Adriatic
Aerospace
Association

JADRANSKA AERO-SVEMIRSKA ASOCIJACIJA

Challenges of Space for the world to come

Ramon SpaceLab
University of Tel Aviv
28.1.2019

The World to Come

Conquest of Space

Space Age

- Permanent human presence
  - Open ended development
  - Very demanding on technology
  - Global endeavor

Space of Intelligent Automata

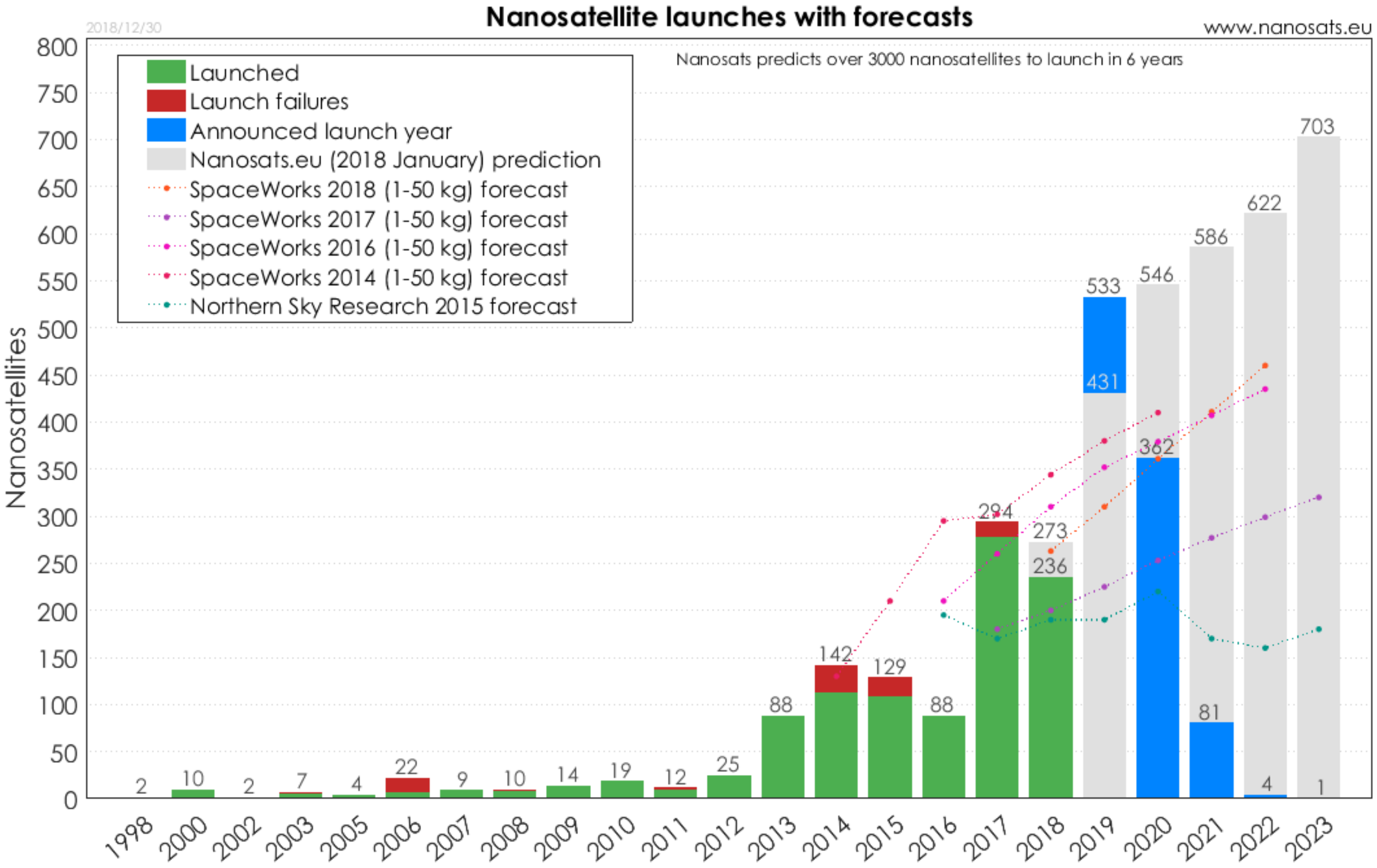
- No human presence
  - Finite ended development
  - No demands on technology
  - Competition of scattered subjects

Adriatic
Aerospace
Association

JADRANSKA AERO-SVEMIRSKA ASOCIJACIJA

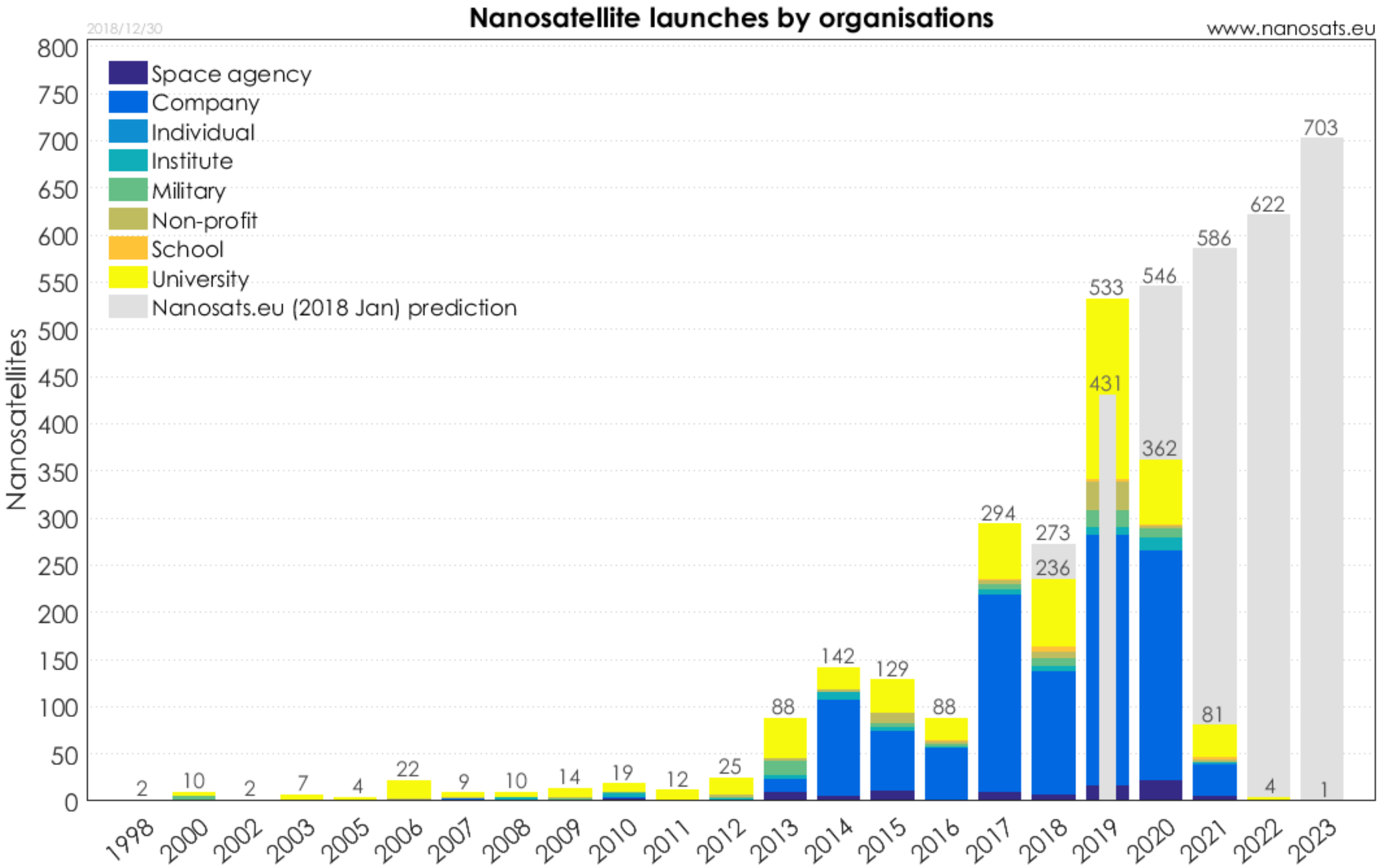
Entering Space Age

This is not the Space Age. It is not even the beginning of the Space Age. But it is, perhaps, the beginning of the beginning of Space Age.



https://www.nanosats.eu/

Signs of the beginning of the beginning of Space Age



https://www.nanosats.eu/

„Henry Ford” of Space Age is required

Central problem

Cheap, safe and without stress transport of humans to LEO.

- It is likely than in the 2030 time-frame, both low production cost and reusability on launchers would be a reality. However, neither low-cost production and operation or reusability on their own can significantly reduce the cost of launch (i.e. by orders of magnitude). (**Global Trends in Small Satellites , IDA-STPI**)

Alternatives to rocket launch

Use atmosphere as lifting media

Lift force of wings

$$\boldsymbol{F = q\,\frac{\rho v^2}{2}}$$

Density of atmosphere

$$\boldsymbol{\rho = 1.2\; e^{-0.000141\,h}} \quad \text{kg m}^{-3}$$

h= 10 000 m ; v= 256 m/s ; F= 9600 kg m^{-2}

h= 40 000 m ; v= 5 Ma ; F= 6160 kg m^{-2}

h= 80 000 m ; v= 10 Ma ; F= 86 kg m^{-2}

Possible solutions

- No alternative to chemical propulsion
  - Perhaps electric jet engines
- Synergy of jet engine and two component propulsion (**Reaction Engines**)
- Airplane – spacecraft combination (**Virgin Galactic**)

Atmospheric reentry

- As yet no satisfactory solution
- Development of efficient space propulsion system for slowing down to controlled flight velocity.

Deep space travel

Challenges

Propulsion

Ratio of payload to propellant large

Energy

Specific energy of source very large

Human crew

Self sustained bio systems

Adriatic
Aerospace
Association

JADRANSKA AERO-SVEMIRSKA ASOCIJACIJA

Propulsion systems for small satellites

(Global Trends in Small Satellites , IDA-STPI)

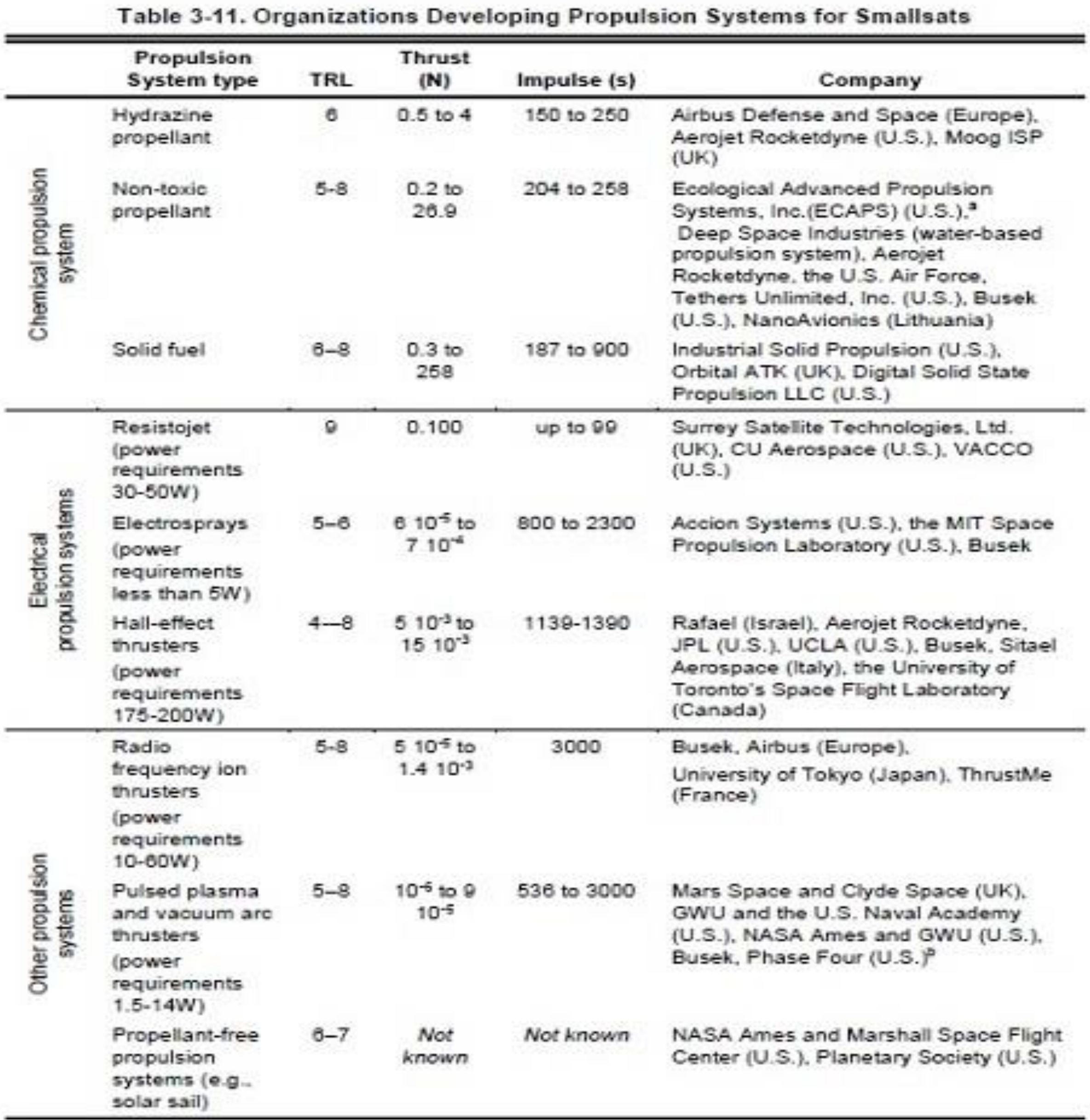


Table 3-11. Organizations Developing Propulsion Systems for Smallsats

	Propulsion System type	TRL	Thrust (N)	Impulse (s)	Company
Chemical propulsion system	Hydrazine propellant	6	0.5 to 4	150 to 250	Airbus Defense and Space (Europe), Aerojet Rocketdyne (U.S.), Moog ISP (UK)
	Non-toxic propellant	5-8	0.2 to 26.9	204 to 258	Ecological Advanced Propulsion Systems, Inc.(ECAPS) (U.S.),[a] Deep Space Industries (water-based propulsion system), Aerojet Rocketdyne, the U.S. Air Force, Tethers Unlimited, Inc. (U.S.), Busek (U.S.), NanoAvionics (Lithuania)
	Solid fuel	6–8	0.3 to 258	187 to 900	Industrial Solid Propulsion (U.S.), Orbital ATK (UK), Digital Solid State Propulsion LLC (U.S.)
Electrical propulsion systems	Resistojet (power requirements 30-50W)	9	0.100	up to 99	Surrey Satellite Technologies, Ltd. (UK), CU Aerospace (U.S.), VACCO (U.S.)
	Electrosprays (power requirements less than 5W)	5–6	$6\ 10^{-5}$ to $7\ 10^{-4}$	800 to 2300	Accion Systems (U.S.), the MIT Space Propulsion Laboratory (U.S.), Busek
	Hall-effect thrusters (power requirements 175-200W)	4—8	$5\ 10^{-3}$ to $15\ 10^{-3}$	1139-1390	Rafael (Israel), Aerojet Rocketdyne, JPL (U.S.), UCLA (U.S.), Busek, Sitael Aerospace (Italy), the University of Toronto's Space Flight Laboratory (Canada)
Other propulsion systems	Radio frequency ion thrusters (power requirements 10-60W)	5-8	$5\ 10^{-5}$ to $1.4\ 10^{-3}$	3000	Busek, Airbus (Europe), University of Tokyo (Japan), ThrustMe (France)
	Pulsed plasma and vacuum arc thrusters (power requirements 1.5-14W)	5–8	10^{-6} to $9\ 10^{-5}$	536 to 3000	Mars Space and Clyde Space (UK), GWU and the U.S. Naval Academy (U.S.), NASA Ames and GWU (U.S.), Busek, Phase Four (U.S.)[b]
	Propellant-free propulsion systems (e.g., solar sail)	6–7	*Not known*	*Not known*	NASA Ames and Marshall Space Flight Center (U.S.), Planetary Society (U.S.)

Energy balance for deep space travel with EM propulsion

Ionization power

$$\boldsymbol{power(MW) = 96\,\frac{eV(diss)\;m\left(\frac{fuel}{sec}\right)}{m(species\ in\ AU)}}$$

Energy for propulsion

For 1kg Xe ions in second 8.8 MW is necessary

Exhaust velocity 20 km/sec requires 200 MW power

Cylindrical flow of high density plasma

Plasma is in a cylinder of radius R, with velocity v and mass flow m_t of singly charged spices with mass M in AU.

Self repelling electric field in the flow is

$$\boldsymbol{E = 1.7 \times 10^{18} \frac{m_t r}{M v R^2} \left(\frac{Volt}{m}\right)}$$

which at r=R gives M acceleration

$$\boldsymbol{a = \frac{1.6}{M} 10^{26} \left(\frac{m}{s^2}\right)}$$

Confinement of plasma by self B field

- Magnetic field produced by plasma

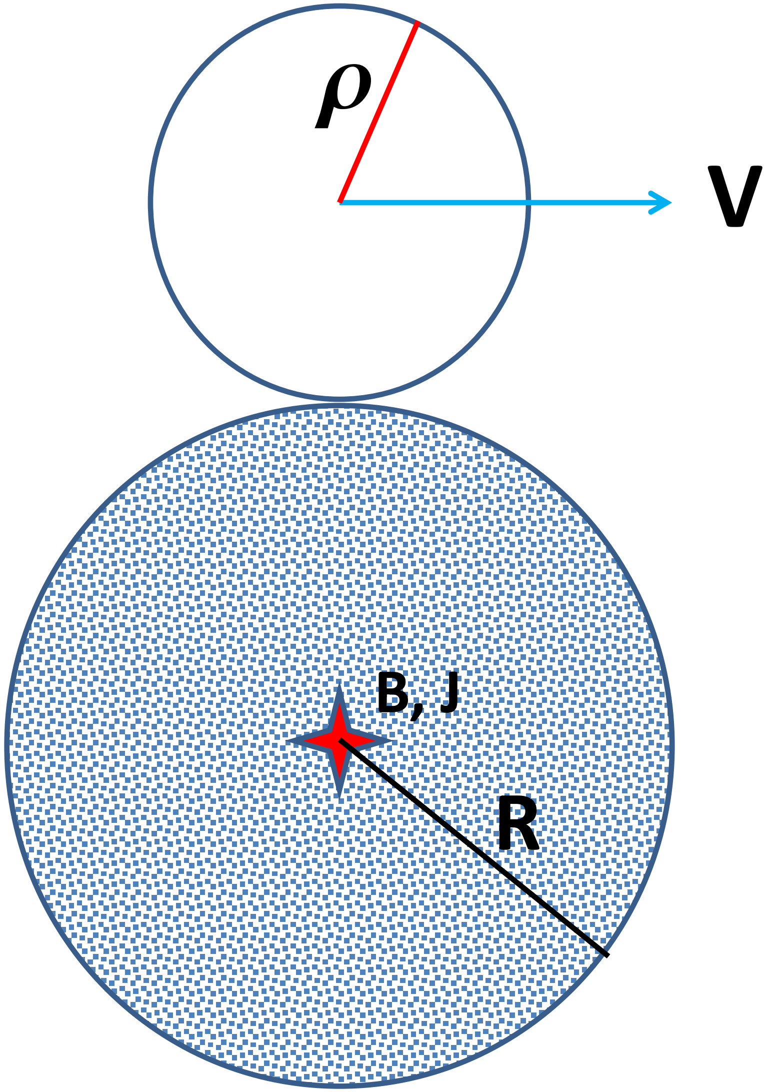
$$\boldsymbol{B = 19.2\,\frac{m_t r v}{M R^2}\ (T)}$$

It is by factor v^2/c^2 smaller than self repelling force by electric field.

Confinement with a ring current

$$\rho = 1.8 \times 10^{10} \frac{m_t}{RvB^2}$$

$$V = 1.72 \times 10^{18} \frac{m_t}{RvMB}$$



EM drive

- Propulsion could be source of EM radiation (microwaves, masers, light sources).
- Propulsion force is

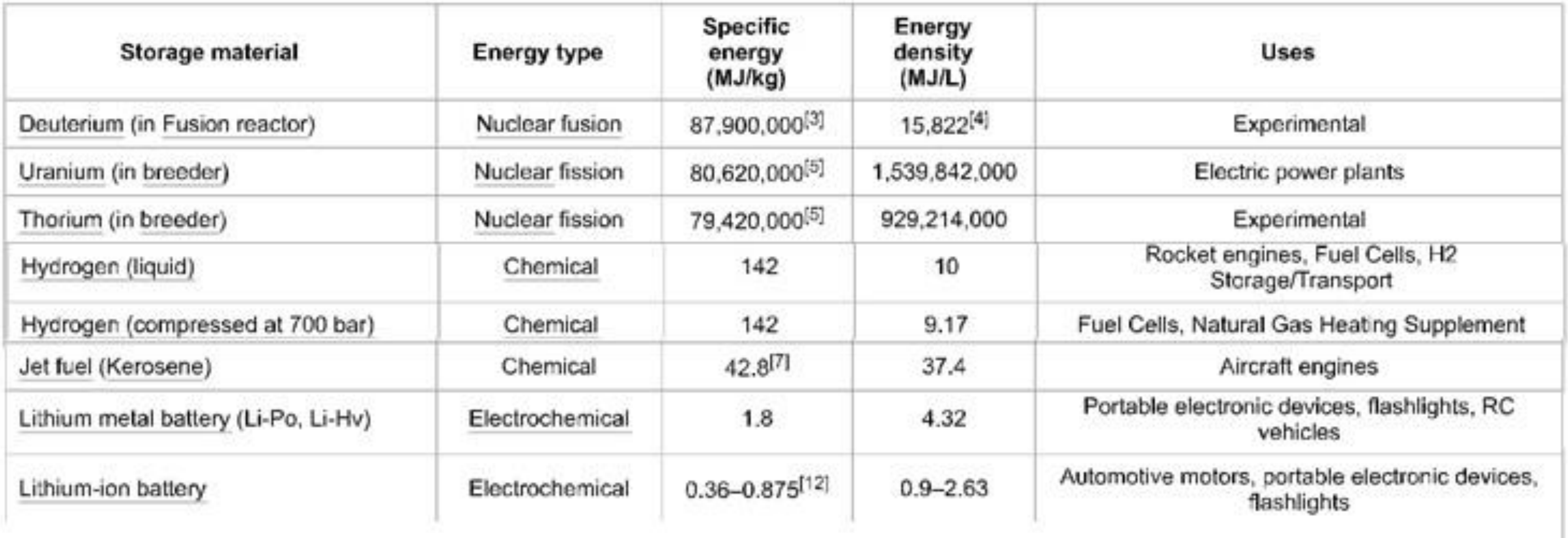
$$F = \frac{P(oyting\ power)}{c}\ (\frac{N}{m^2})$$

Power of 1000 MW/m^2 produces force of 3.3 N/m^2.

Sources of energy

required high specific energy

Energy density - Wikipedia



Storage material	Energy type	Specific energy (MJ/kg)	Energy density (MJ/L)	Uses
Deuterium (in Fusion reactor)	Nuclear fusion	87,900,000[3]	15,822[4]	Experimental
Uranium (in breeder)	Nuclear fission	80,620,000[5]	1,539,842,000	Electric power plants
Thorium (in breeder)	Nuclear fission	79,420,000[5]	929,214,000	Experimental
Hydrogen (liquid)	Chemical	142	10	Rocket engines, Fuel Cells, H2 Storage/Transport
Hydrogen (compressed at 700 bar)	Chemical	142	9.17	Fuel Cells, Natural Gas Heating Supplement
Jet fuel (Kerosene)	Chemical	42.8[7]	37.4	Aircraft engines
Lithium metal battery (Li-Po, Li-Hv)	Electrochemical	1.8	4.32	Portable electronic devices, flashlights, RC vehicles
Lithium-ion battery	Electrochemical	0.36–0.875[12]	0.9–2.63	Automotive motors, portable electronic devices, flashlights

The table does not include infrastructure for harnessing energy

Fission

Conversion of neutron energy into electricity

- Thermoelectricity – efficiency 15-20%
  - It is not feasible because of large power required and heating of the media would be prohibited.
- Photo electricity
  - Heating media to high temperature and converting radiative cooling emission into electricity.
  - At 1000 K appr. radiation power 57 kW/m^2

Fission for Space

- Technology well understood
- Safety from radiation impact on biological matter is easier achieved in space
- Infrastructure with new materials may considerably reduce its mass
- Control of energy output is manageable

Fusion

Most promising reaction

$$\mathrm{D+D} \longrightarrow \mathrm{T+p}$$

$$\longrightarrow \mathrm{He + n}$$

Li – scarce element

T – “short lifetime” and radioactive

Fusion

- Technology
  - Magnetic containment
    - Overcome Coulomb barrier (high temperature required), small cross section (high density required)
  - Muon assisted fusion
  - Laser induced fusion
- Absorbing energy of products is great problem
  - 1 GW at r = 10m sphere has power flux 800 kW/m^2
  - Larger scale of absorber smaller power flux but more difficult containment.

Solar energy

- Circular Solar energy collector of radius **r** in Space produces approximate power

$$P = .5 \times 1.36\, r^2 \pi \ (kW)$$

For r=1000 m the power output is P=4 300 000 MW

- No adequate energy storage system for such power output and use in systems with large intake of power.

Is this a vision of future space travel?