Comparison of EAPs with Other Actuator Technologies

Actuator Type (specific example)	Maximum Strain (%)	Maximum Pressure (MPa)	Specific Elastic Energy Density (J/g)	Elastic Energy Density (J/cm^3)	Coupling Efficiency k^2 (%)	Maximum Efficiency (%)	Specific Density	Relative Speed (full cycle)
Electroactive Polymer Artificial Muscle [1]								
Acrylic	215	7.2	3.4	3.4	~60	60–80	1	Medium
Silicone (CF19-2186)	63	3.0	0.75	0.75	63	90	1	Fast
Electrostrictor Polymer (P(VDF-TrFE)[2]	4	15	0.17	0.3	5.5	–	1.8	Fast
Electrostatic Devices (Integrated Force Array)[3]	50	0.03	0.0015	0.0015	~50	> 90	1	Fast
Electromagnetic (Voice Coil) [4]	50	0.10	0.003	0.025	n/a	> 90	8	Fast
Piezoelectric								
Ceramic (PZT)[5]	0.2	110	0.013	0.10	52	> 90	7.7	Fast
Single Crystal (PZN-PT)[6]	1.7	131	0.13	1.0	81	> 90	7.7	Fast
Polymer(PVDF) [7]	0.1	4.8	0.0013	0.0024	7	n/a	1.8	Fast
Shape Memory Alloy (TiNi) [8]	> 5	> 200	> 15	> 100	5	< 10	6.5	Slow
Shape Memory Polymer[9]	100	4	2	2	–	< 10	1	Slow
Thermal (Expansion) [10]	1	78	0.15	0.4	–	< 10	2.7	Slow
Electrochemo-mechanical Conducting Polymer (Polyaniline)[11]	10	450	23	23	< 1	< 1%	~1	Slow
Mechano-chemical Polymer/Gels (polyelectrolyte)[12]	> 40	0.3	0.06	0.06	–	30	~1	Slow
Magnetostrictive (Terfenol-D, Etrema Products) [13]	0.2	70	0.0027	0.025	–	60	9	Fast
Natural Muscle (Human Skeletal)[14]	> 40	0.35	0.07	0.07	n/a	> 35	1	Medium

References from table

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4. These values are based on an array of 0.01 m thick voice coils, 50% conductor, 50% permanent magnet, 1 T magnetic field, 2 ohm-cm resistivity, and 40,000 W/m2 power dissipation.
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10. Aluminum, with a temperature change of 500°C.
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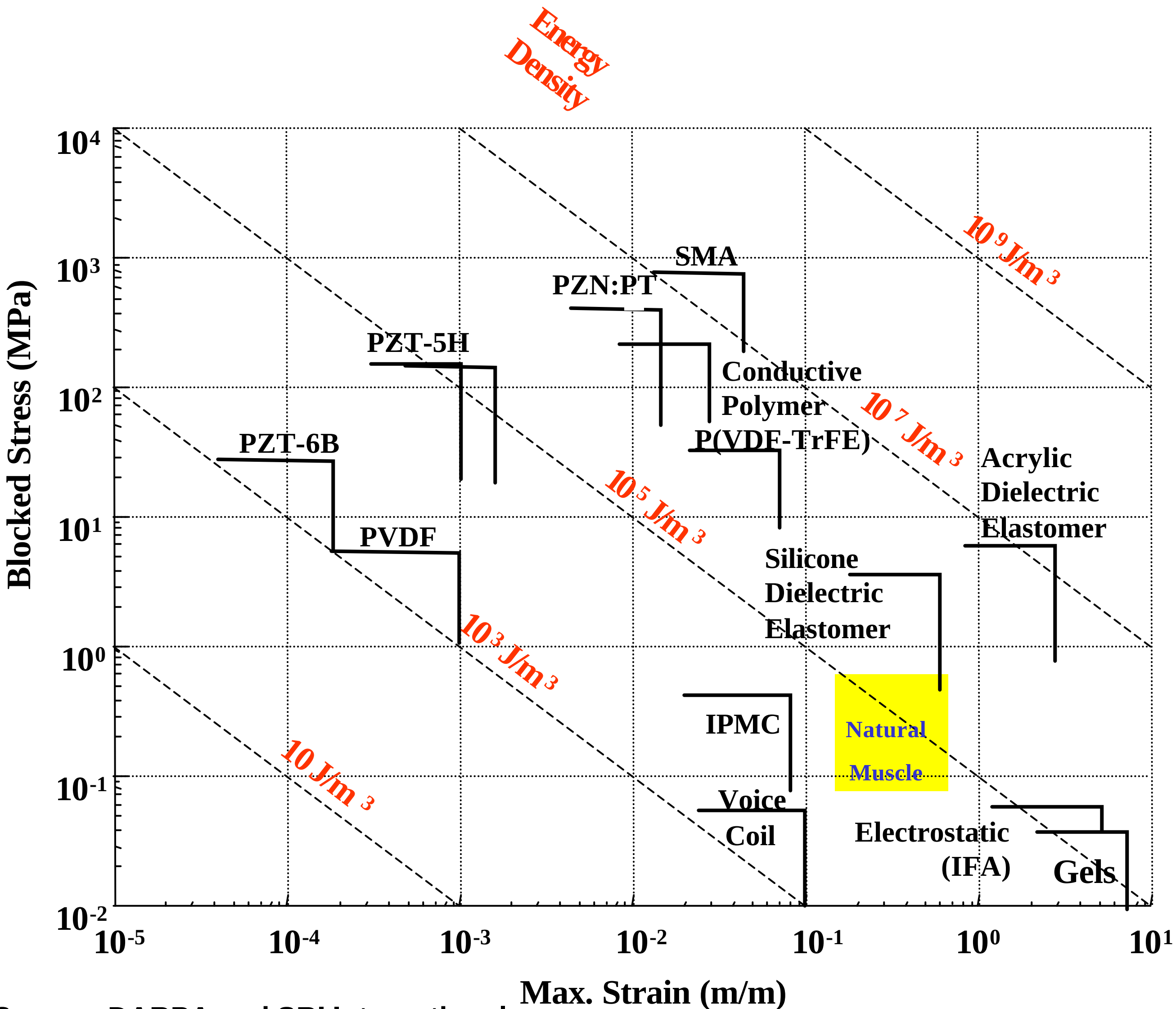
13. Terfenol-D Etrema Products
14. Hunter, I.W., and S. Lafontaine. 1992. “A Comparison of Muscle with Artificial Actuators,” *Technical Digest of the IEEE Solid-State Sensor and Actuator Workshop*, Hilton Head, South Carolina, pp. 178–185.

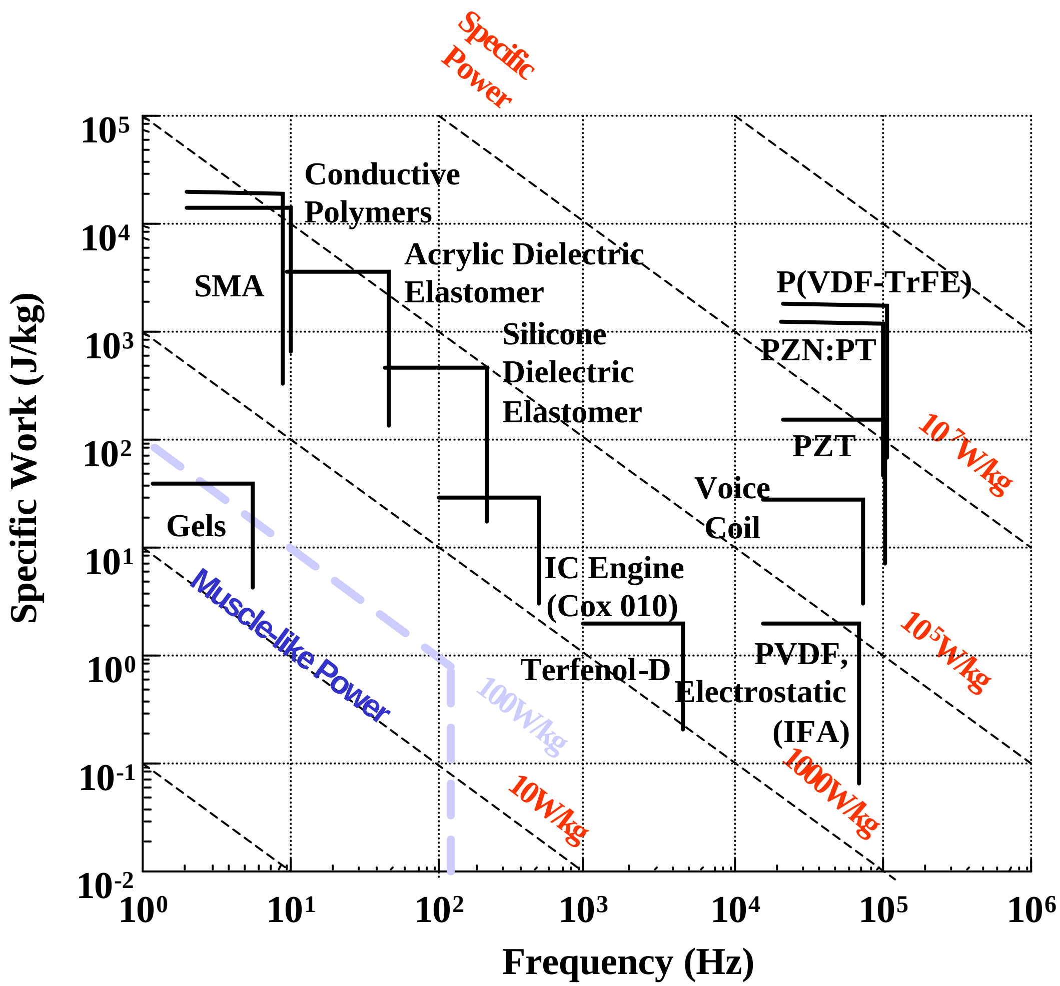
Actuator Technology Comparisons - Energy



Source: DARPA and SRI International

- Some polymer actuator technologies have muscle-like performance
- Much of this data is preliminary and for active material mass only
  - practical values can be as much as 10 or 100 times lower

Actuator Technology comparisons - Power



Source: DARPA and SRI International

- Much of this data is preliminary and for active material mass only
  - practical values can be as much as 10 or 100 times lower
- Actuator selection must also consider other factors such as efficiency
- Several smart material or muscle-like actuator technologies look promising considering specific power
  - Field activated materials look promising