## 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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8. Hunter, I., S. Lafontaine, J. Hollerbach, and P. Hunter. 1991. “Fast Reversible NiTi Fibers for Use in MicroRobotics,” *Proc. 1991 IEEE Micro Electro Mechanical Systems—MEMS ’91*, Nara, Japan, pp. 166–170.
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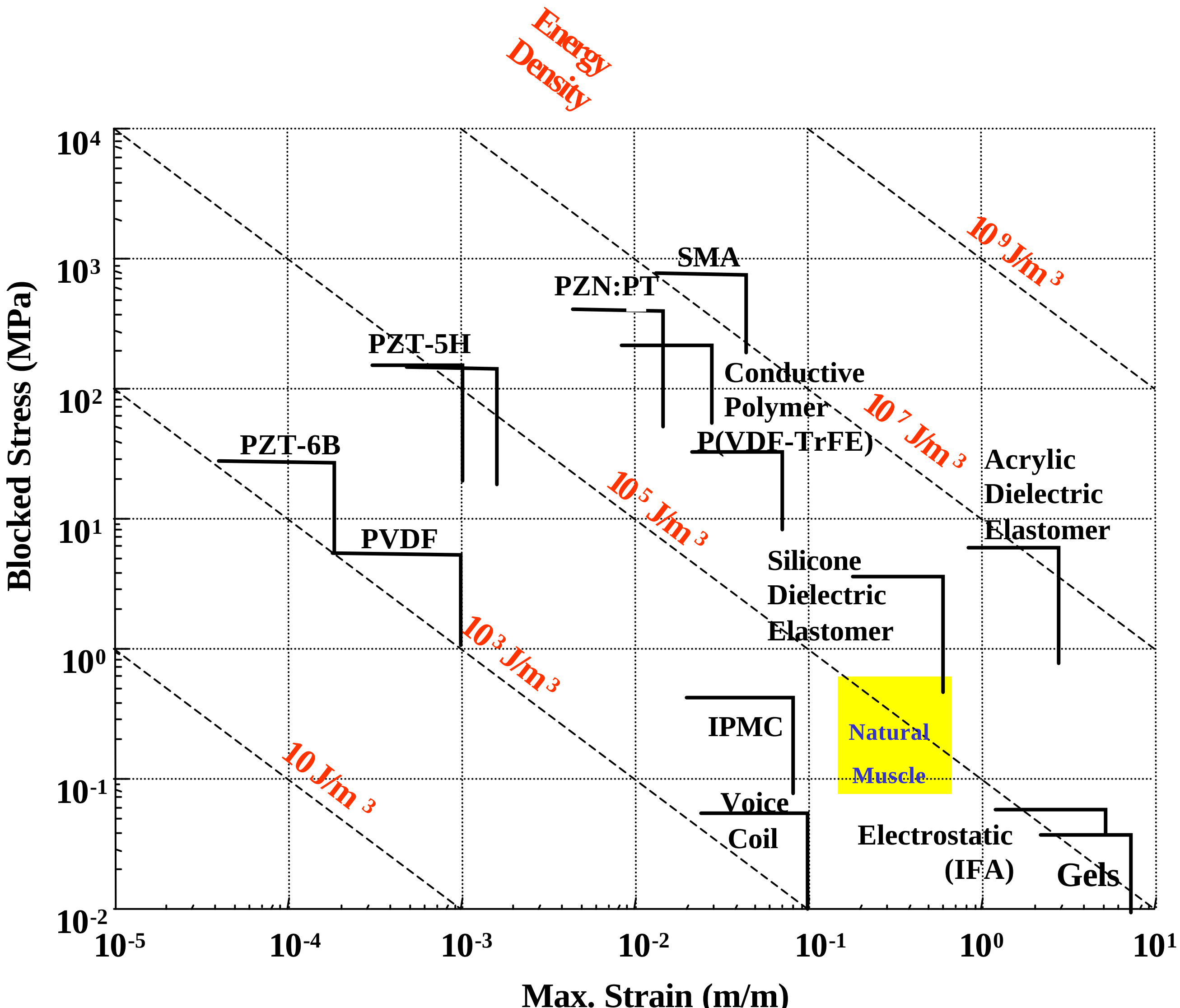
13. Terfenol-D Etrema Products
14. Hunter, I.W., and S. Lafontaine. 1992. “A Comparison of Muscle with Artificial Actuators,” *Technical Digest of the IEEE Solid-State Sensor and Actuator Workshop*, Hilton Head, South Carolina, pp. 178–185.

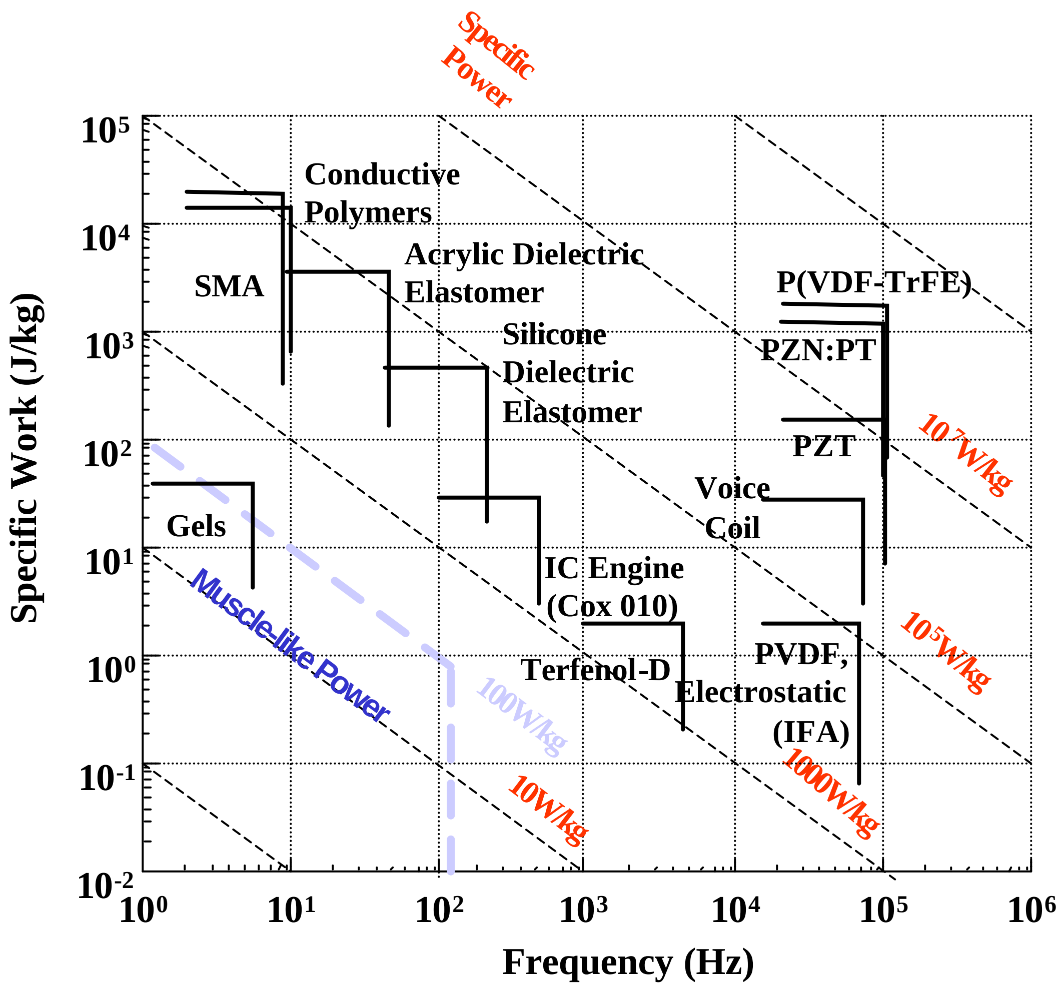
# Actuator Technology Comparisons - Energy




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