FROM RESEARCH TO INDUSTRY

Madmax Collaboration Meeting
CEA magnet activities status

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CEA – MPI contract

Technical offer:

- Has been updated after the negotiations phase with MPI.
- 3 studies has been transformed in optional studies like “NbTi magnet concept design” and “Conductor detailed specification”

Financial offer:

- An effort has been made by CEA on the man power rate to reduce the overall project cost

Legal part:

- After several months of legal discussions, all the points of the contract has finally been agreed (last week) by both CEA and MPI

The contract is presently in the signature process in both MPI and CEA → should be officially signed in the days/weeks coming → The work will actively begin from now in CEA

Update of the technical specifications

Since the July 2017 kick off meeting:

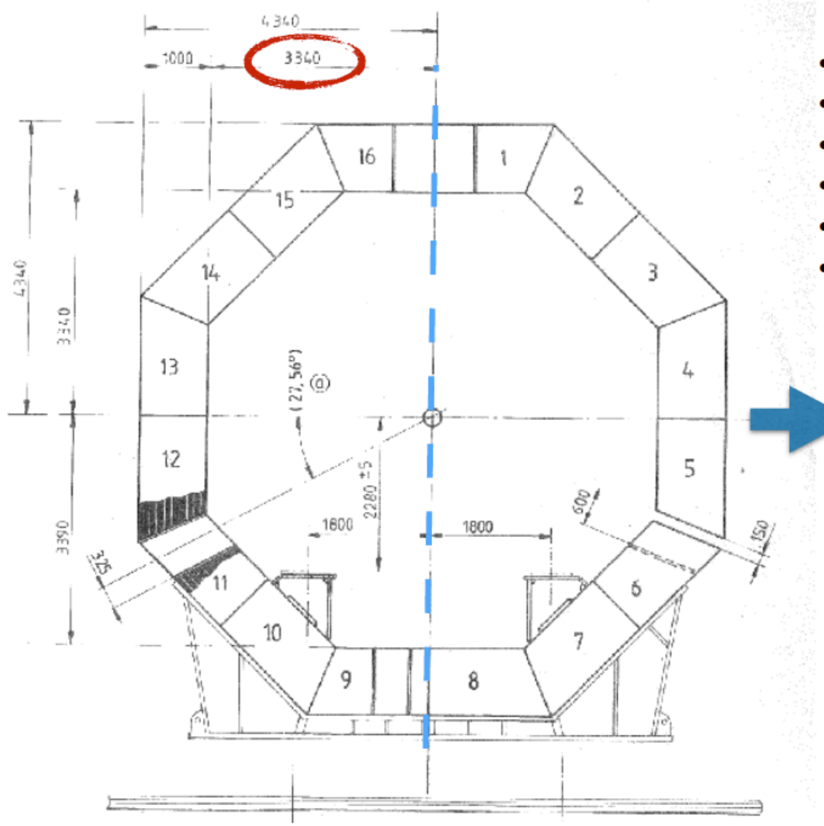
- Main specifications of the magnet have been discussed such as:
  - The main magnetic field and stray field
  - Mechanical interfaces with the booster
  - Cryogenics supply

- Main magnetic field numerical specifications have been updated by CEA to fit the $B^2A = 100\ T^2m^2$ FoM

	Config 1	Config 2	Config 3
Diameter	1 m	1.25 m	0.75 m
Old B field specifications	*10 T*	*8 T*	*13 T*
New B field specifications	**11.3 T**	**9 T**	**15 T**

- The possibility to use the H1 iron yoke will be integrated in the design strategy

The H1 magnet yoke



- 60 cm thick stainless steel
- inner radius 3.3 m
- divided in two vertical halves
- mounted on movable rails
- can be opened to access inner volume
- 2 m movement in ~ 20 min.

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Work plan (2 next months): operating margins

- **Parameters to be fixed (usual examples - not Madmax values) :**
  - Temperature margin : > 1 K
  - Load line margin against critical current : > 15 %
  - Mechanical maximum stress : < 180 MPa in Rutherford/Copper conductors AND < 660 MPa in Cable In Conduit Conductor with SS jacket
  - Hot spot temperature : between 100 K and 300 K depending on magnets
  - Maximum discharge voltage : higher than 2 kV induces technological complications and risks
  - Maximum allowable pressure : < 20 bar

- **Define the main operating margins :**
  - Optimized for the Madmax magnet design
  - Close enough to the state of the art to ensure a “safe” design

Work plan (2 next months): magnet pre-study

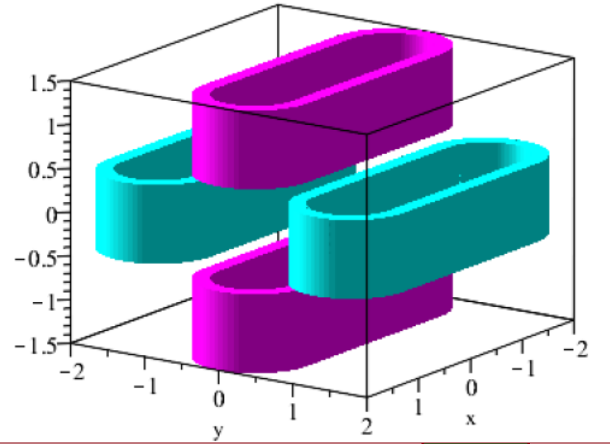
- **Magnet pre-study:**
  - Evaluate different magnet types / magnetic configurations
  - Evaluate different shielding concepts (including the H1 yoke)

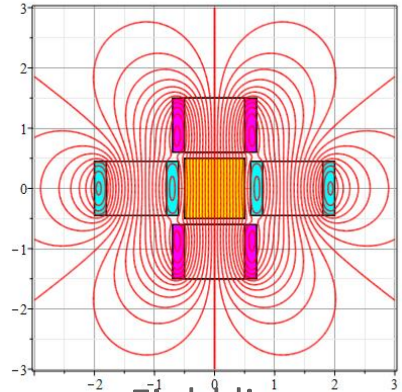
- **Optimization process:**
  - Optimize the field quality in the Oxy plan (+/- 5 % in the Madmax specification)
  - Minimize the peak field on the conductor
  - Fit with the stray field specification (< 3 mT at 10 m of the magnet)
  - Minimize the conductor/magnet volume → roughly proportional to the cost

- **In order to take into account the H1 yoke in the concept strategy, three magnet types / configurations can be added to the first CEA proposal:**
  - 4 racetrack coils actively shielded magnet (first CEA proposal)
  - Usual Cos Theta dipole accelerator magnets (passive shielding)
  - Usual Block dipole accelerator magnets (passive shielding)
  - Canted Cosine Theta “new” magnets (passive shielding)

- **First evaluations have been made thanks to 2D/3D analytical equations and engineering tools (no use of 3D modeling tools)**

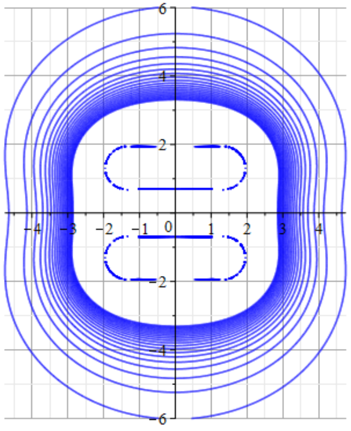
First evaluations: 4 racetracks actively shielded dipole





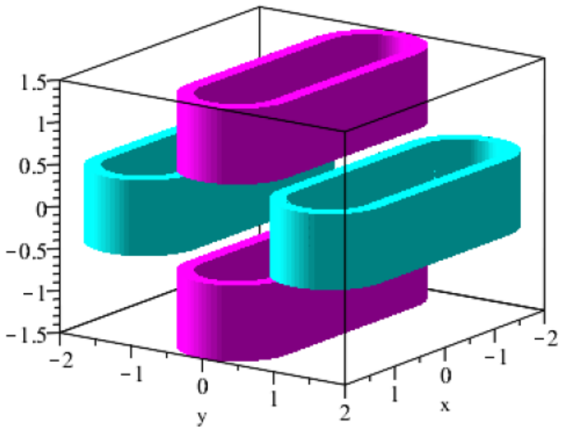
Field lines

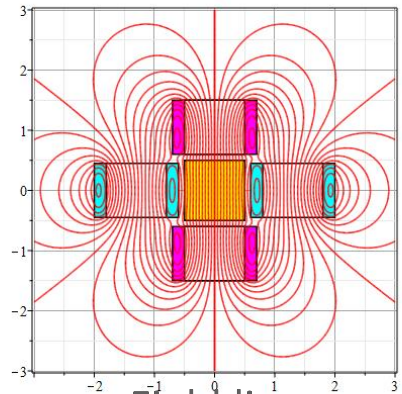
Stray field
(0.5 T – 25 mT)



Field specification	+ +	**10 T in 1 m^2 feasible**
Peak field	-	
Stress analysis	+	**~ 600 MPa – border limit but possible with CICC**
Conductor design	+	**Possible with CICC design**
Mechanical layout	+ +	**Planar racetracks & “far” form each other**
Superconductor	-	
Stray field	+ +	**Active shielding fits with stray field specification (first idea: better than several hundreds tons of iron)**
Compatibility H1 yoke	- -	
Magnet volume	+	**Optimized for active shielding but still big (6 m^3 of conductor)**

First evaluations: 4 racetracks actively shielded dipole





Field lines

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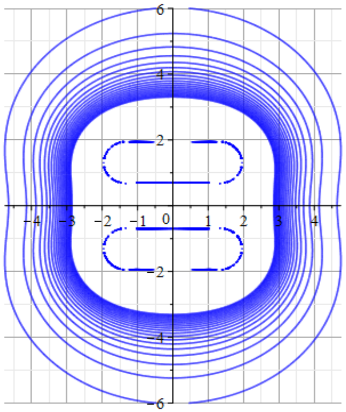
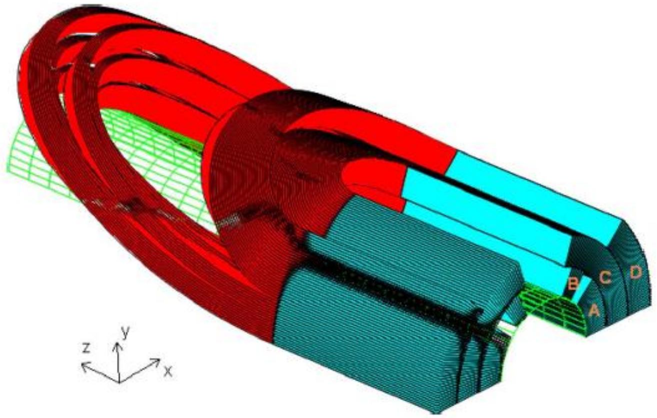


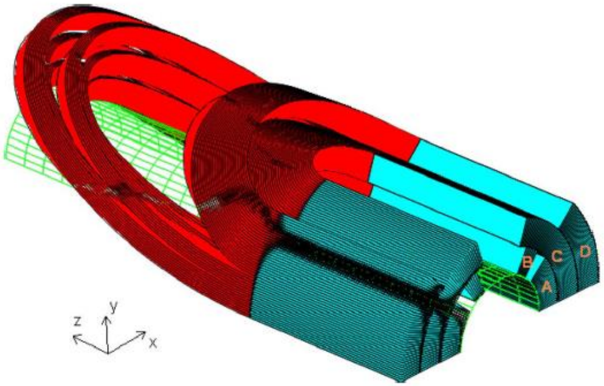
Field specification	+ +	
Peak field	-	**15.7 T is quite high → should be optimized**
Stress analysis	+	
Conductor design	+	
Mechanical layout	+ +	
Superconductor	-	**Only feasible with Nb3Sn due to high peak field**
Stray field	+ +	
Compatibility H1 yoke	- -	**Useless yoke / Could be too big for the H1 yoke (already 4mx3m with no layout, shields and cryostat) / Shielding coils contribute to 40 % of the main field so cannot be just taken off from the design**
Magnet volume	+	

First evaluations: cos theta dipole



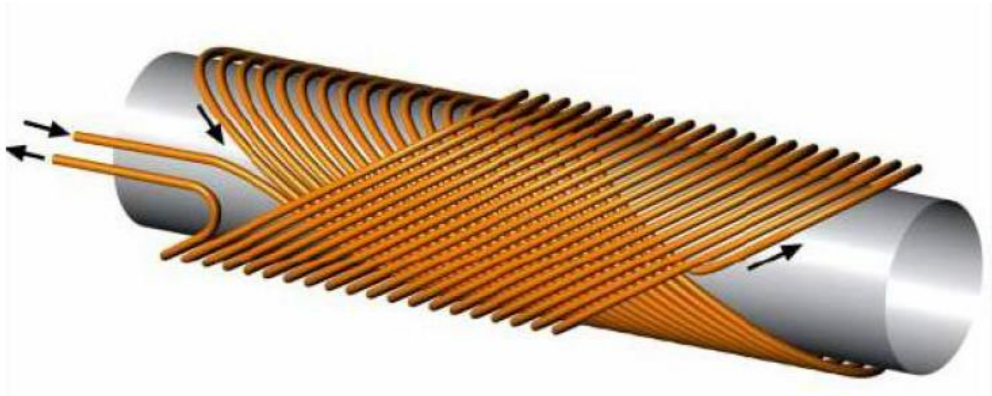
Field specification	+ +	10 T in 1 m² feasible
Peak field	++	Usually around 2% higher than bore field
Stress analysis	- -	
Conductor design	- -	
Mechanical layout	- -	
Superconductor	+ +	Could be feasible with NbTi due to low peak field
Stray field	- -	
Compatibility H1 yoke	+ +	Compact so OK with yoke dimension + needs shielding
Magnet volume	+ +	Compact and close to bore → < 3 m³ of conductor

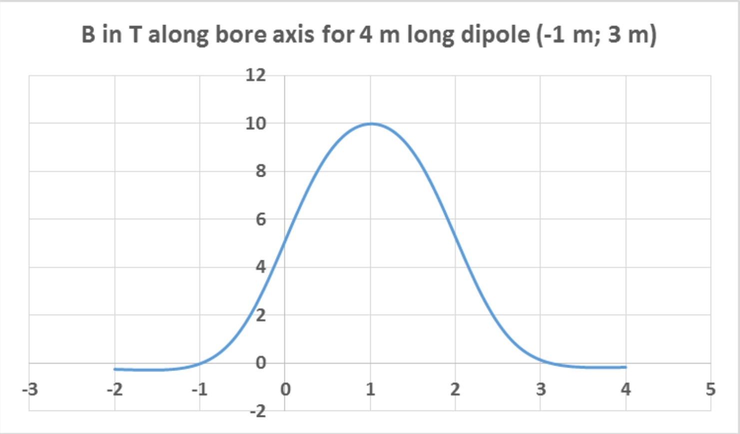
First evaluations: cos theta dipole



Field specification	+ +	
Peak field	++	
Stress analysis	- -	~ 400 MPa cannot be afforded by Rutherford cable. No Cos theta magnet ever built with CICC
Conductor design	- -	First protection estimation needs conductor dimension much higher than what Rutherford cabling technology can do
Mechanical layout	- -	Would need more than 10 layers VS usual number is 2-4
Superconductor	+ +	
Stray field	- -	No shielding
Compatibility H1 yoke	+ +	
Magnet volume	+ +	

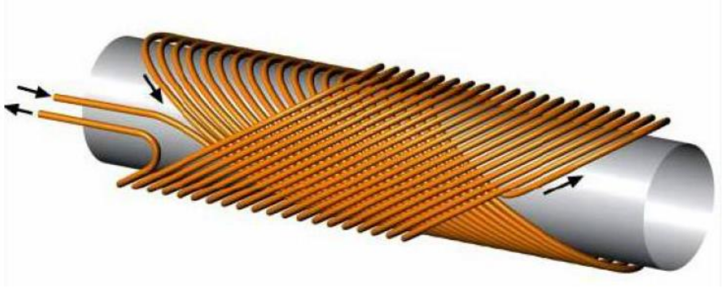
First evaluations: canted cosine theta dipole

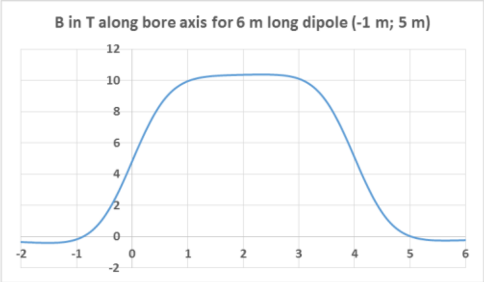


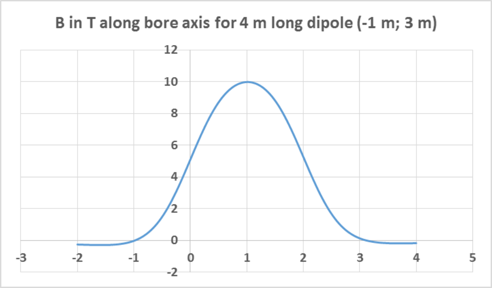


Field specification	- -	
Peak field	+	Better than the 4 racetrack coils design
Stress analysis	- -	
Conductor design	- -	
Mechanical layout	+ +	Cylinder shape and conductor ribs makes it easier
Superconductor	+	Could be feasible with NbTi due to lower peak field
Stray field	- -	
Compatibility H1 yoke	-	
Magnet volume	- -	

First evaluations: canted cosine theta dipole

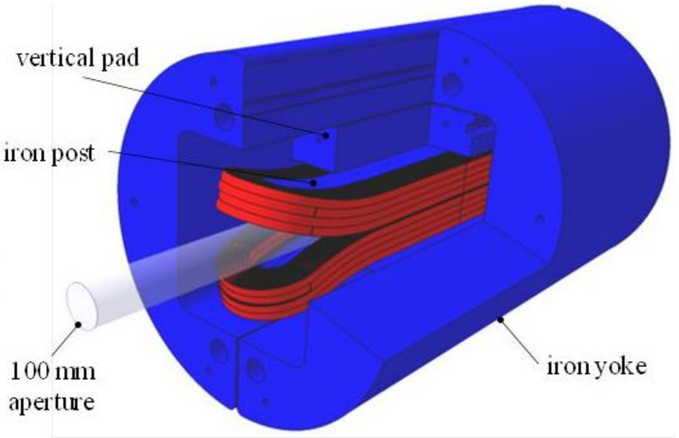


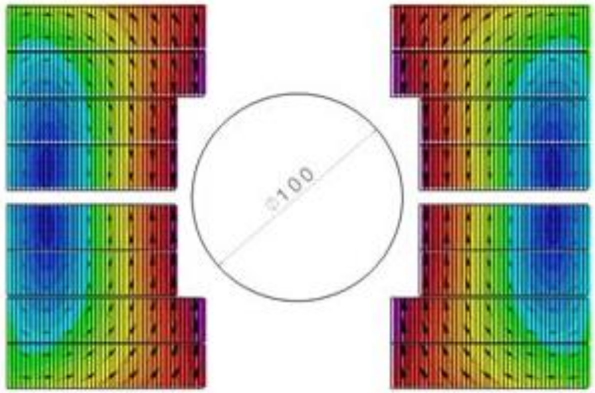




Field specification	- -	Loss of 50 % of the FoM in the 2 m of magnetic length (on 4 m)
Peak field	+	
Stress analysis	- -	~ 400 MPa cannot be afforded by Rutherford cable. No CCT magnet ever built with CICC
Conductor design	- -	First protection estimations needs conductor dimension much higher than what Rutherford cabling technology can do
Mechanical layout	+ +	
Superconductor	+	
Stray field	- -	No shielding
Compatibility H1 yoke	-	Too long if we want to fit to the axial bore field specification
Magnet volume	- -	Needs > 6 m long dipole to have “constant” field in the 2 m magnetic length / Part of the volume is useless due to the axial solenoidal compensated field

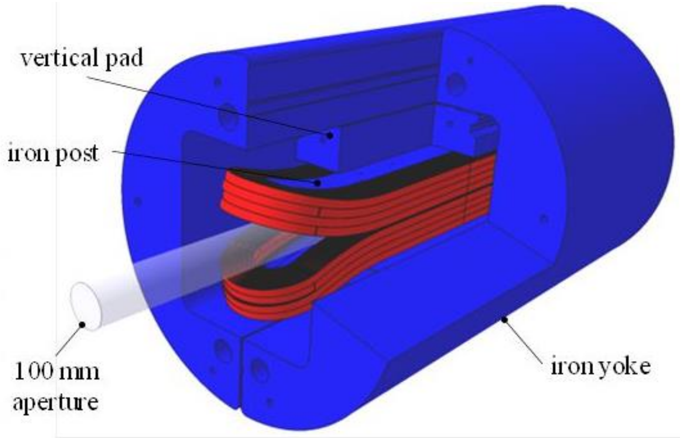
First evaluations: block dipole

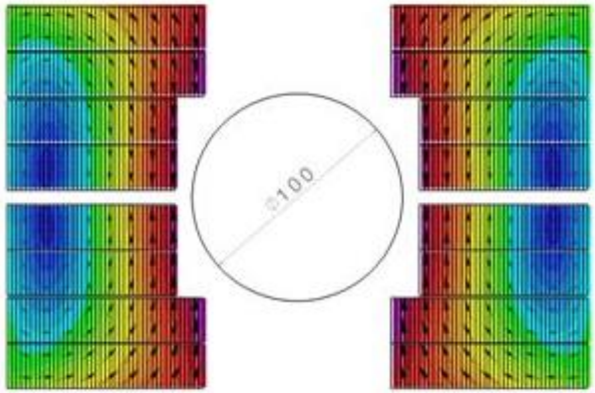




Field specification	+ +	10 T in 1 m² feasible
Peak field	++	Usually around 5% higher than bore field
Stress analysis	+	~ 400 MPa and could be less if we increase the magnet volume
Conductor design	+	Compatible with CICC technology used in fusion magnets
Mechanical layout	- -	
Superconductor	+ +	Could be feasible with NbTi due to low peak field
Stray field	- -	
Compatibility H1 yoke	+ +	Compact so OK with yoke dimension + needs shielding
Magnet volume	+ +	Compact and close to bore → < 3 m³ of conductor

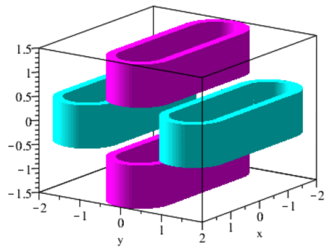
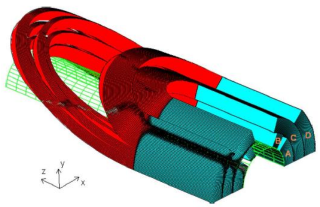
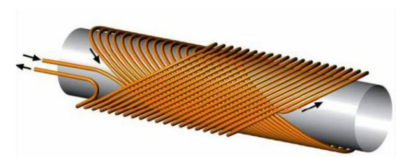
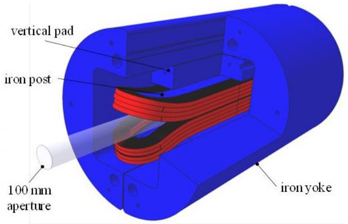
First evaluations: block dipole





Field specification	+ +	
Peak field	++	
Stress analysis	+	
Conductor design	+	
Mechanical layout	- -	Coils' ends mechanics and bending + stress management are challenging points
Superconductor	+ +	
Stray field	- -	No shielding
Compatibility H1 yoke	+ +	
Magnet volume	+ +	

First evaluations summary

Field specification	+ +	+ +	- -	+ +
Peak field	-	++	+	++
Stress analysis	+	- -	- -	+
Conductor design	+	- -	- -	+
Mechanical layout	+ +	- -	+ +	- -
Superconductor	-	+ +	+	+ +
Stray field	+ +	- -	- -	- -
Compatibility H1 yoke	- -	+ +	-	+ +
Magnet volume	+	+ +	- -	+ +
First order conclusions that will be confirmed by further detailed studies	**Encouraging solution that has to be optimized if shielding is required**	**Seems not feasible due to technological limits (conductor , layers, …)**	**Seems not feasible due to design, techno and cost limits (field, cond, vol)**	**Encouraging solution if the H1 yoke fits with the stray field requirements**

Conclusion

- **The Madmax contract is in the signature process and the magnet study will now really begin in CEA**

- **As the magnet specification is challenging all ideas should be raised and evaluated**

- **Using the H1 yoke or not is a very important configuration parameter that can completely change the design and the cost**

- **A feasible magnet design is not only a theoretical magnetic design but a mix between a certain number of scientific, engineering and technological considerations → we have two encouraging designs → The best design could be one of the usual ones or a hybrid mix of several concepts**

- **Even if Madmax is a big challenging magnet, we stay confident in our capacity to realize it (R3B ~ 50 tons / Iseult ~ 130 tons / Madmax ~ ☺ ?)**

Thank you for your attention