generator set
* Stress analysis of rotors for burst limitation
* Fluid flow analysis within the chamber
* Vacuum pump and equipment selection
* Rolling element bearing design and selection
* Vacuum casing design
* Explosion containment system design
* Foundations design
* Selection of materials

Questions?