- What I hope to convey to you is that rare earths are uniquely required for high performance magnets.

- First a quick introduction to Arnold – the company I've worked for since 1992.
- Arnold's history in magnetics and magnetic materials extends back to 1895 and has included almost every commercially supplied permanent and soft magnetic product.
- Today Arnold is focused on: SmCo, Alnico and bonded permanent magnets; precision thin metals – both magnetic and non-magnetic; magnetic assemblies for motors, magnetic levitation, sensing and separation technologies; and most recently we have responded to customer requests to develop and supply ultra-high performance permanent magnet motors for select applications.

Agenda

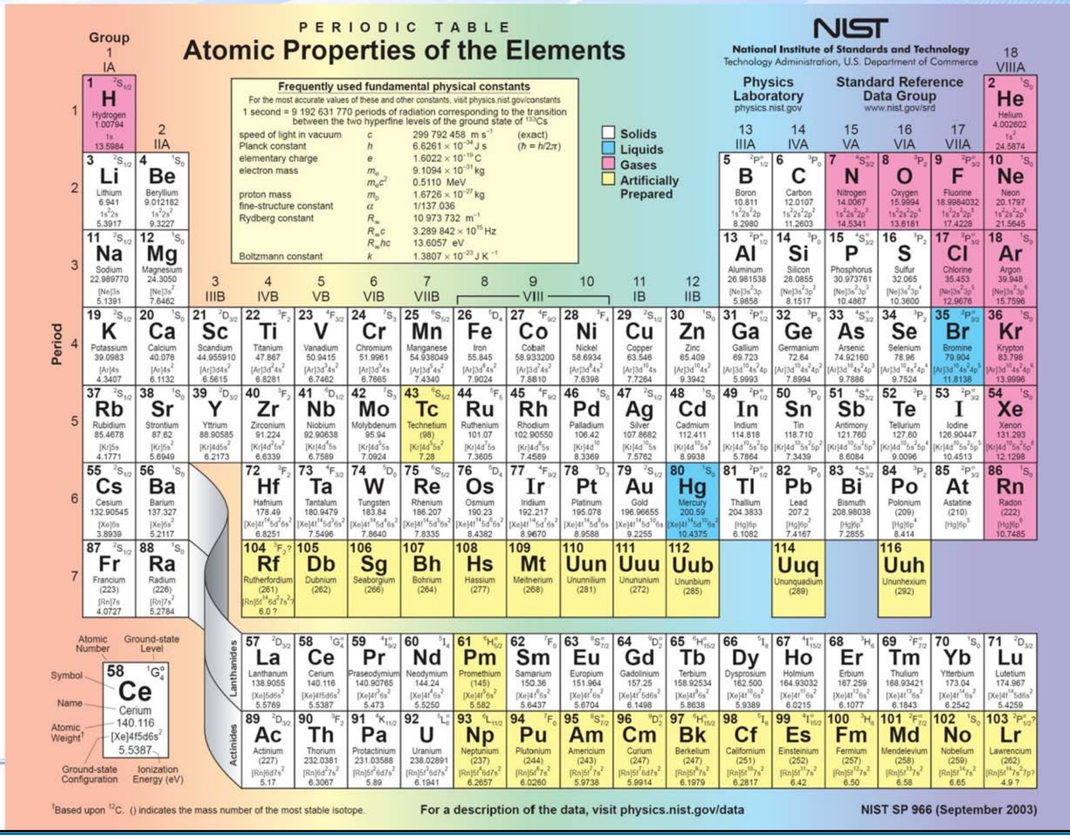
- **What makes rare earth elements special?**
- Small applications
- Powerful applications

© Arnold Magnetic Technologies

ARNOLD MAGNETIC TECHNOLOGIES

- Let’s start by answering this question: What makes rare earth elements so special?

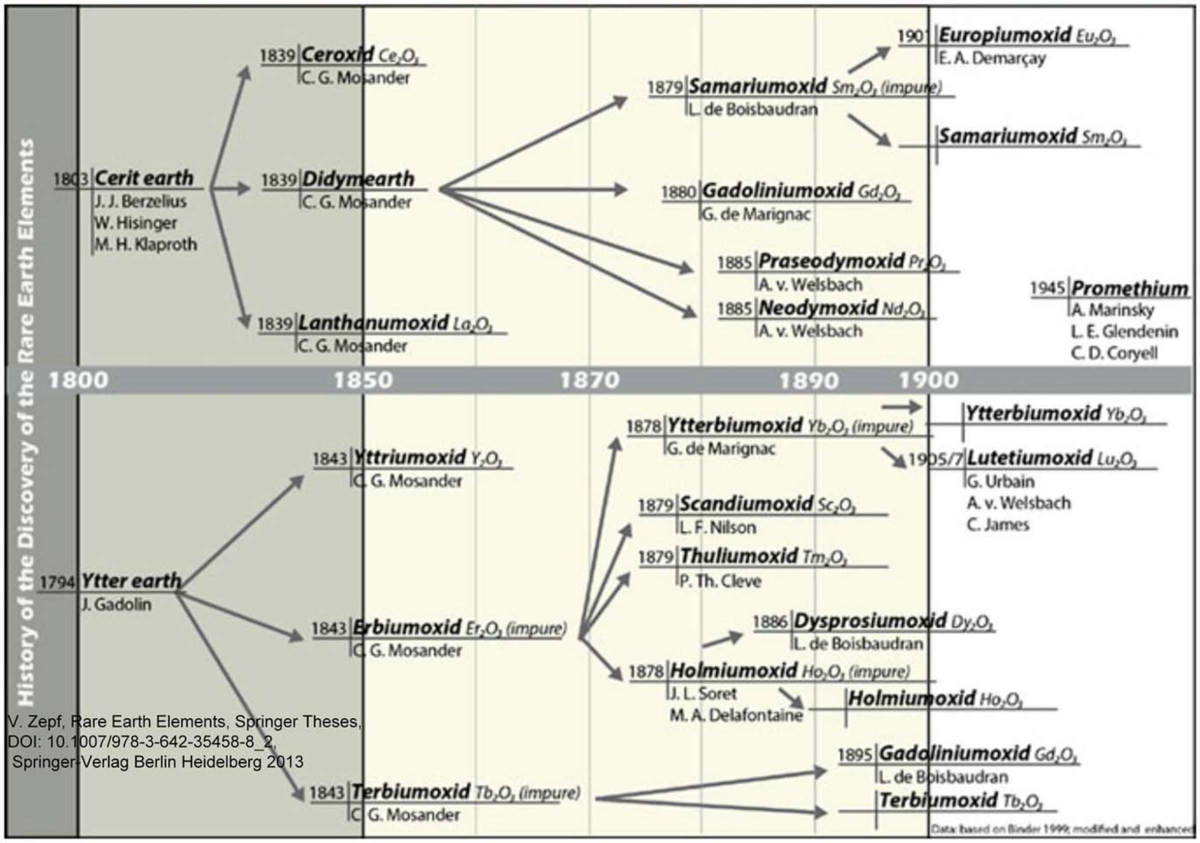
The rare earth elements



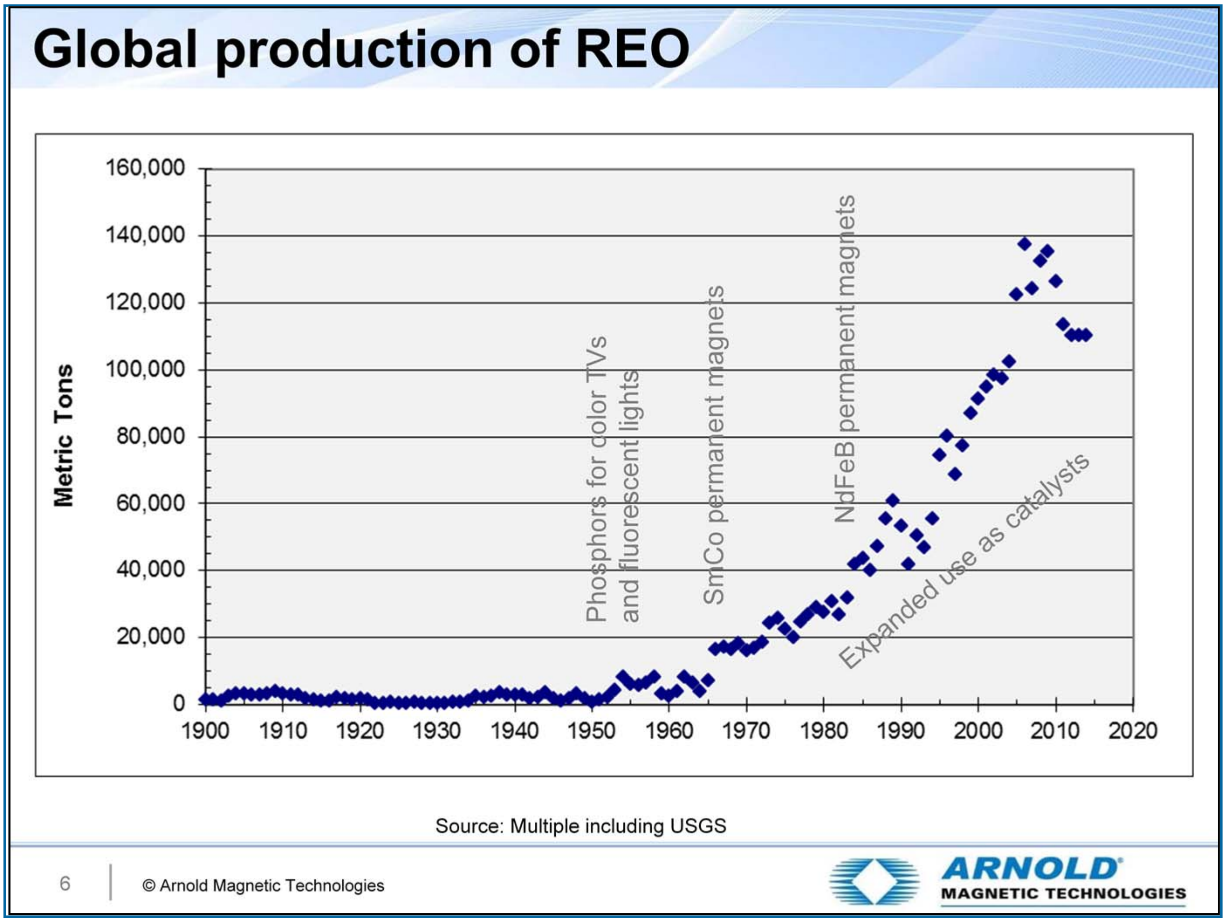
4

- The rare earth elements consist of the 15 lanthanide elements (lanthanum to lutetium) plus yttrium and scandium.
- Yttrium and scandium are directly above lanthanum in the periodic table and have chemical properties that are very similar to the lanthanides – that is why they are usually included with them.
- Note cesium and barium precede lanthanum in row 6 of the periodic table and that hafnium, element number 72, continues row 6 right after lutetium, the lanthanide with the highest atomic number, 71.
- Note too, row 4 of the table which contains the transition elements including iron, cobalt and nickel. We'll be making some comparison between the two groups of elements in later slides.

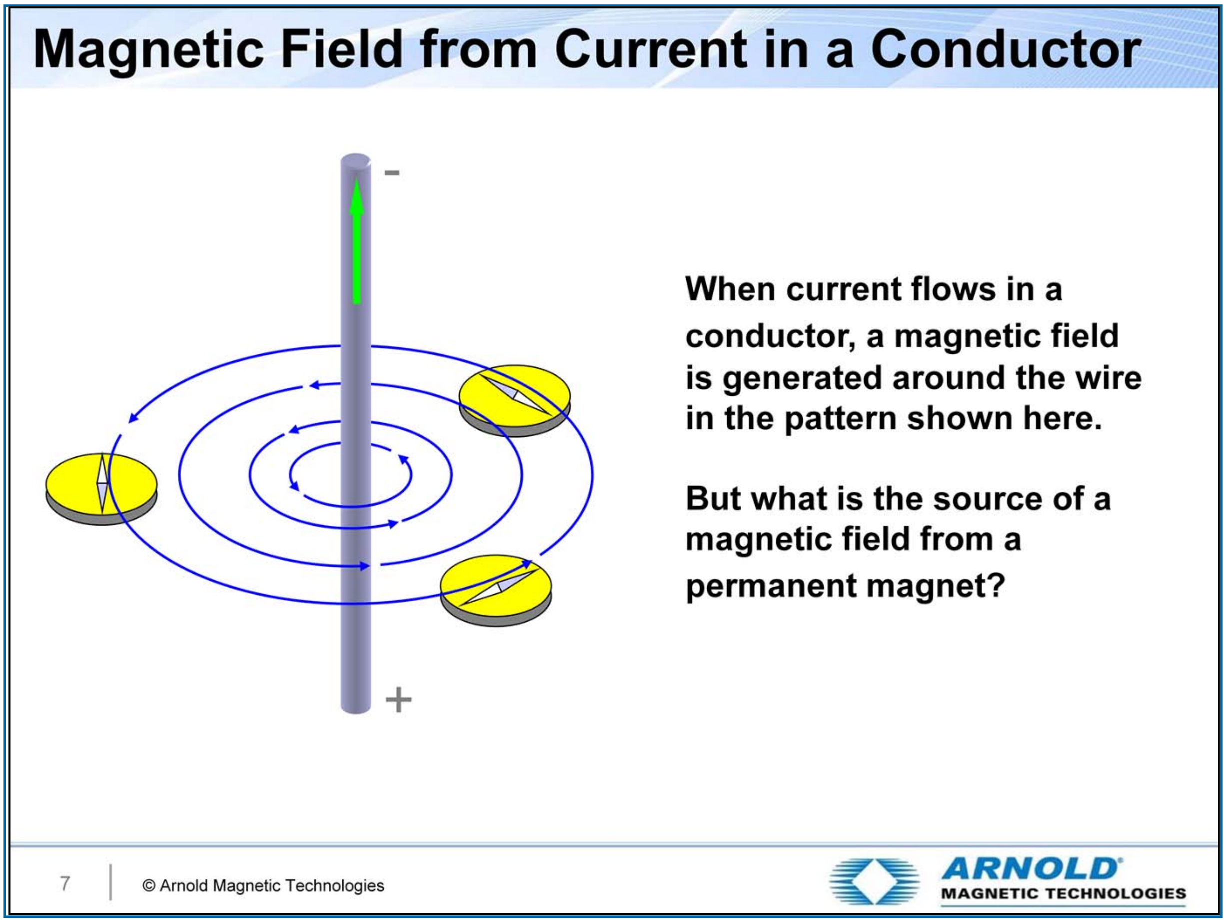
REEs: discovery and separation timeline



- Rare earth elements (REEs) have considerable chemical similarities thus making them difficult to separate from each other.
- That is one reason they were late in being discovered, isolated and incorporated in alloys and compounds.
- In this table from Volker Zepf, we see that some separated materials were found to comprise multiple elements and required further separation.
- The last stable rare earth element, lutetium, was separated in 1905-7.
- Promethium is a highly unstable and far more rare element and was not identified until 1945-7.
- It is my contention that REEs should be considered “modern materials” as their commercial use was not common until the late 1950s.



- The commercial production of rare earth elements (quantities expressed as oxides) was small until the 1950s and has grown rapidly since then with the discovery of more uses and expansion of existing ones.



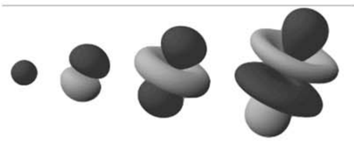
- Since this talk is focused on the use of REEs in the field of magnetism, the first issue we should deal with is why REEs are so important.
- We will start with a very basic introduction to (electro)magnetism.
- Electrons flowing in a conductor generate a magnetic field around the conductor as shown by the alignment of these compasses in proximity to the current-carrying wire.
- Summary: moving electrons generate magnetic fields!

Origin of the Field - 1

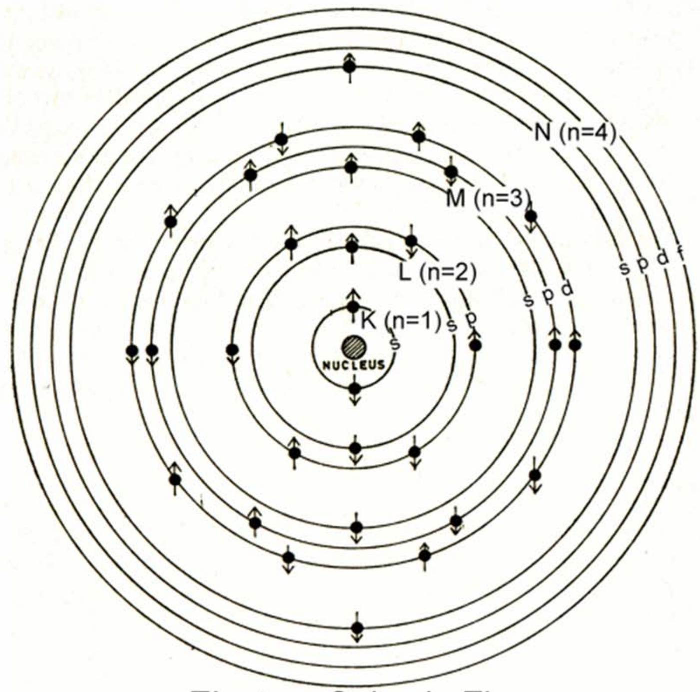
- A permanent magnet (PM) produces a magnetic field without external assistance
- This field is derived from the electron spin in specified electron orbitals and occurs naturally in Fe, Ni and Co

Conceptual →

Per quantum mechanics ↓



1s 2p 3d 4f



Electron Spins in Zinc

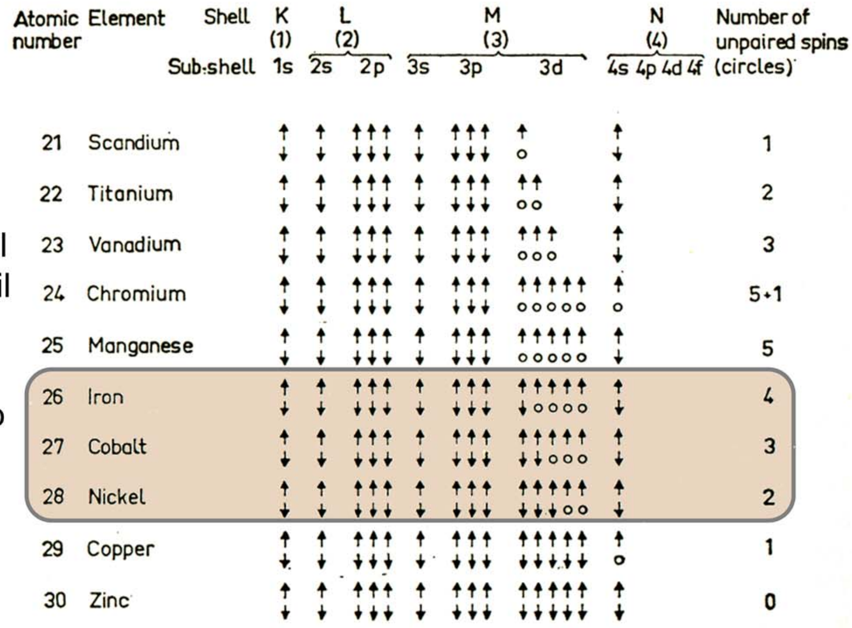
© Arnold Magnetic Technologies

ARNOLD® MAGNETIC TECHNOLOGIES

- Atoms of a material consist of numerous entities including protons, neutrons, mesons, gluons, etc. - and electrons.
- Electrons exist in spatial orbit around the nucleus. The exact positions are beyond our ability to detect, but quantum mechanics allows us (or capable physicists) to calculate a probability of a location. These probability fields have unusual shapes as shown by a few illustrations at the bottom left of the slide.
- For simplicity, we will use the illustration to the right which shows a nucleus at the center surrounded by groups of rings.
- Each group, or “shell”, has a name, a letter, starting with “K” and continuing with L, M, N, O, P, etc.
- Each shell is also assigned a principle quantum number starting with 1 for the K shell, 2 for the L shell, etc.
- Within each shell are sub-shells, called orbitals, designated by the letters s, p, d, and f (all lower case letters).
- Each orbital can contain a fixed maximum number of electrons. The s orbital can contain 2, p can contain 6, d contains up to 10 and f contains up to 14.
- Electrons have “spin” designated as positive or negative and represented here by either an upward pointing arrow or downward pointing arrow.

Origin of the Field - 2

- Filling of the 3d shell doesn't proceed until the 4s shell is filled
- Incomplete filling of the 3d shell is key to magnetism

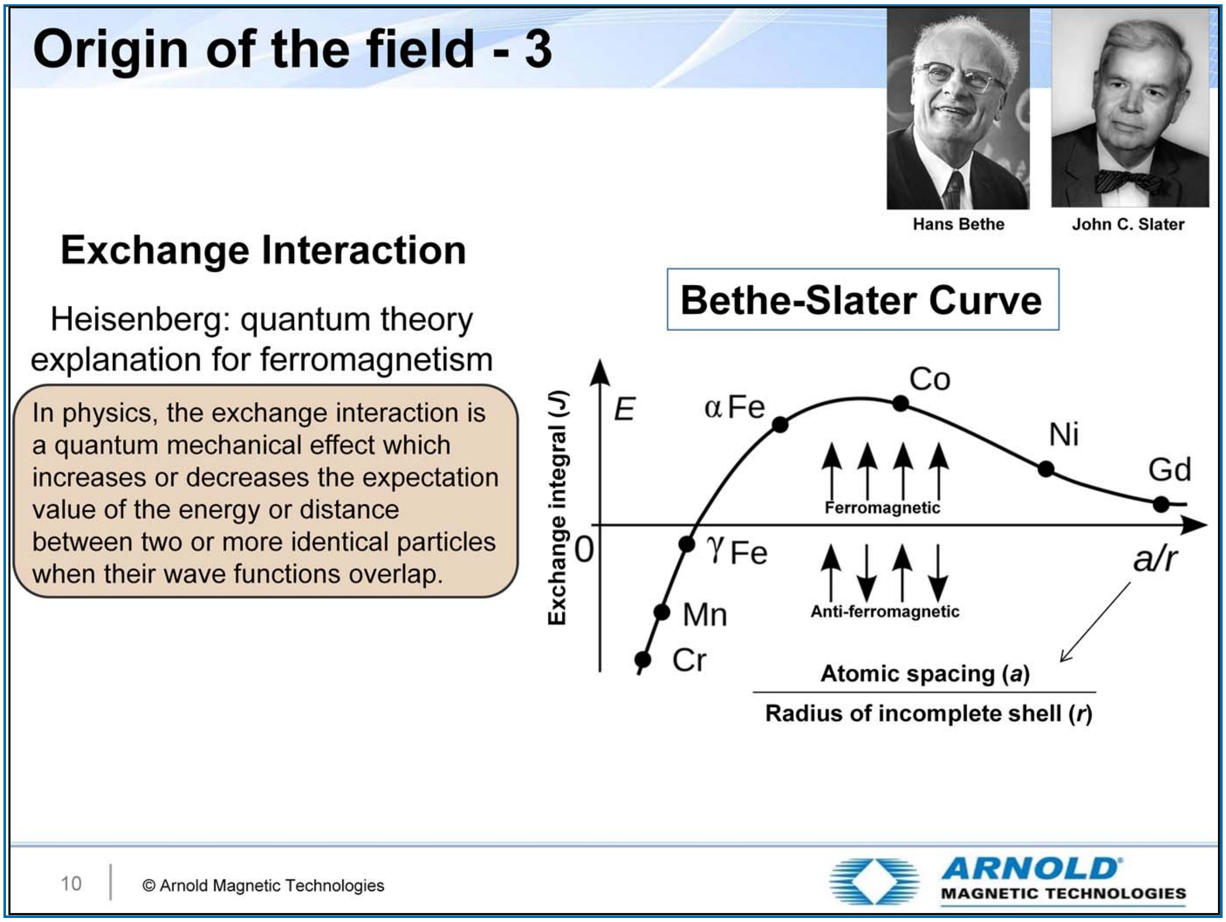


Pairing of electron spins in selected transition metal elements

© Arnold Magnetic Technologies

ARNOLD MAGNETIC TECHNOLOGIES

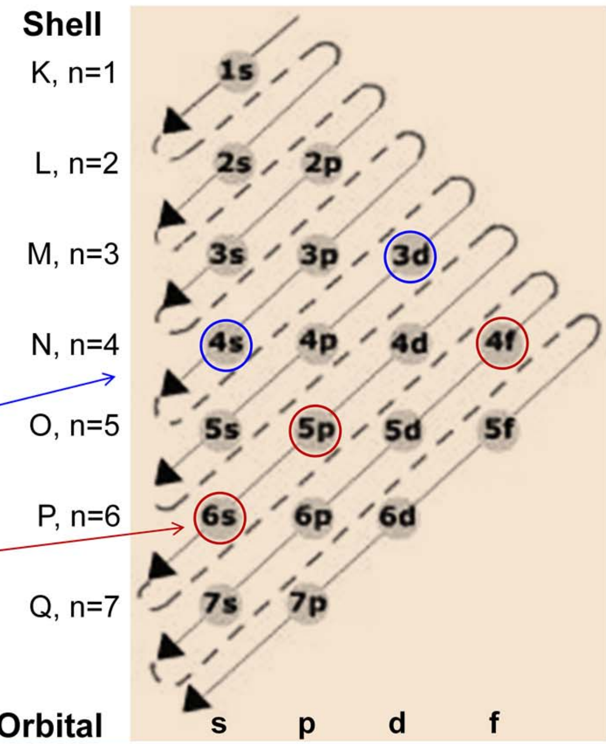
- This is an illustration of the electron arrangement for the element zinc.
- Note there are two electrons in the 1s orbital, the maximum possible number, and that one arrow is pointing up and one down.
- In other orbitals where there is a small "o" under an arrow, it indicates there is an absence of an electron resulting in a "spin imbalance".
- Where ever there is a spin imbalance, there is a net magnetic field created by the moving electron that is not "balanced" by one of opposite spin.
- The magnitude of the field can be calculated and is called the magneton – actually it is the Bohr magneton named in honor of Niels Bohr, one of the founders of quantum mechanics.
- Thus, the greater the number of spin imbalances, indicated in the right-most column, the greater the net magnetic field generated by the material.
- However, neither chromium nor manganese, for example, exhibit natural ferromagnetism. Why is that?



- Materials exist as collections of atoms – usually in a crystalline form.
- The proximity of one atom to another causes an interaction of the electrons of each atom.
- Heisenberg, using the quantum theory, in 1928 explained that as atoms with partially filled electronic shells at large distances from each other move closer to one another their shells begin to overlap and quantum mechanical exchange forces arise between the incomplete shells. The corresponding energy appears in the mathematical formulation as an "exchange integral".
- When the exchange energy is positive, as it is for Fe, Co and Ni, ferromagnetic properties are exhibited. This occurs when the atomic spacing (a) is about 3-4 times the radius of the incomplete shell (r).
- Additionally, some combinations of otherwise weak magnetic materials have strong magnetic characteristics. Examples are MnAlC and MnBi. Alloying modifies the atomic spacing between adjacent manganese atoms changing the exchange interaction for manganese, moving it from a negative value to positive and causing the material to exhibit ferromagnetism.
- Conversely, when iron transforms into a FCC crystal structure, interatomic distances cause it (gamma Fe) to become anti-ferromagnetic.
- Metallic gadolinium, a rare earth element, exhibits natural ferromagnetism.

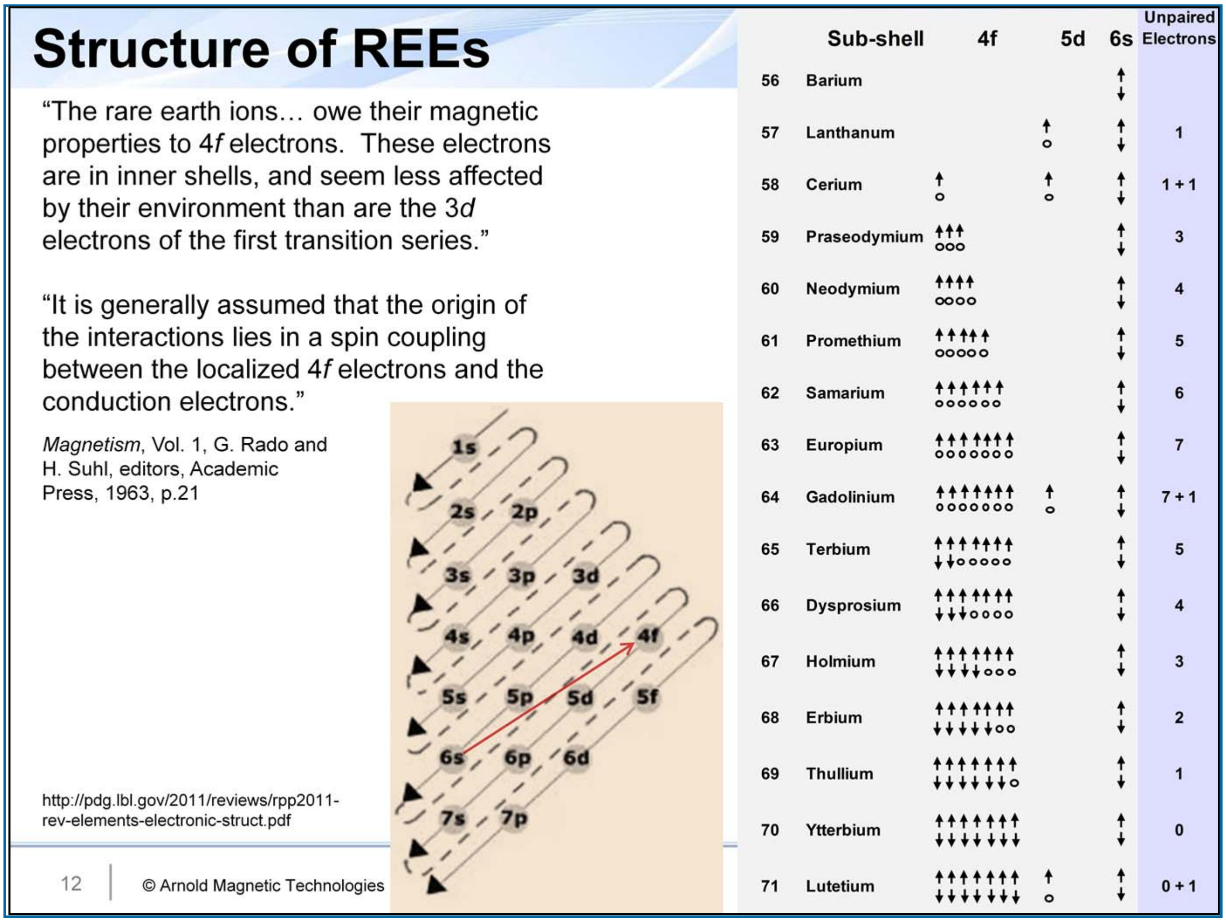
Aufbau (Madelung) Principle

- Electrons fill the orbitals starting with the lowest energy orbital
- The sequence of orbital fill follows the solid and dashed lines in this illustration
- For Fe, Co and Ni, the 4s electrons are added prior to 3d electrons
- For the rare earths, the 5p and 6s orbitals are filled prior to the 4f orbital



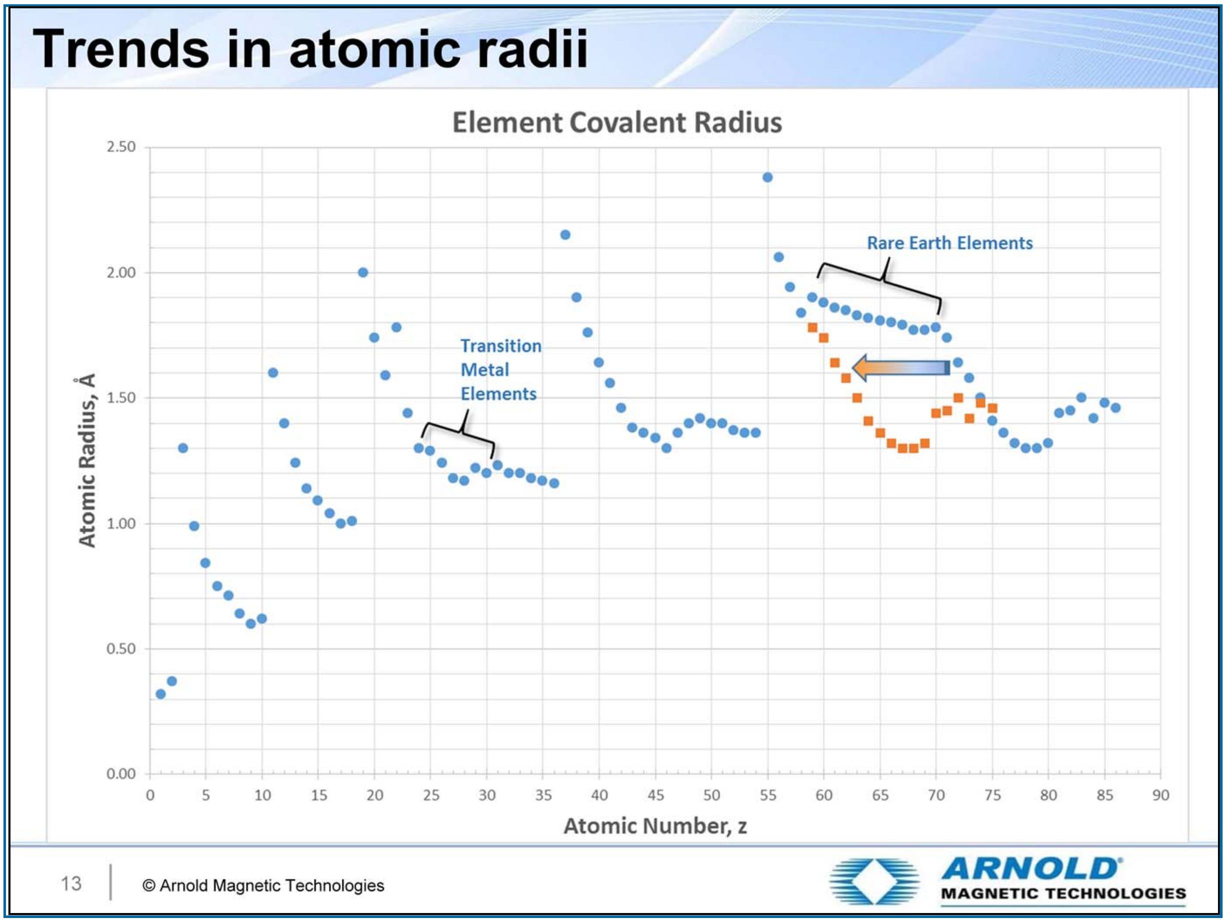
© Arnold Magnetic Technologies
ARNOLD MAGNETIC TECHNOLOGIES

- As we move to higher atomic numbers, electrons are added according to certain rules.
- These include: Hund's 3 rules, the Pauli exclusion principle, and the Aufbau principle (Madelung energy ordering rule) which incorporates Hund's and Pauli's rules.
- Simply stated, the electron arrangement that results in the lowest atomic potential energy is created first.
- This means, for many elements, adding electrons to some of the outer orbitals prior to filling the inner orbitals.

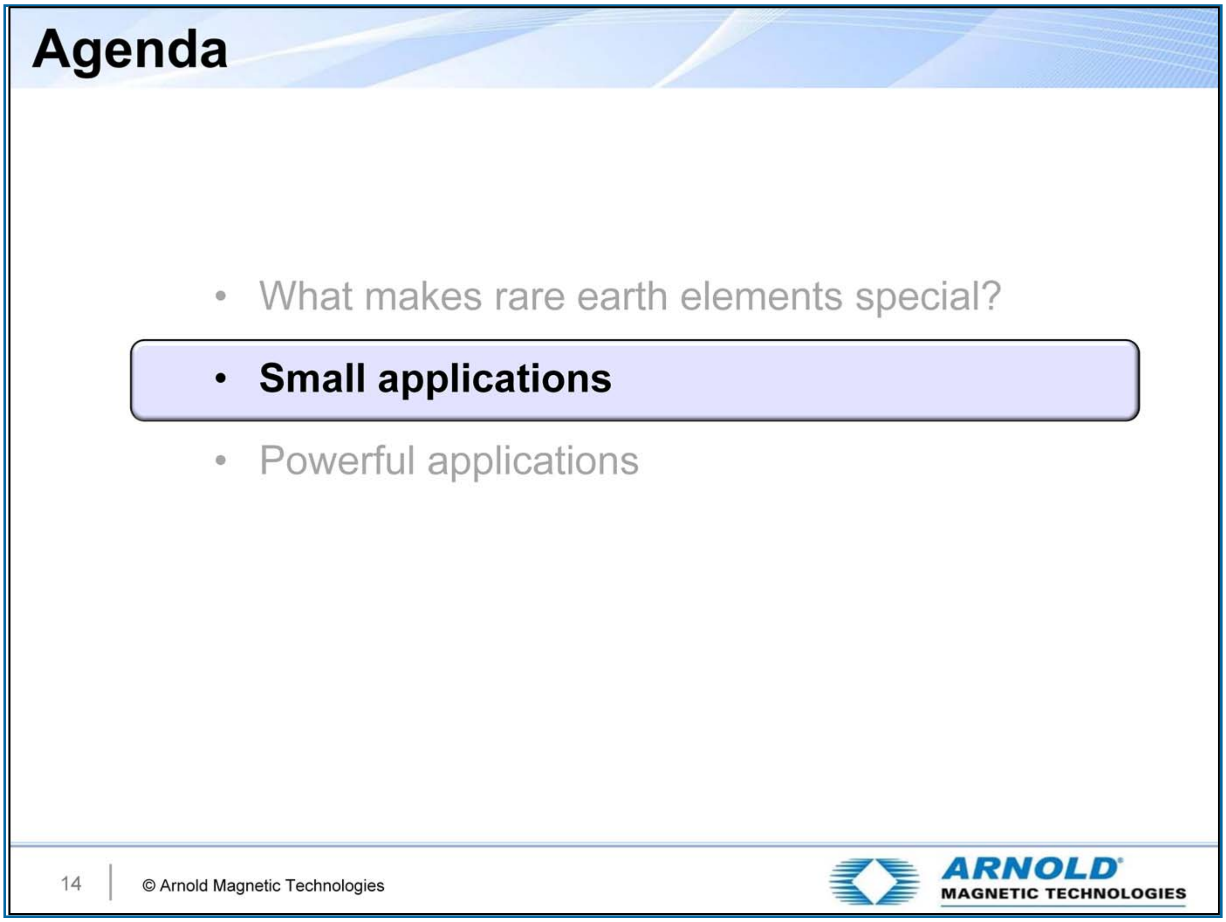


- The rare earth elements owe their magnetic properties to the 4f electrons. Unpaired electrons increase to a maximum of 7+1 for gadolinium, the only rare earth to exhibit natural ferromagnetic behavior.
- "In solid-state physics, the valence band and conduction band are the bands closest to the Fermi level and thus determine the electrical conductivity of the solid. The valence band is the highest range of electron energies in which electrons are normally present at absolute zero temperature, while the conduction band is the lowest range of vacant electronic states. On a graph of the electronic band structure of a material, the valence band is located below the Fermi level, while the conduction band is located above it. This distinction is meaningless in metals as the highest band is partially filled, taking on the properties of both the valence and conduction bands."

From https://en.wikipedia.org/wiki/Valence_and_conduction_bands

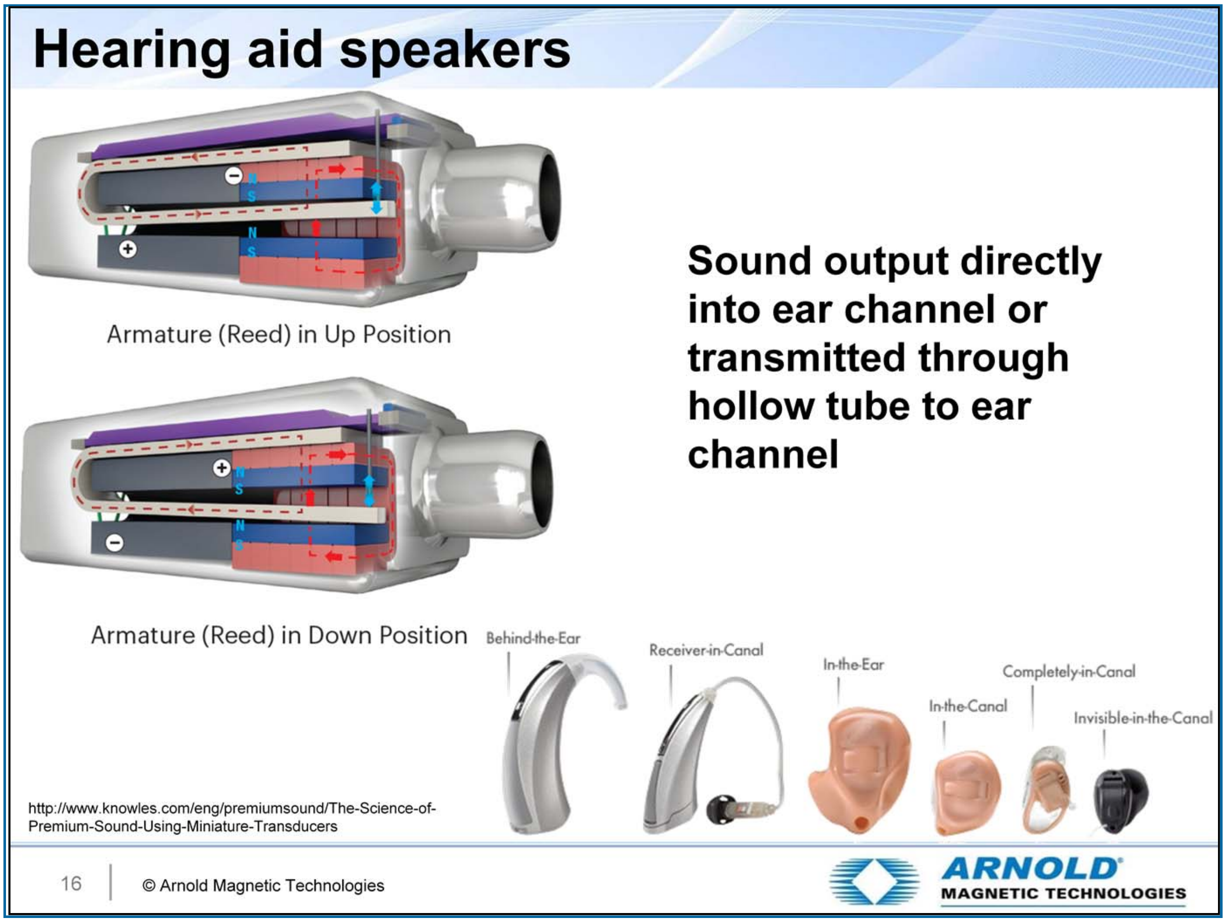


- An interesting aberration of the lanthanide series resides in the progression of the radii of the atoms.
- Cref. “lanthanide contraction”: “The effect results from poor shielding of nuclear charge (nuclear attractive force on electrons) by 4f electrons; the 6s electrons are drawn towards the nucleus, thus resulting in a smaller atomic radius.”
- Thus, as electrons are added to the 4f orbital, increased shielding of the nuclear force allows the 5p and 6s electrons to expand, partially offsetting the natural reduction in radius that would otherwise occur.
- If the elements from hafnium and greater atomic number are shifted to the left in the chart on this slide, we see their radii would then fit into the natural progression of radii.
- A similar, but smaller effect is noted in the 3d transition metals which include Fe, Co, and Ni.

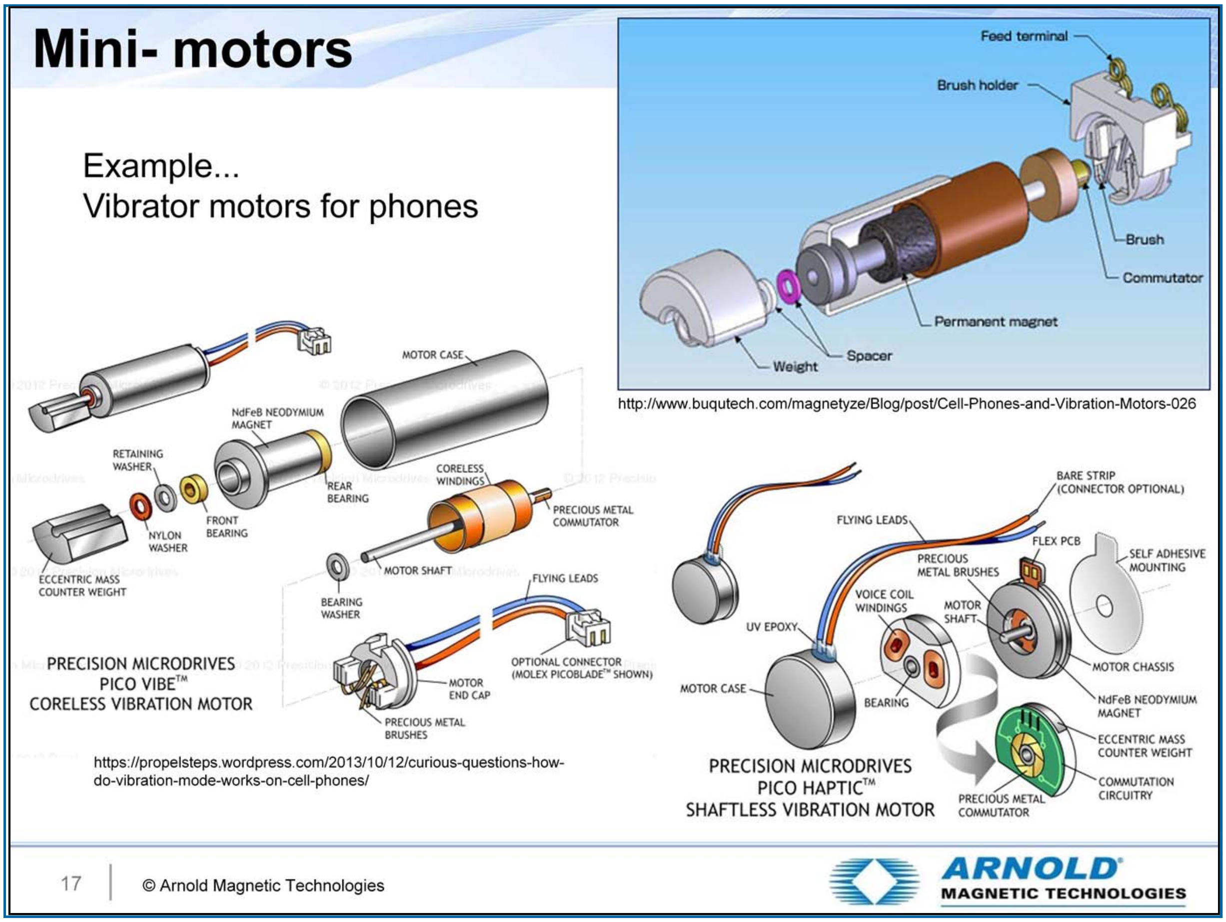


- When rare earth elements are combined with the 3d transition elements, especially iron and cobalt, the result is a number of ferromagnetic alloys.
- The most powerful magnet materials are, in order of discovery and commercialization: SmCo 1:5, SmCo 2:17, NdFeB and SmFeN.
- Since SmFeN is only available in powder form suitable for bonded magnets, it’s magnet strength is severely diluted by the non-magnetic binder.
- Between SmCo 1:5 and SmCo 2:17, the more powerful is SmCo 2:17.
- The two rare earth magnets of most commercial importance are therefore, SmCo 2:17 and NdFeB.
- It is these materials that permit very small devices and very powerful ones.

- Some of the more conventional commercial small-magnet applications are shown here.
- For example, the “ear bud“ magnet is approximately 0.2 gram per ear bud. At a production quantity of 200,000,000 units, total mass is about 40 tons of magnets.
- While this may seem like a lot, several magnet companies can produce over 5,000 tons per year – 40 tons is inconsequential.
- Due to the small size of these devices, use of magnets other than rare earth magnets is not feasible.



- If you imagine a hearing aid fitting within the ear channel, size of the sound generating device ("acoustic generator") becomes almost unimaginably small.



- Cell phones can be set to “vibrate mode” – as I trust yours are now.
- The vibration is generated by an eccentric cam on a motor – a motor containing a small permanent magnet.
- Cell phone sales in 2013 were 1.8 billion with 1 billion of them being smart phones.
- Each phone has at least one speaker and a vibrator both using rare earth (NdFeB) magnets.
- That’s a lot of magnets. But they are very small so tonnage is limited.
- Point: these are only possible, at this small size, by using rare earth magnets.

Mini-motors for photonics

Faulhaber 0816 SR Series DC Motors
(MICROMO)

CLEARWATER, Fla., June 26, 2013 — Micromo’s Faulhaber high-power 0816 SR Series DC coreless micromotors deliver continuous torque up to 0.7 mNm and a stall torque of 1.2 mNm. They are 8 mm in diameter and weigh 4.5 g, making them suitable for battery-operated device integration.

Through the use of materials such as **rare-earth magnets**, the motors deliver a performance curve of 11,000 rpm/mNm. They feature nominal voltage versions of 3, 6, 9 and 12 V, with sintered bearings standard and optional ball bearings available for higher radial shaft loads.

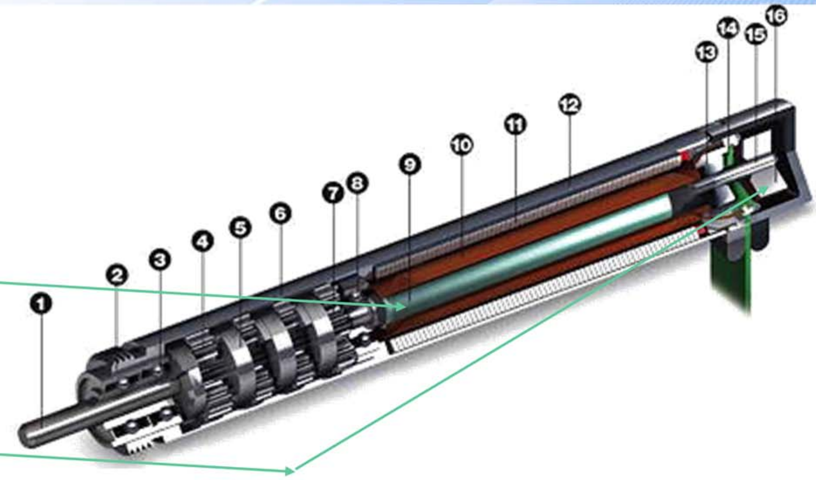
http://www.photonics.com/Product.aspx?PRID=54231

© Arnold Magnetic Technologies

- Numerous small commercial motors are produced, such as this one.
- They are used for micro-tools and micro-motion.
- Some are used in toys such as small cars and trains to provide motive force.

Mini- and micro-motors – medical & diagnostic

maxon gear GP 4
1 Output shaft
2 Flange
3 Ball bearings
4 Planetary wheels
5 Ceramic planetary carrier
6 Ring gear
7 Motor pinion (sun wheel)
maxon EC motor EC 4
8 Ball bearings
9 Permanent magnet
10 Winding
11 Stator stack
12 Housing
13 Ceramic bearing
14 Circuit board with Hall sensors
15 Shaft
16 Control magnet



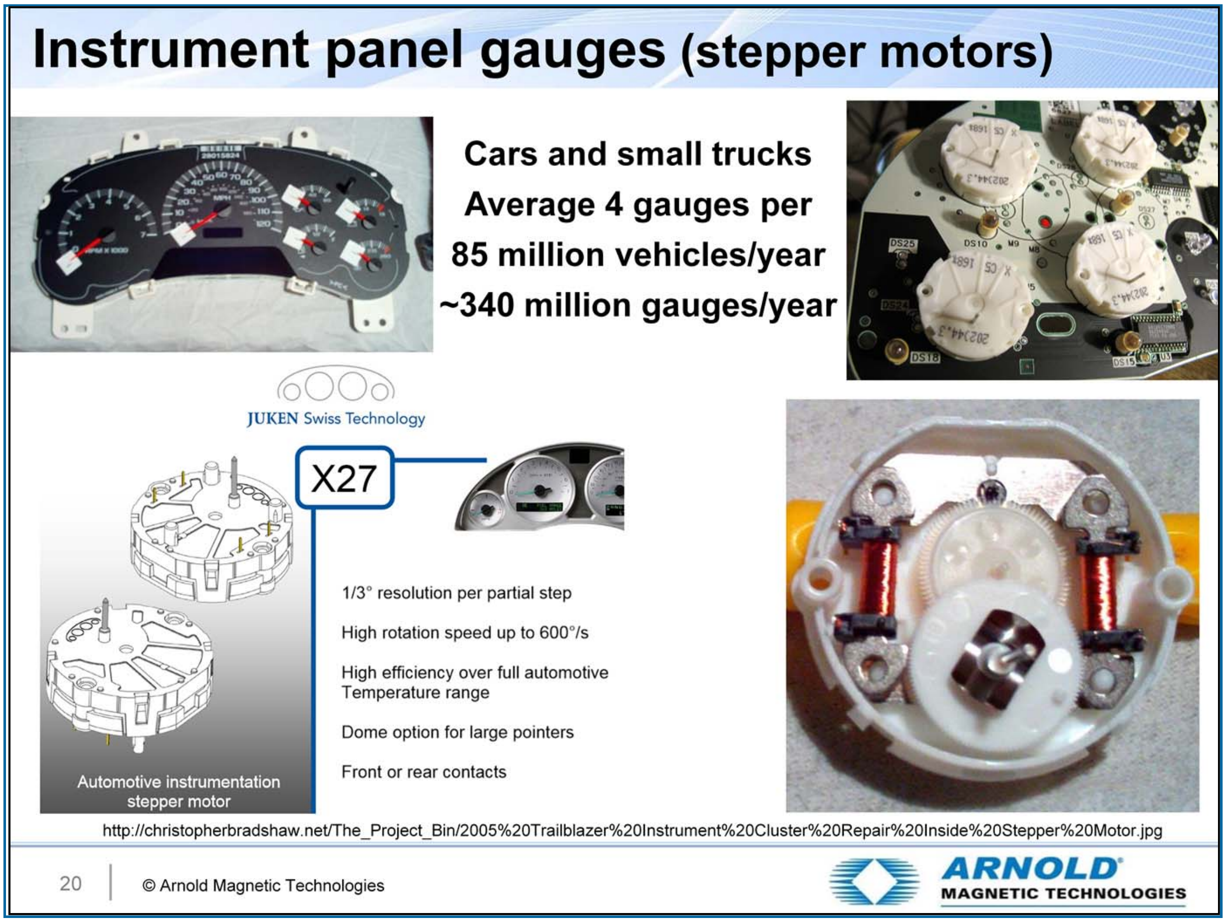
The motor's speed/torque gradient is 50,000 rpm mN/m, with a continuous torque of 0.4mNm. It is available in a long version with a nominal power rating of 1W, or a shorter version with a 0.5W rating.
Maxon expects the motors to be used for applications such as micropumps, analytic and diagnostic devices, surgical devices, laboratory robots, and endoscopes.

http://www.drivesncontrols.com/news/fullstory.php/aid/3799/4mm_micromotor_delivers_power_from_a_standstill.html#sthash.4rWQJSog.dpuf

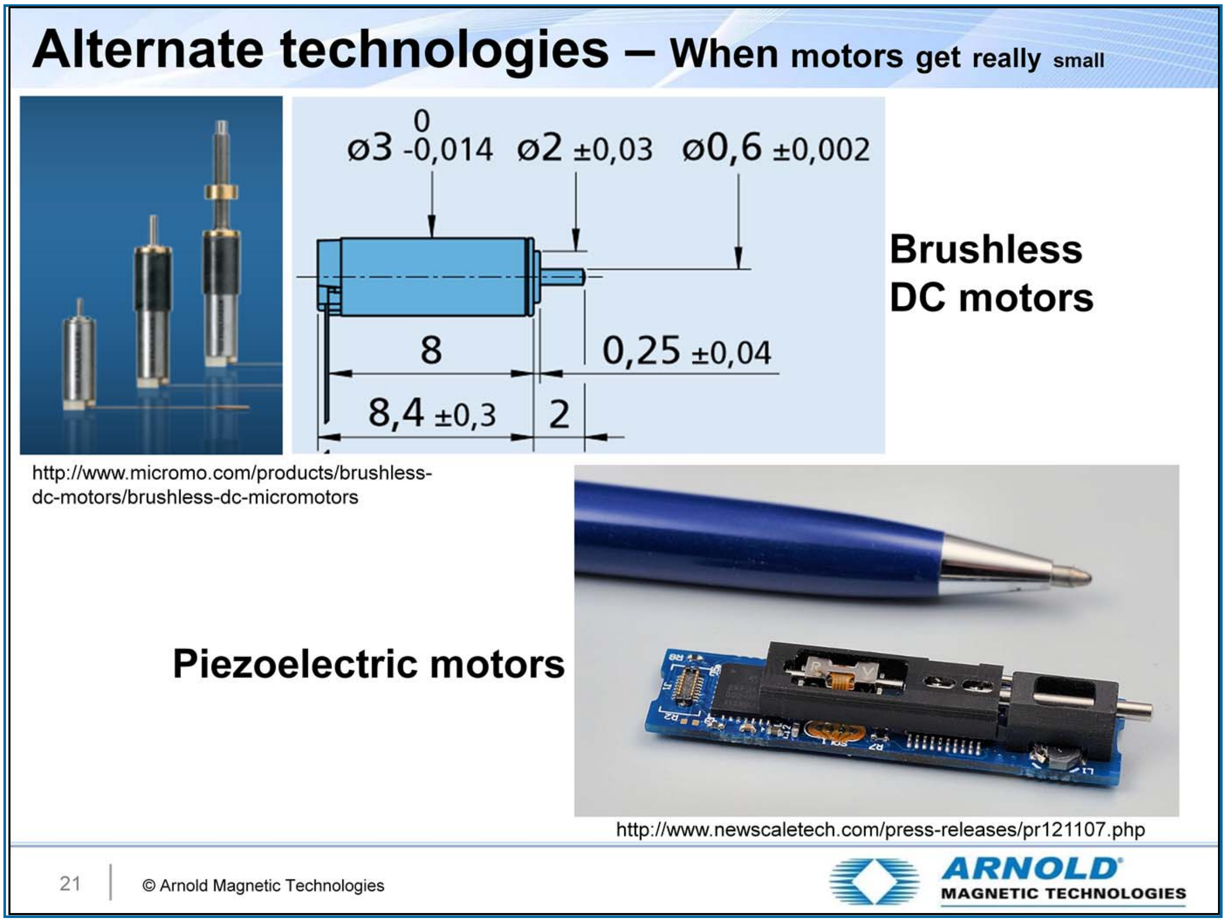
 © Arnold Magnetic Technologies

ARNOLD® MAGNETIC TECHNOLOGIES

- An example is shown here of a motor for medical applications.



- One small device is the stepper motor used to align pointers on gauges in the instrument cluster of cars, trucks, boats, and other transportation vehicles.
- Some of these use ferrite magnets, but most utilize the superior strength of rare earth magnets to provide fast and reliable gauging.
- Quantities are high, but the size of the magnet is small – minimizing total tonnage.



- As with most product situations, if an alternative technology exists, selection of device will be made based on a number of factors, such as performance, cost and availability.
- One small motor technology does not use copper wire, a steel flux guide or a magnet. This device is based on piezoelectric properties of the motor components that cause physical motion with the direct application of electric potential (voltage).

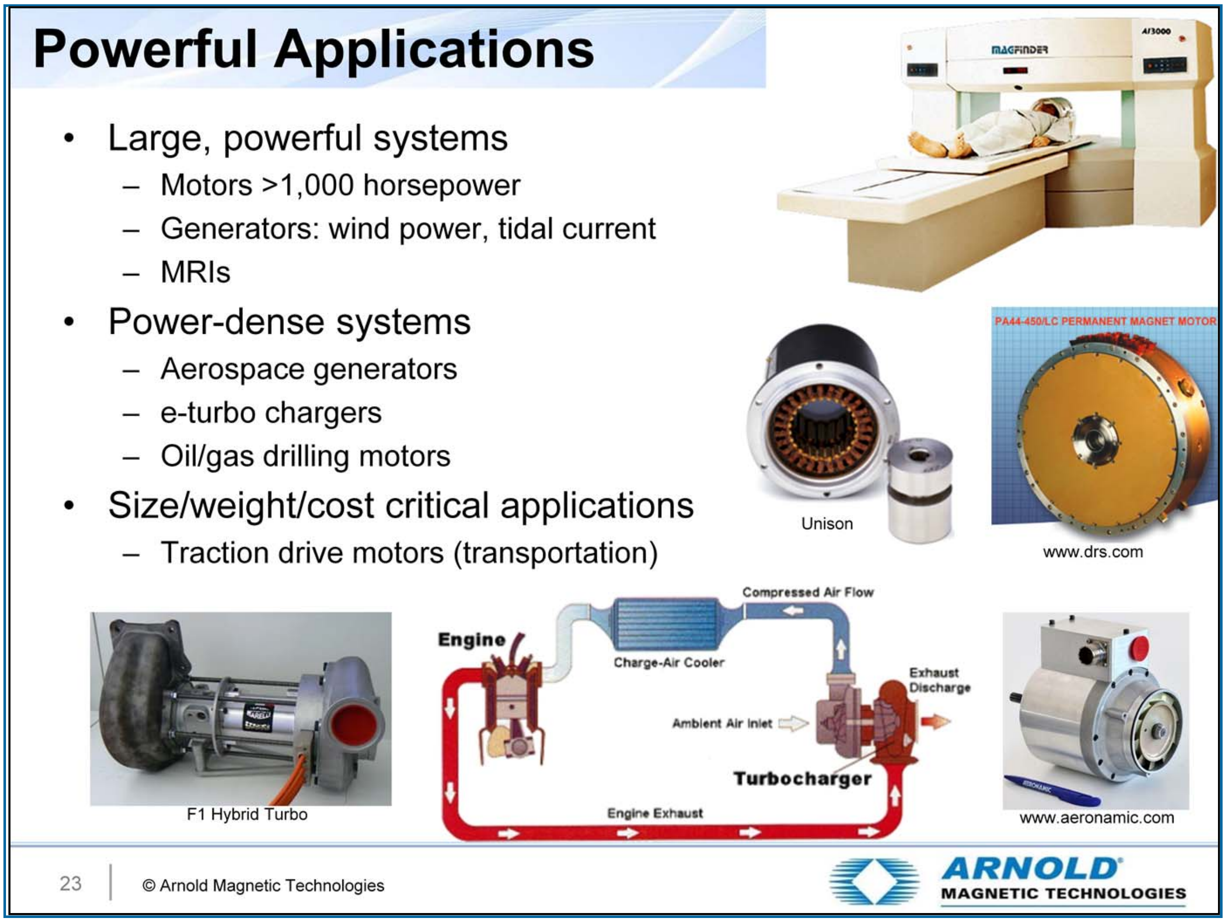
Agenda

- What makes rare earth elements special?
- Small applications
- **Powerful applications**

© Arnold Magnetic Technologies

ARNOLD® MAGNETIC TECHNOLOGIES

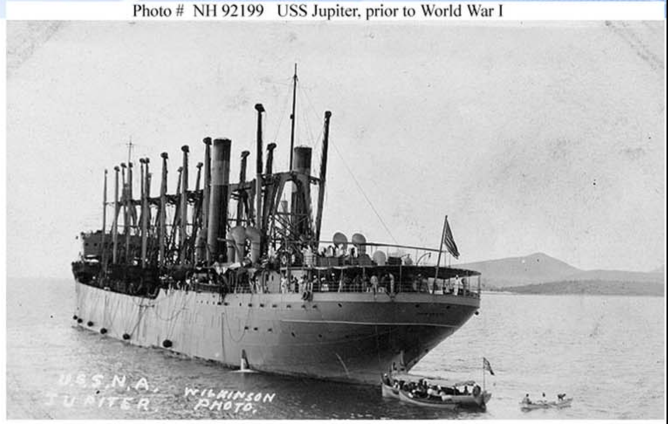
- Rare earth magnets are enabling materials.
- In addition to enabling very small devices, rare earth magnets are useful, even necessary, in some large and powerful applications.



- Examples shown here range from large (MRIs) to very power-dense (electric turbo).
- One example, the aerospace generator (bottom right), is limited in size and weight, but requires high power output. Typical designs utilize SmCo magnets, thin gauge lamination steel and high temperature wire insulation. They are sealed devices and run-temperatures can approach 220 °C.
- Another power dense application is the newly developed electric turbo drive (e-Turbo) which uses an ultra-high performance motor to temporarily power a turbo boost on car and truck engines. Standard systems are powered off exhaust gases. When acceleration is suddenly demanded, there is not enough exhaust gas pressure to provide the turbo boost. This momentary lag is mitigated with a fast starting, high power output electric motor.
- Let’s examine some more large and powerful applications.

Electric motor driven naval vessels

Photo # NH 92199 USS Jupiter, prior to World War I



Jupiter

Published March 19, 2011. The First U.S. Naval Ship Powered by Electric Motors

Photo # NH 63545 Aeromarine 39-B landing on USS Langley, circa 1922

She was later converted into the first aircraft carrier (see image below) and renamed the USS Langley.

© Arnold Magnetic Technologies

- The first electric motor powered (USA) navy vessel dates back to ~1911, so the concept is not new.

Electric motor driven naval vessels

"…the Zumwalt's propellers and drive shafts are turned by electric motors, rather than being directly attached to combustion engines. Such electric-drive systems, while a rarity for the U.S. Navy, have long been standard on big ships. What's new and different about the one on the Zumwalt is that it's flexible enough to propel the ship, fire railguns or directed-energy weapons (should these eventually be deployed), or both at the same time."

http://cleantechnica.com/2013/11/05/us-navy-launches-new-all-electric-zumwalt-destroyer/

© Arnold Magnetic Technologies
ARNOLD® MAGNETIC TECHNOLOGIES

- For the past few years, design and construction has taken place on the US Navy's Zumwalt destroyer which is driven by an "advanced induction motor" – no permanent magnets.

Electric motor drives for submarines

Two early nuclear-powered electric drive submarines: USS *Tullibee* (SSN-597, top), and USS *Glenard P. Lipscomb* (SSN-685, bottom). Immature electric-drive technology in the 1960s and 1970s limited the performance of these boats in comparison to their mechanical-drive counterparts.

http://www.navy.mil/navydata/cno/n87/usw/issue_9/power_system.html

An Integrated Electric Power System:
the NEXT STEP
by ADM Frank L. "Skip" Bowman, USN

Advantages for Submarines

Stealth Enhancement: Stealth is the single most important operational advantage of any submarine. It permits use of the submarine in politically sensitive or militarily contested areas to gain and sustain access for the rest of the battle force. It creates uncertainty, fear, and disproportionate diversion of resources on the part of the adversary. It allows submarines to be used in many covert and non-provocative, intelligence collecting operations. An integrated electric power system will enable necessary changes to key propulsion plant parameters, afford more flexibility in equipment selection and location, and permit use of other quieting methods. Electric drive opens the door to new methods for improving stealth by leveraging state-of-the-art technology with good future growth potential.

ARNOLD MAGNETIC TECHNOLOGIES

- However, Ohio Class replacement submarines will use electric motor drives.
- Unlike these earlier electric motor driven submarines, newer technologies have greatly improved performance and efficiency.
- The low noise signature is a compelling reason to pursue electric drive technology.

Electric Motors for ship propulsion

Specifications: 36.5 MW PM
Machine for Electric Ship Propulsion

Performance	
Output	50,000 HP (36.5 MW)
Speed	1-127 RPM
Torque	>2 M ft. lbs. (2.7M Nm)
Motor Efficiency	97.5%
Mechanical	
Motor Length	202 inches (5.1 meters)
Motor Width	214 inches (5.4 meters)
Motor Height	209 inches (5.3 meters)
Motor Weight	280,000 lbs. (127 tonnes, 127,000 kg)
Cooling Method	Fresh water
Electrical	
Voltage	1450 VAC
Phases	Doubly-fed, 3-phase
Insulation Class	R (220° C)
Temperature Rise	H (180° C)

http://www.drs.com/index.aspx

© Arnold Magnetic Technologies
ARNOLD® MAGNETIC TECHNOLOGIES

- One of the possible drive motors is shown here.
- DRS specializes in large motor systems.

Mid-size hybrid drive system

Hybrid Electric Ship Propulsion Motors/Generators

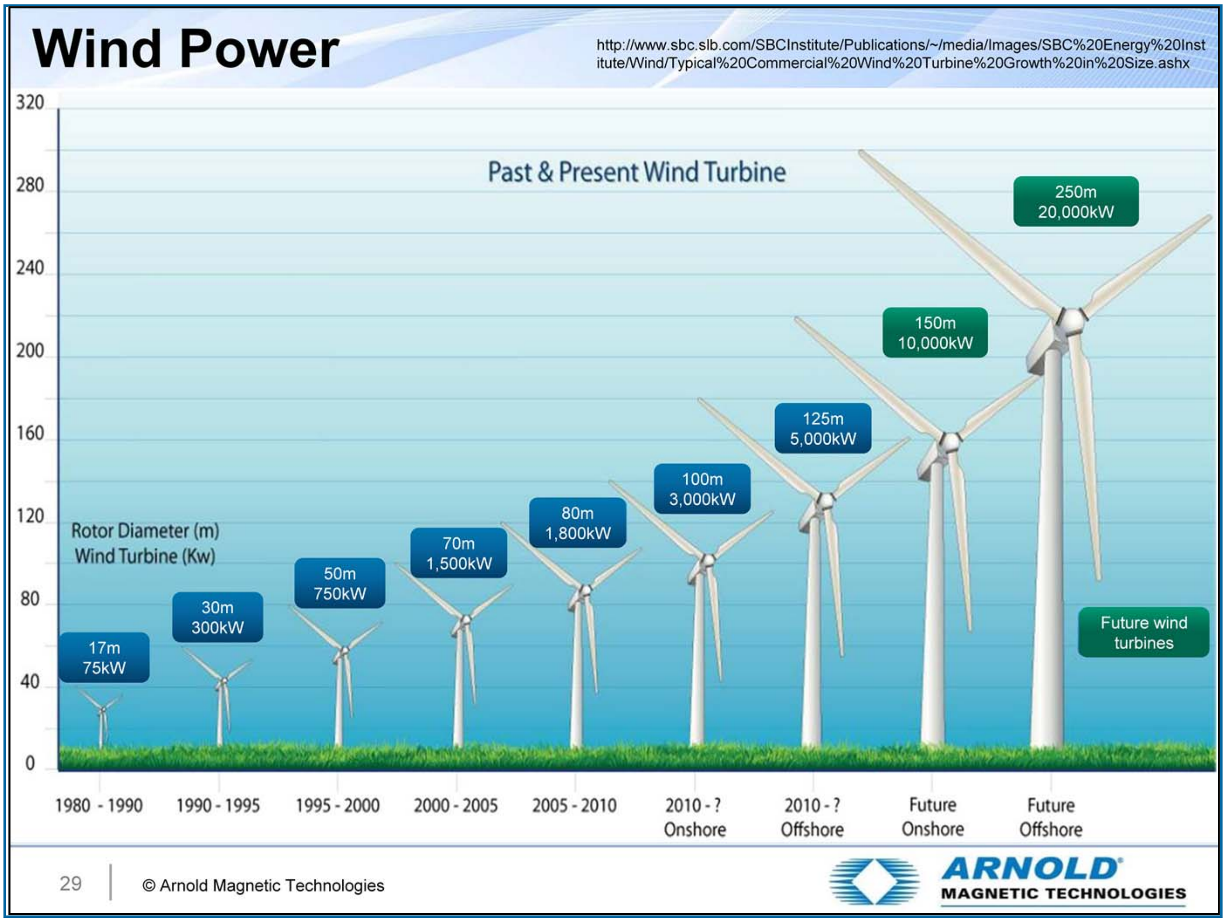
Highlights

- Space & weight benefits –High torque in a compact package means minimal engine room impact
- Fuel savings – Using PM power at low speeds can save thousands of barrels of fuel
- Life cycle costs – Reduced gas turbine or diesel motor operation time saves on maintenance costs
- Easy integration and minimum impact to engine room
- DRS PM machines provide a mature technology: evolved from a lineage of fielded permanent magnet motors with a history of performance in extreme operating conditions

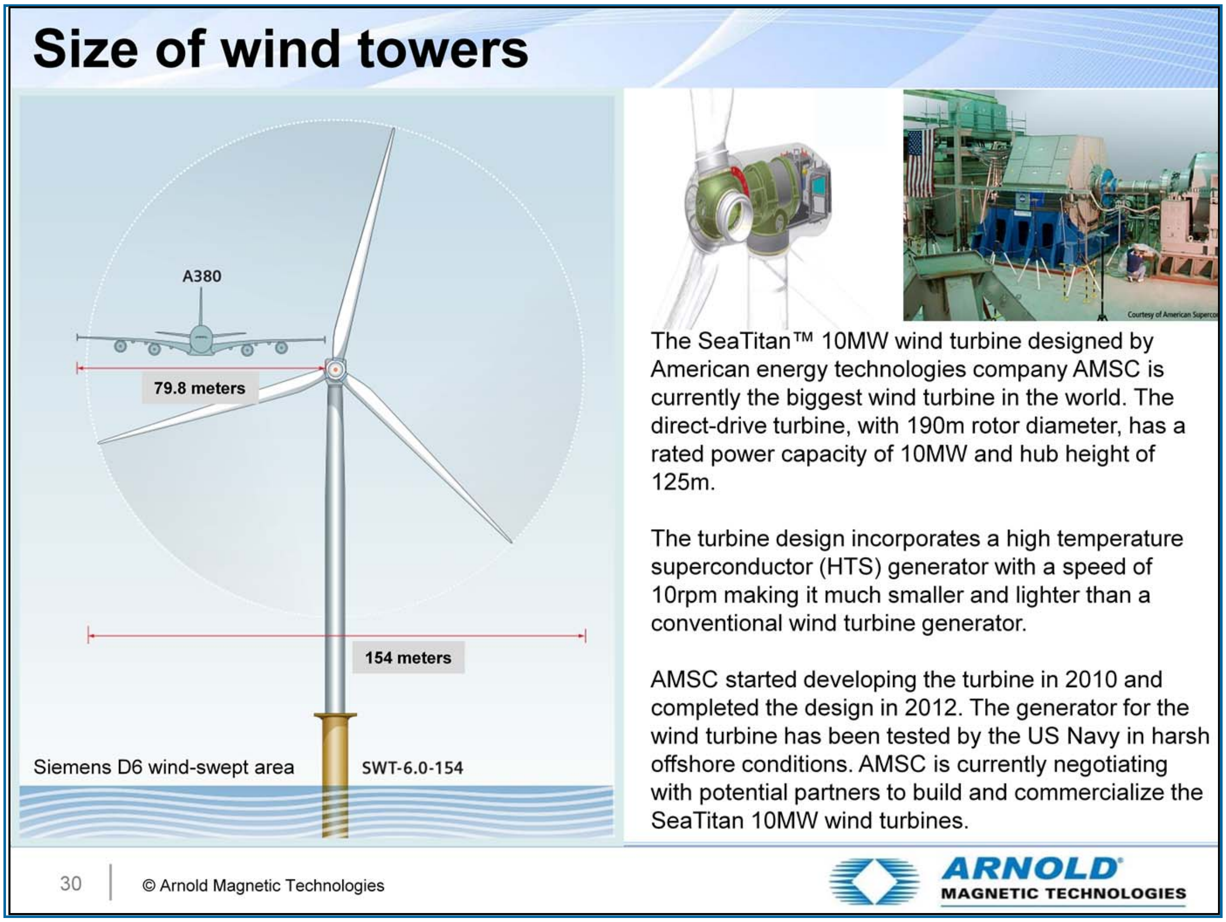
http://www.drs.com/index.aspx

ARNOLD® MAGNETIC TECHNOLOGIES

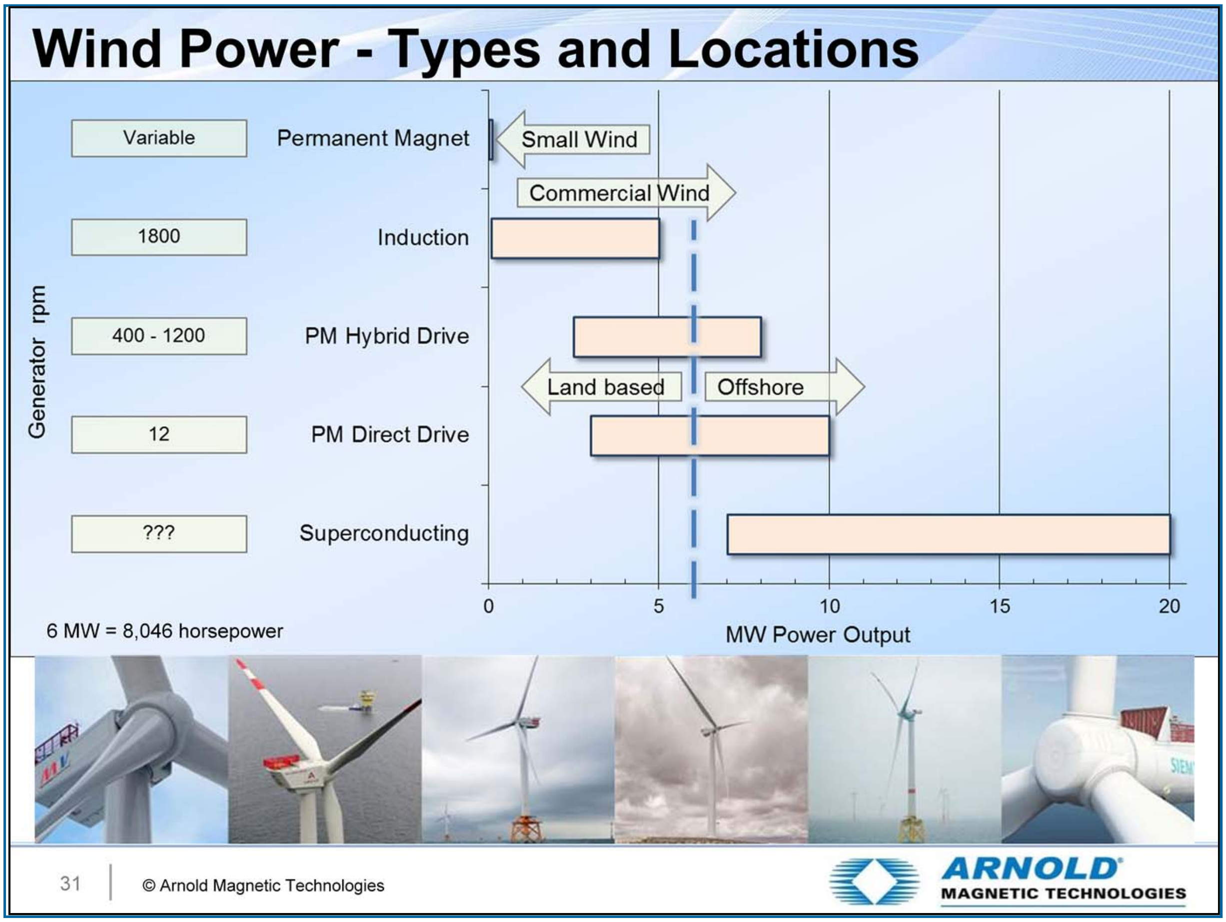
- An intermediate size motor is available from DRS for hybrid ship drive systems.
- Both this and the previous motor are dependent upon rare earth magnets.



- In an earlier presentation, we learned about wind power as a renewable, “green” technology for producing electricity.
- The number of and size of installations continues to grow.



- Current commercial scale power generating systems are large!
- As size increases, alternate technologies, such as the one illustrated on the right – a superconducting generator – may be necessary.



- Larger capacity is more efficient to install and operate – this is especially true for off-shore installations.
- Why move from an induction generator to permanent magnet (PM) generator? Smaller size, lower weight, reduced or eliminated gear box, larger power output potential...

- ...and lower maintenance.
- Permanent magnet generators permit reducing the gear box to 2-stage (from 3) or eliminating it altogether in direct drive generators.

Offshore Turbine development

TOP TEN OFFSHORE TURBINES *The wind industry's biggest, heaviest and most expensive products compared and contrasted*

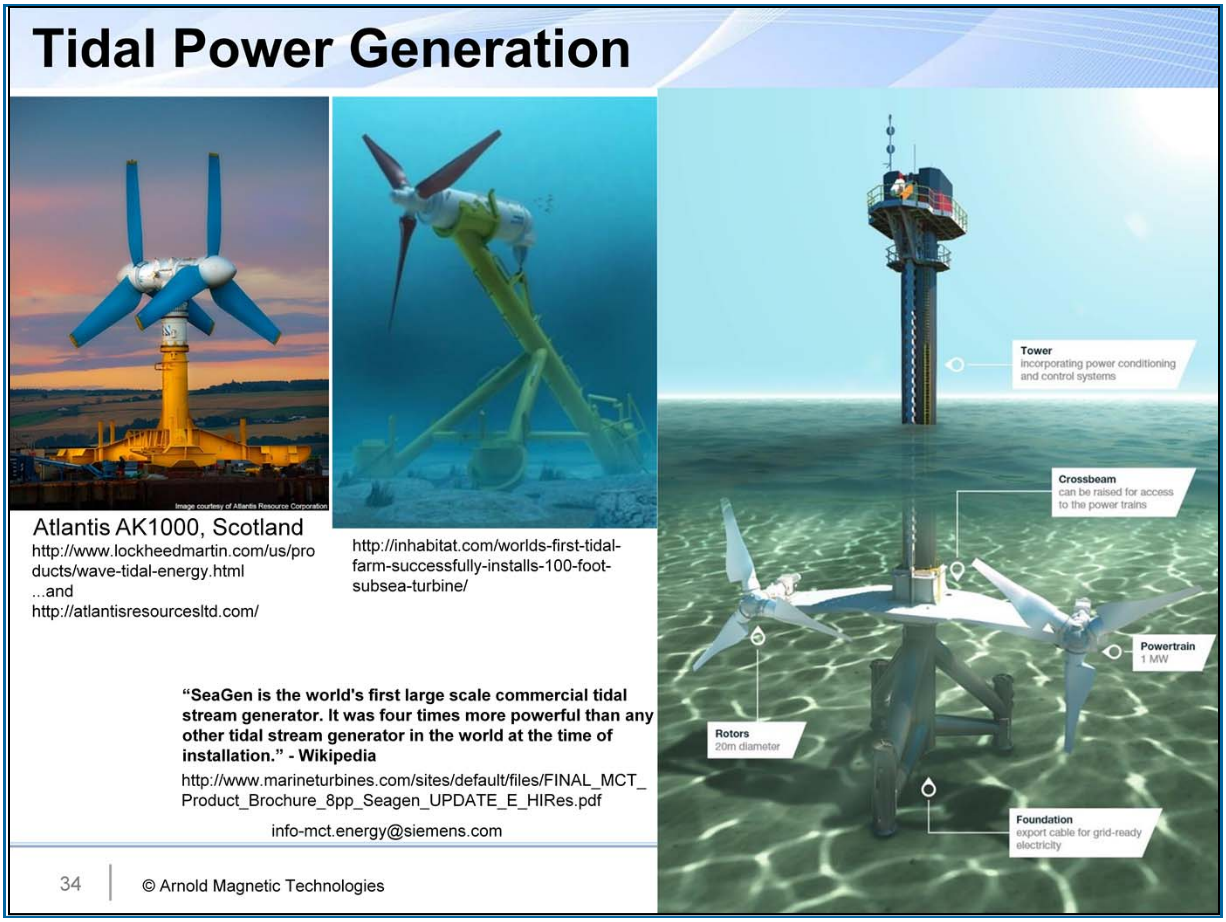
Model	IEC class	Power rating	Rotor diameter	Drive system	Noteworthy
MHI-Vestas V164-8.0MW (Denmark)	S	8MW	164m	MSG, PMG	Clever combination of evolutionary and innovative design features; flanged tube-shaped drivetrain, favourable 500-tonne head mass
Ming Yang SCD 6.0 (China)	IIB	6MW	140m	MSG, PMG	Innovative two-blade downwind turbine with compact semi-integrated drivetrain and single rotor bearing, focused at typhoon-prone markets
Siemens SWT-6.0-154 (Germany)	I	6MW	154m	DD, PMG	Single rotor bearing; largest rotor diameter in 6MW class, converter and transformer in nacelle; favourable head mass
Alstom Haliade 150-6MW (France)	I	6MW	150.8m	DD, PMG	Stationary main shaft (pin); "pure torque" principle decouples rotor-bending moments and generator drive torque
Siemens SWT-4.0-130 (Germany)	I	4MW	130m	HSG, IG	Evolutionary development and optimisation of SWT-3.6-120 model, which has been the offshore market leader for several years
Senvion 6.2M152 (Germany)	S	6.15MW	152m	HSG, DFIG	Developed from pioneering 5MW turbine introduced in 2004; prototype of more powerful model with longer blades installed in 2014
Areva M5000-135 (France)	S	5MW	135m	MSG, PMG	Extensive upgrade of M5000-116 introduced in 2004; features clever pioneering low-speed hybrid-drive design
Gamesa G128-5.0MW (Spain)	IB	5MW	128m	MSG, PMG	Pioneer tube-type drivetrain; builds on 2009's G128-4.5MW platform; new variant with 132m rotor diameter has been announced
Hyundai HQ5500/140 (South Korea)	I	5.5MW	140m	HSG, PMG	Sister product of Dongfang 5.5MW, co-developed with AMSC; Sinovel SL5000/SL6000 uses same AMSC product platform
Goldwind GW 6MW (China)	I	6MW	150m	DD, PMG	Specification not verified; initial design basis 5MW power rating

BDFIG Brushless doubly-fed induction generator
CGFRE Carbon & glass-fibre reinforced epoxy
DD Direct drive
DFIG Doubly-fed induction generator
EESG Electrically excited synchronous generator
GFRE Glass-fibre reinforced epoxy
HH Hub height
HSG/LSG High-speed geared/Low-speed geared
IG Induction generator
MSG medium-speed geared
PMG permanent magnet generator
PCVS Pitch-controlled variable-speed

Source: http://www.windpowermonthly.com/10-biggest-turbines

© Arnold Magnetic Technologies

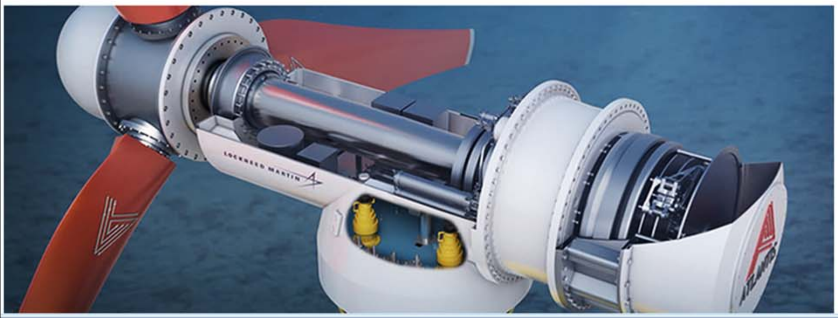
- The largest generators have been designed for use off-shore.
- Of the current top ten generators, 8 are PM type.
- The largest to-date is the MHI-Vestas 8.0 MW generator.



- Numerous companies are developing, testing and installing power generating facilities that depend on tidal current or wave motion.
- Water is far more dense than air, so higher output capacity is possible with smaller swept-area devices.
- The Atlantis AK1000 is pictured here prior to installation and now testing is completed.
- SeaGen is a product of MCT which is now a wholly owned subsidiary of Siemens.

Tidal Power Generation

- The AR1500 is the latest tidal power turbine system under development at Atlantis
- Rated capacity of 1.5MW at 3.0 m/s
- Design completed by Lockheed Martin Corporation during 2014
- AR1500 system will have pitching blades and full nacelle yaw rotation capability to facilitate operation in highly energetic deployment locations
- This turbine represents best in class, with features such as:
  - Variable pitch rotor blades for maximum energy capture
  - Integrated gearbox and bearing-less **permanent magnet generator**
  - Fast deployment and connection system; nacelle deployment less than 90 minutes
  - 360 degree yaw capacity and survival lock system
  - Multiple, fully redundant electrical systems for long term operation subsea
- The first unit is due for pre-delivery on-shore acceptance testing at the end of 2015.

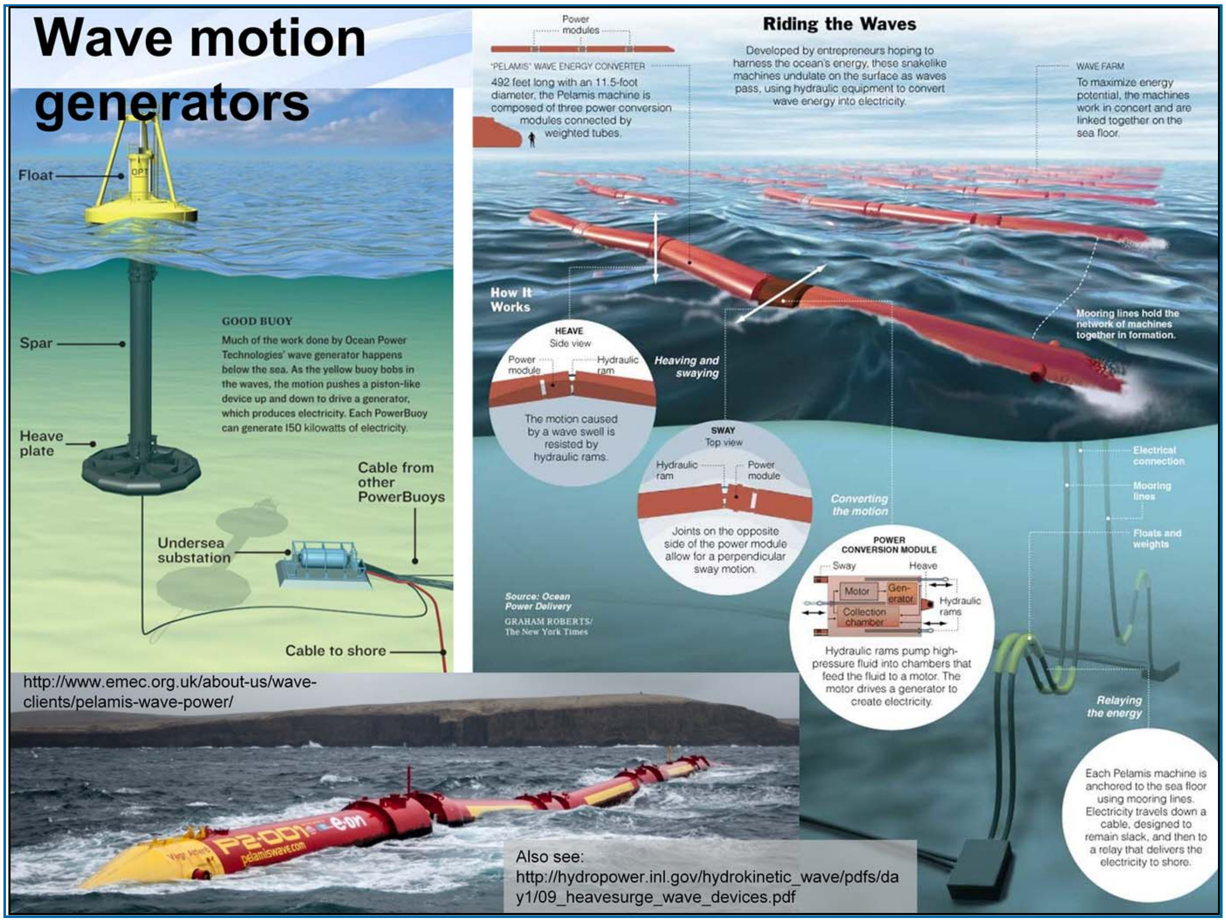


http://atlantisresourcesltd.com/turbines/ar-series/ar1500series.html

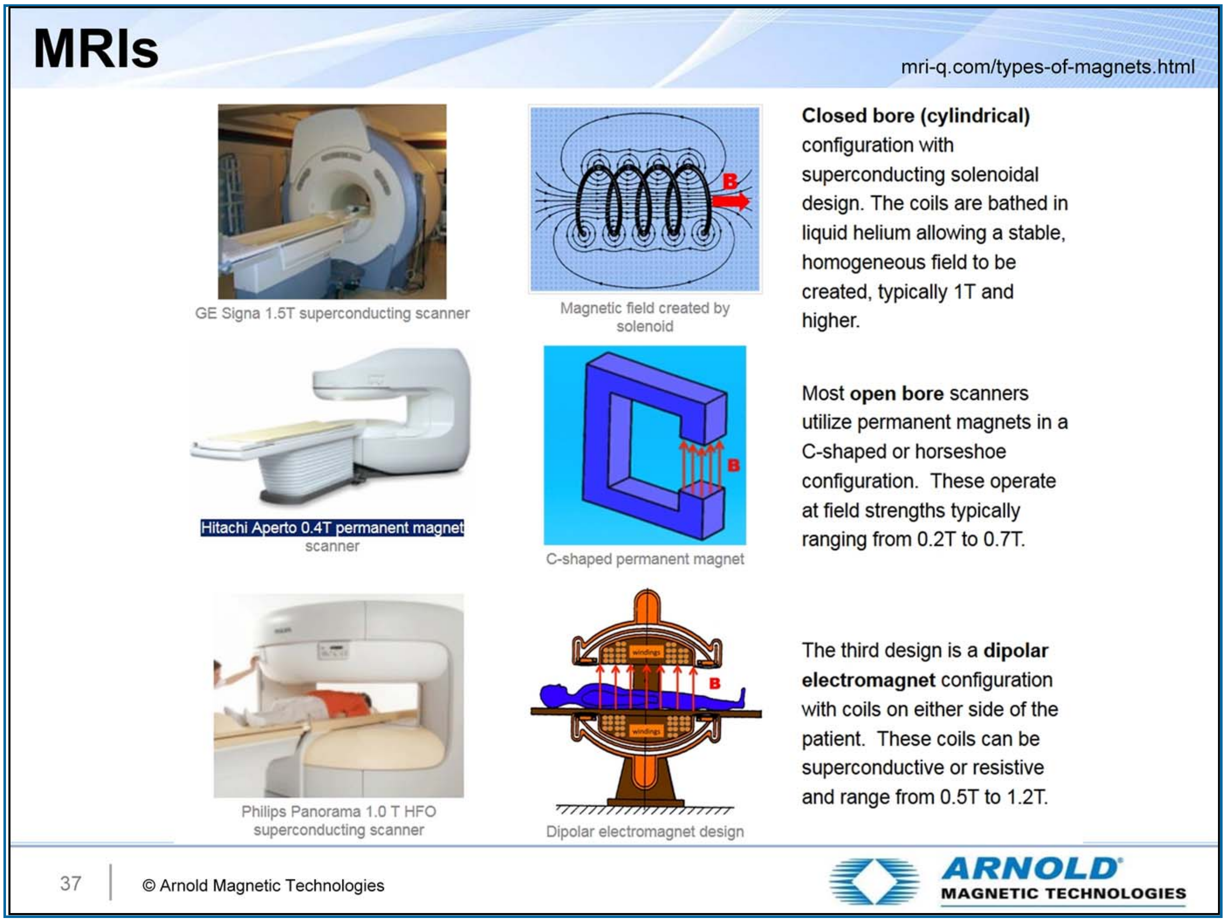
© Arnold Magnetic Technologies

- The first Atlantis Resources 1.5 MW generator is scheduled for delivery at the end of 2015.
- As noted, it was designed by Lockheed-Martin.

Wave motion generators



- In addition to the previously shown “propeller-type” generator, numerous other methods have and are being investigated to use movement of water to power electric generators including long undulating segments and bobbing buoys.
- These technologies are still immature, but likely to utilize rare earth permanent magnets due to the slow movement of wave motion.



- Magnetic Resonance Imaging or MRI is a well-developed technology using interaction between a strong, static magnetic field and a modulating frequency wave generator. The combination of fields act differently on the human body depending on tissue type and density.
- The static magnetic field can be generated by permanent magnet, by a superconducting coil or by a conventional resistive coil.
- Size of the magnet structure depends on whether the scanner if “full-body” or designed to look at smaller sections of the body, such as an arm or leg.
- Early superconducting structures were shaped like a solenoid – a hollow cylinder. Sliding into the cylinder has caused claustrophobia and anxiety.
- To avoid these negative effects, newer designs are of the open type as in the second and third illustration on the slide.
- When permanent magnets are used, the most powerful permanent magnet possible is utilized. Magnet weight in the full body scanner can be 3 tons or more and is constructed of numerous large blocks of magnet, precision ground for close assembly and then “tuned” to provide a precisely uniform field.

SC versus PM

	Current Models	Discontinued Models	Totals
SC (superconducting	27	15	42
PM (permanent magnet)	22	17	39
Totals	49	32	

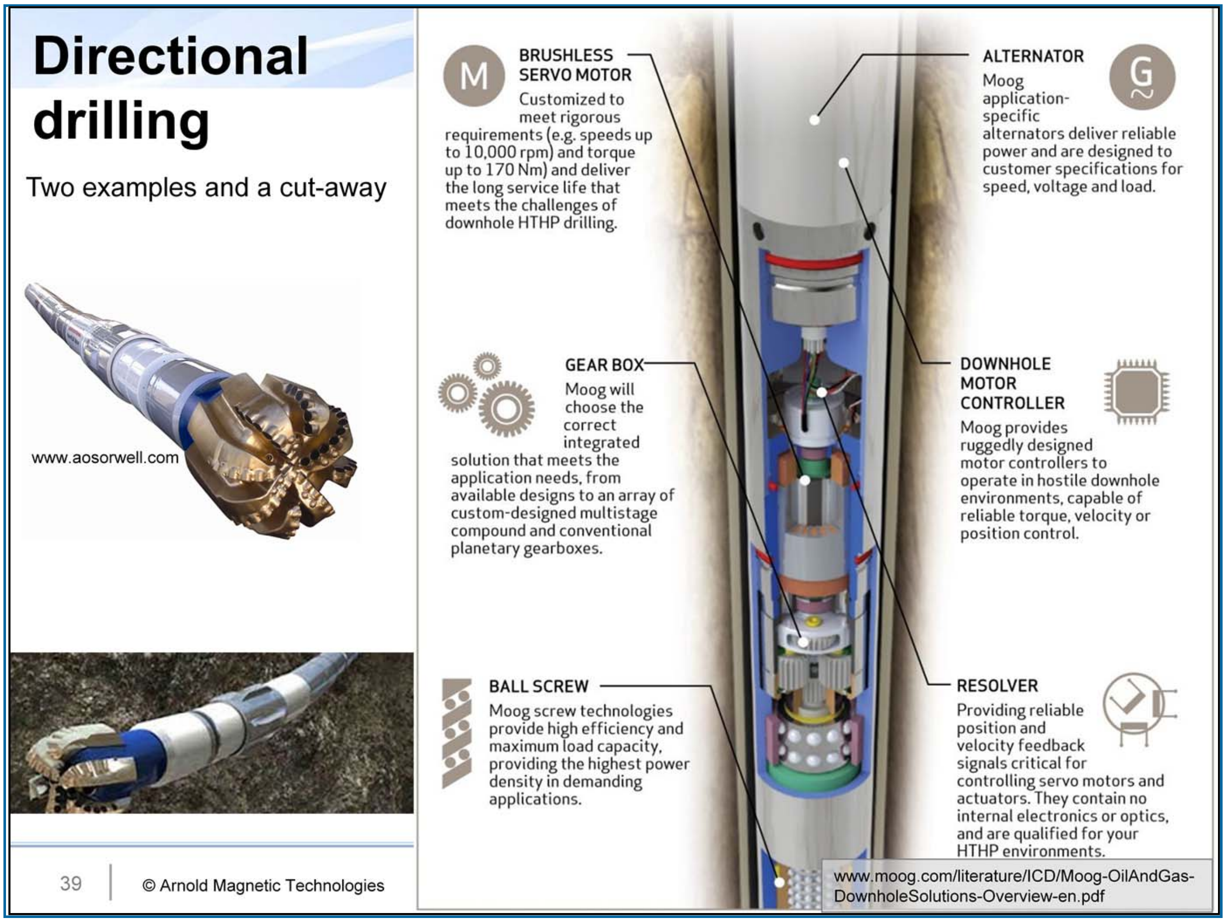
The Four Leading Manufacturers

Current Models	GE	Hitachi	Philips	Siemens
SC (superconducting	6	2	4	4
PM (permanent magnet)	0	1	0	1

http://mri-q.com/brands-of-scanners.html

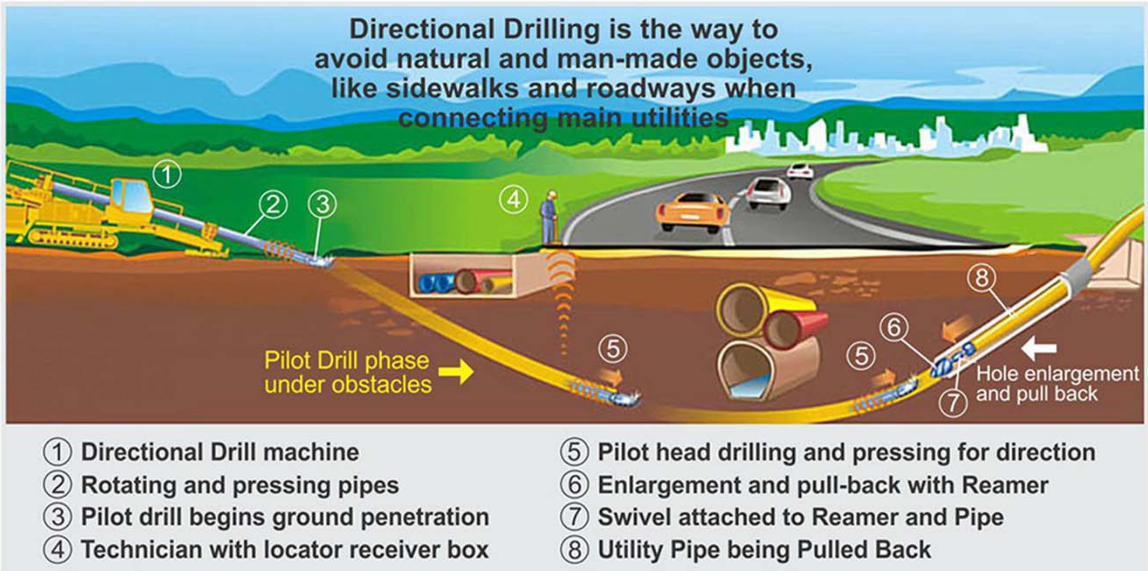
© Arnold Magnetic Technologies

- The maximum field strength in the opening of the MRI from strong NdFeB permanent magnets is about 0.7 Tesla (7,000 Gauss).
- Superconducting MRIs can produce fields 5 or more times stronger resulting in stronger signal output and clearer images.
- The cost of operating a superconducting MRI is higher than a PM type.
- However, the field of the PM can not be turned off and represents a danger during installation, use and transportation.
- The trend appears to be away from price-volatile NdFeB and to high-performing superconducting MRIs.



- Directional drilling utilizes one or more PM motors to drive the drill bit and force it in the desired direction.
- Directional drilling is the technology behind “Unconventional well drilling” also called high volume hydro-fracking – or just plain “fracking”.

Directional drilling – more than oil & gas



© Arnold Magnetic Technologies

ARNOLD MAGNETIC TECHNOLOGIES

- Directional drilling can and is being used for more than oil & gas drilling.
- It aids installation of utilities by avoiding obstacles – drilling under roads, under stream beds, under or around urban underground structures including previously installed utility services, and to avoid disturbing established lawns, trees, driveways, etc.

Wrapping it up

- Rare earth elements have unique chemical structures that make them excellent additions to iron and cobalt-containing magnet alloys
- The high energy of rare earth magnets makes them
  - Required for very small devices that benefit from high output
  - Required for large applications in order to minimize size and weight

 © Arnold Magnetic Technologies