**Planet Disassembly**

As has been pointed out by [Freeman Dyson](http://www.aeiveos.com:8080/%7Ebradbury/ETI/Authors/Dyson-FJ/index.html) and others, planets are not a particularly useful form for the matter in the universe.  The gravity imposes travel costs for people or machines who would like to travel over a wider range than the planet on which they originated.  Perhaps the only benefit we may see in gravity is that in sufficient quantity it causes the retention of an atmosphere which allows the evolution of life.  In the form of planets, a significant majority of the matter is unavailable for useful purposes.  Planets sequester materials which may be valuable and useful in the construction of machines or structures which have a concrete benefit to intelligent pursuits.

It would be much better if the barriers to travel were reduced and heretofore unusable matter were made available for the construction of biological or non-biological machines.  To achieve this result we must discuss the disassembly or dismantlement of the planets.

One of the earliest references to this idea is the paper [*Search for Artificial Stellar Sources of Infrared Radiation*](http://www.aeiveos.com:8080/%7Ebradbury/ETI/Authors/Dyson-FJ/SfASSoIR.html) by [Freeman Dyson](http://www.aeiveos.com:8080/%7Ebradbury/ETI/Authors/Dyson-FJ/index.html) in [Science](http://www.sciencemag.org/) in 1960.  In that paper Dyson documented that the mass of Jupiter (2 ×1027 kg) could be disassembled and put to useful purposes using the energy generated by the sun in 800 years (1044 ergs).  The purpose of this discussion is to update the ideas promoted by Dyson in light of more recent engineering concepts such as Solar Cells, Solar Power Satellites, Mass Drivers and Nanotechnology.

The simplest calculations of the energy required to disassemble a planet relate to the energy required to gravitationally disrupt the body by accelerating each particle of matter to its escape velocity.  This is the energy required is known as the [gravitational binding energy](http://www.wikipedia.org/wiki/Gravitational_binding_energy) (see also [Wong [1998]](file:///C:\Users\Todd\Desktop\MatrioshkaBrainsPaper_files\PlntDssmbly.html#WongM1998)) and is given by the formula: 

|  |  |  |
| --- | --- | --- |
|  | *U* = (3/5) (*Gm*2) / *r* | (1) |

where *G* is Newton's Gravitational constant, *m* is the mass of the planet, *r* is the radius and *U* is the gravitational binding energy. If we can develop a scheme to deliver the energy, *U*, to each particle of the planet we will have effectively disassembled (or destroyed) it.

**Planet Vaporization**

Future technologies might produce giant reflectors to focus IR, visible and UV photons produced by the sun onto the planet.  Materials making up the surface of solid planets have boiling points from 2500 to 3800oK.  Applying sufficient energy would heat the surface material of the planet to the boiling point.  If enough energy were applied, a significant fraction of the gas molecules would achieve escape velocity and the planet would literally evaporate.  The efficiencies of this process are high, perhaps 90% of the energy released by the sun could be utilized in this process.  However, the resulting gas would have to be captured and put through successive cooling phases in order to separate out useful materials.  Since, these methods are not typically used in materials processing due to the high energy costs, there is little research on the mass requirements and techniques that could utilize this process.  As a result it is difficult to make estimates of the time scales involved.

**Mechanical Disassembly**

An alternate approach is to convert solar energy to electricity and use the electricity to do mechanical disassembly of the planet.  Since this approach has precedents in our current material processing industries, e.g. the aluminium and steel industries, there is much more information available on the energy costs and production methods.

The Sun produces 3.82 ×1026 W of energy.  The highest efficiency solar cells can achieve a conversion efficiency of 35%[FN1](file:///C:\Users\Todd\Desktop\MatrioshkaBrainsPaper_files\PlntDssmbly.html#FootNote1).  Solar cells currently in mass production have lower efficiencies in the 12-20% range. Assuming high efficiency conversion of sunlight to electricity,  the energy available for the disassembly of planets in our solar system would be ~1.15 ×1026 W.   [Table 1](file:///C:\Users\Todd\Desktop\MatrioshkaBrainsPaper_files\PlntDssmbly.html#Table1) provides a list of bodies in the solar system, their gravitational binding energy and disassembly times using estimated available power. 

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Table 1. Gravitational Binding Energy and Disassembly Time** | | | | |
| **Body** | **Mass** | **Radius** | **Gravitational   Binding Energy** | **Total Solar Output   Disassembly Time** |
| (kg) | (km) | (J) |
| Mercury | 3.3 ×1023 | 2,440 | 1.80 ×1030 | 5 hours |
| Venus | 4.9 ×1024 | 6,052 | 1.58 ×1032 | 16 days |
| Earth | 5.9 ×1024 | 6,378 | 2.18 ×1032 | 22 days |
| Mars | 6.4 ×1023 | 3,397 | 4.90 ×1030 | 12 hours |
| Jupiter | 1.9 ×1027 | 71,492 | 2.04 ×1036 | 563 years[\*](file:///C:\Users\Todd\Desktop\MatrioshkaBrainsPaper_files\PlntDssmbly.html#FootNote1) |
| Saturn | 5.7 ×1026 | 60,268 | 2.16 ×1035 | 60 years |
| Uranus | 8.7 ×1025 | 25,559 | 1.19 ×1034 | 3.3 years |
| Neptune | 1.0 ×1026 | 24,766 | 1.72 ×1034 | 8.2 years |
| Pluto | 1.3 ×1022 | 1,137 | 5.91 ×1027 | 2 minutes |
| Moon | 7.4 ×1022 | 1,738 | 1.25 ×1029 | 19 minutes |
| Asteroid (1km) | 1.6 ×1012 | 0.5 | 1.98 ×1011 | << 1 microsecond |

\* It is worth noting that the 563 year disassembly time for Jupiter would be only 169 years if the full power output of the sun were available.  These numbers are not significantly different from [Dyson's](http://www.aeiveos.com:8080/%7Ebradbury/ETI/Authors/Dyson-FJ/index.html)[estimate of 800 years](http://www.aeiveos.com:8080/%7Ebradbury/ETI/Authors/Dyson-FJ/SfASSoIR.html#JupiterDisassemblyTime) which was based on both the time to disassemble Jupiter and rearrange the resulting material into more useful orbits.

The good news is that planet disassembly using available energy seems feasible in reasonable time scales.  Particularly important is the observation that a total of only 12 years of available solar power is required to push all of the matter out of the gravitational wells of all of the planets and asteroids with the exception of Jupiter and Saturn.  Less than 100 years is required if we include Saturn but not Jupiter .  The bad news is that we do not have even a small fraction of the Sun's power output at our disposal.  We must develop an approach which would make available a large amount of power if planet disassembly is to be a realistic discussion.

Obviously we need to leverage our efforts to get us to the point where we have a significant fraction of the solar power available for construction work.  There are two possible approaches to this, leverage with asteroid(s) or leverage with Mercury.  In either of these approaches the basic job is to disassemble a smaller body to provide the surface area required to collect a significantly larger amount of energy than is available to the body itself.

**Solar Collectors**

Solar power converter systems (collectors) generally consist of solar concentrators (either reflectors or lenses) and solar cells.  This is because the solar cell conversion efficiencies are achieved at solar flux concentrations greater than 100x the normal Earth orbit solar flux levels.  To get the highest conversion efficiencies, the sunlight must be concentrated.

On Mercury the solar flux is very high (9214 W/m2) while at the asteroid belt it is rather low (~ 200500 W/m2).  The choice of whether to use asteroids or Mercury as a base for solar collection has significant effects on the architecture of the solar collectors and solar cells.   On Mercury a concentration of ~10x would produce the highest power conversion efficiencies.  The high temperatures and radiation levels near Mercury would however require significant attention to keeping the solar cells cool and shielding them from excessive radiation.  In contrast in the asteroid belt, solar concentrations of 1000x might be required to produce the highest efficiencies.  Cooling and radiation on the other hand are much smaller problems in the asteroid belt.  Collectors on or near Mercury will have small reflectors or concentrators and careful attention to the rejection of infrared radiation and shielding from solar radiation.  Collectors in the asteroid belt will require very large reflectors or concentrators and have minimal cooling and shielding requirements.  Lacking specific designs, it is difficult to say in which location the element availability best matches the solar collector designs.  We must assume that there should be material in both locations in significant excess of the actual collector design requirements.  Since there are a variety of collector architectures it is distinctly possible that their designs would be tailored to match the element availabilities of the two locations.

**Solar Collectors from Asteroids**

The asteroid approach has some advantages.  Asteroids may pass relatively close to the Earth and so travel time to them may be minimal and the work could be supported from Earth.  Solar system evolutionary theory would predict that because many asteroids evolved in the middle regions of the solar system, they are likely to contain higher percentages of the lighter elements such as carbon and aluminium compared with bodies formed in the inner regions of the Solar System such as Mercury.  This is reflected in the lower density of  asteroids, averaging 3.0 g/cm3 compared to Mercury's 5.43 g/cm3.  The lighter elements are the preferred materials for solar collector construction for reasons of weight and strength.   Asteroids have disadvantages as well.  The development of multiple asteroids may be required to provide all of the material necessary for Sun-surrounding solar collectors.  Significant orbital corrections would be required to reposition solar collectors produced from asteroid material in more optimal locations closer to the sun where the solar power flux is greater.  Orbital corrections usually require the expenditure of mass which might be better utilized in the construction of the collectors themselves.

**Solar Collectors from Mercury**

The Mercury approach has the key advantage of a very high solar flux.  So at least an order of magnitude less material is required for collectors in an orbit near Mercury, compared with orbits near the asteroid belt for the same amount of solar energy harvested.  A disadvantage may be that the heat and radiation levels as so high in the vicinity of Mercury may shorten the life of the solar collectors.  An orbit between Mercury and Venus may be more suitable for longer lived solar collectors.  Even in an orbit near Venus, the solar flux (2660 W/m2) is still much higher than the asteroid belt.  The mass of Mercury is 3.3 ×1023 kg, the estimated mass of the asteroids is 5.9 ×1021 kg, so even if the fraction of ideal elements for solar collectors is lower in Mercury than it is in the asteroids, it provides much more material to work with.

The basic strategy for mining operations would be relatively simple.  First deliver to Mercury a von Neumann automated factory (or nanoassembler factory) which is designed to replicate itself.  Available power is used to process sufficient materials to replicate solar cells over much of the surface of the planet.   Mining machines then burrow into the planet, cutting planetary materials into convenient blocks which are delivered to rail guns which accelerate the materials into space at escape velocity.  The factories have to produce four basic machine types: solar collectors, mining machines, transportation machines and rail guns.   Primitive forms of all of these machines have been previously designed and built.  Only large scale mining machines and rail guns remain untested in space conditions.  The requirement for transportation machines could be minimized by positioning the rail guns at the bottom of ever deepening craters and allowing the mining machines to cut away blocks that fall down the slopes into the rail gun intakes.

The surface of Mercury could provide approximately ~3.4 ×1017 W of power, which would allow planet disassembly in ~550,000 years.  However, if the material blocks which are lifted into space are reprocessed by space factories into large thin solar collectors, an exponential growth in the amount of power available is possible.   If the power is delivered back to the planet and used to accelerate disassembly operations then the time drops considerably.  A fully efficient cycle would allow the disassembly of Mercury in less than month!  The factors affecting the disassembly time the most would be the fraction of material in the planet useful for collector construction, the solar collectors mass per area (areal mass) and the transport time for the material to the final collector positions.

**Collector Composition**

[Table 2](file:///C:\Users\Todd\Desktop\MatrioshkaBrainsPaper_files\PlntDssmbly.html#Table2) details the composition of the Earth, some reasonable adjustments for Mercury and an estimate of the quantity of materials available. 

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Table 2.  Composition of  Earth and Mercury** | | | | | |
| **Element** | **Earth's Mass %** | | | **Mercury (est.)** | |
| **Crust** | **Core** | **Whole Planet** | **Mass %** | **kg** |
| Oxygen (O) | 46.6% | 5.18% | 31.7% | 25% | 8.2 ×1022 |
| Iron (Fe) | 5.00% | 85.55% | 32.0% | 36% | 1.2 ×1023 |
| Magnesium (Mg) | 2.09% | 0.35% | 14.9% | 14% | 4.6 ×1022 |
| Silicon (Si) | 27.7% | ? | 14.6% | 16% | 5.2 ×1022 |
| Nickel (Ni) |  | 2.69% | 1.7% | 2% | 6.6 ×1021 |
| Calcium (Ca) | 3.63% | ~0% | 1.7% | 2% | 6.6 ×1021 |
| Aluminium (Al) | 8.13% | ~0% | 1.4% | 1% | 3.3 ×1021 |
| Sulfur (S) |  | 0.45% | 0.9% | 1.1% | 3.6 ×1021 |
| Chromium (Cr) |  | 0.41% | 0.3% | 0.5% | 1.6 ×1021 |
| Sodium (Na) | 2.83% | 0.01% | 0.2% | 0.1% | 3.3 ×1021 |
| Manganese (Mn) | 0.10% | 0.41% | 0.2% | 0.4% | 1.3 ×1021 |
| Phosphorus (P) | 0.12% | 0.35% | 0.1% | 0.1% | 3.3 ×1021 |
| Cobalt (Co) |  | 0.22% | 0.1% | 0.2% | 6.6 ×1021 |
| Titanium (Ti) | 0.44% | 0.08% | 0.07% | 0.2% | 6.6 ×1021 |
| Potassium (K) | 2.59% | 0.02% | 0.02% | 0.01% | 3.3 ×1020 |
| Other nonmetals   (excluding noble gases) | 0.01-0.0001% each | | |  |  |
| Other metals (nonradioactive) | 0.01-10-7% each | | |  |  |

Source: Earth composition adapted from [Kargel & Lewis (1993)](file:///C:\\Users\\Todd\\Desktop\\MatrioshkaBrainsPaper_files\\PlntDssmbly.html" \l "KargelJS1993)

A sphere surrounding the sun in Mercury's orbit has an area of 4.2 ×1022 m2, while at the orbit of Venus it must have an area of 1.5 ×1023 m2.  Mercury (at 7.8 kg/m2) and Venus (at 33 kg/m2) *both* provide sufficient structural material to envision constructing structures in their respective orbits that would be capable of gathering the entire energy output of the sun. Making use of the most abundant materials, it would appear that the solar cells should be constructed from hematite (Fe2O3) with a silicon surface on the sun side.  These structures could be reinforced with sapphire (Al2O3) or diamond whiskers, or buckytubes. Carbon constitutes 27% of the 5 ×1020 kg atmosphere of Venus.  Mining operations using rotating sky hooks with large scoops or upper atmosphere ram-jet mining ships could easily provide ~1.4 ×1020 kg of carbon between the orbits of Mercury and Venus.  Dismantlement of Venus itself would be most efficient after first removing the atmosphere to eliminate drag losses on planetary materials accelerated into space..

**Collector Areal Mass**

The collector areal mass is a key determinant of the disassembly time.  The lower the areal density, the greater the energy which can be collected from each kg of material delivered from the planet into space and the faster the exponential growth.  Extensive material exists on studies of light-weight solar cells, solar collectors, solar sails, solar power satellites and space-based telescopes.  [Table 3](file:///C:\Users\Todd\Desktop\MatrioshkaBrainsPaper_files\PlntDssmbly.html#Table3) lists some of these designs and areal densities.   
  

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Table 3. Collector Areal Densities** | | | | |
| **Collector Description** | **Diameter   (m)** | **Areal Density   (kg / m2)** | **Comments** | **Source(s)** |
| Large Amateur Telescope Primary Mirror | 1.8 | 431 |  | [LAT Project](http://www.hpl.hp.com/astro/group70/) |
| Keck Primary Mirror | ~8 | ~190 |  |  |
| Hubble Space Telescope Primary Mirror | 2.4 | 183 |  | [STSCI](http://sites.stsci.edu/full/hubble/what/vital.html) |
| International UV Explorer |  | 42 | Be mirror |  |
| NGST Primary Mirror | 6-8 | 15 | Be mirror w/ active control | [NGST SBMD](http://ngst.gsfc.nasa.gov/project/procure/Beryllium.html#references) |
| 5 | Be mirror alone |  |
| NGST Demonstrator Composite Mirror | 0.6 | 1.9 |  | NASA GSFC   [Ultralite Optics](http://snoopy.gsfc.nasa.gov/%7Elunartel/lun7.html) |
| Be mirror |  | 1 | Current limits | SPIE Telescope Seminar |
| Kuiper Express Solar Cells |  | 1 | (proposed) | [21st-Century Spacecraft](http://www.aeiveos.com:8080/%7Ebradbury/ETI/Authors/Dyson-FJ/21stCntSpc/21stCntSpc.html) |
| [BP 590F Solar Power Module](http://www.solarsolutions.ca/mods.htm) | 0.63 m2 | 11.9 | terrestrial |  |
| [NASA Lewis](http://www.grc.nasa.gov/)/[ENTECH](http://www.entechsolar.com/)[ScarletTM](http://www.aec-able.com/solar/scarlet.htm) PV concentrator array |  | 3.3 | On [Deep Space 1](http://nmp.jpl.nasa.gov/ds1/)  GaInP2/GaAs/Ge (22%) | Piszczor, M. F. et al, IEEE Conf., 1991  [Scarlet Program](http://powerweb.grc.nasa.gov/psi/DOC/scarlet.html) |
| Projected Mars Thin-Film Arrays |  |  | 1.7 kW/kg (conservative)   15 kW/kg (optimistic) | [Photovoltaic Power Options for Mars](http://powerweb.lerc.nasa.gov/pv/marspower.html), 1991 |
| Nanotechnology based solar collectors |  | ~10-3 |  | [Drexler, JBIS, 1992](file:///C:\Users\Todd\Desktop\MatrioshkaBrainsPaper_files\PlntDssmbly.html#DrexlerKE1992) |
| Solar Sails |  |  |  |  |
| Theoretical limits |  | 0.001 |  | [21st-Century Spacecraft](http://www.aeiveos.com:8080/%7Ebradbury/ETI/Authors/Dyson-FJ/21stCntSpc/21stCntSpc.html) |

Obviously if the collectors are made too thin they become solar sails and would require significant engineering of positioning technologies such as rockets, ion jets, tether cables, etc. to be kept in a proper orbit.  So a balance must be created between the goal of accelerating energy collection by decreased areal density and the additional engineering problems created by excessively thin cells.  Ideally the mass should be such that the photon radiation pressure and solar wind ion pressure significantly balances the gravitational attraction of the sun.

**Transport Time**

There is a tradeoff regarding the problem of doing material refining on-planet or off-planet.  Doing the material refining on-planet reduces the energy required to transport the material into space because only those materials best suited for solar collector construction are accelerated to escape velocity.  Waste materials remain behind in the planet's gravity well.  Because some of the available energy is being diverted into refining operations, the amount of energy available for material transport (rail-gun power) would be diminished.   Whether this approach would accelerate or decelerate the construction process depends primarily on the fraction of material from the planet which can be efficiently used in the construction of space based factories and collectors.  If the space-usable raw materials percentage is high, then the optimal approach is to send everything into space.  If the space-usable fraction is low, then the optimal approach is to refine on the planet and send only the usable materials into space.  As the amount of power available in space increases and the surface area of the planet which can receive that power decreases, shifts must occur in the process.  If the mining operations create cones with steep side walls, the effective surface area of the planet may be increased to extend the period during which energy transmission from space based solar collectors to the planet surface is possible.

At some point, the amount of power available in space, significantly exceeds the power which can be delivered to the planet in a useful form (raw reflected light or microwave or laser energy).

When the limits of power which can be delivered to the planet are reached and alternate processing method must be implemented.  There are three possible solutions at this point.

1. Planetary vaporization would be possible because there would be ample material in space to capture the escaping gases and factories which could process that material effectively.
2. The planet could be cut into smaller planetesimals that could be separated to make more surface area available for power reception.
3. The planet surface could be grown.  Collector surfaces are placed on supporting columns which vertically grow to place the collectors at an ever increasing altitude where an increased surface for power collection is available.  Small holes in the collectors would provide exit paths for high velocity projectiles from the rail guns.

Further studies are needed to determine the most efficient method or combination of methods is best for the utilization of the exponential growth in available power.

**Footnotes**

1. Theory limits normal solar cells to conversion efficiencies to 43.9% under concentrated sunlight.  Recent work by [Shaller & Klimov (2004)](file:///C:\\Users\\Todd\\Desktop\\MatrioshkaBrainsPaper_files\\PlntDssmbly.html" \l "SchallerRD2004) suggests that using nanocrystals efficiencies for solar cells may be pushed to 60.3%.

**Energy Required to Break Bonds**

The binding strength of a solid is molar enthalpy change required to completely separate the entities (ions or molecules) that compose the solid and is known as its **Lattice Enthalpy** (HL).  Expressed as chemical equations this would be:

LiCl (s)  Li+(g) + Cl(g)

or

H2O (s)  H2O (g)

The **Born-Meyer equation** provides the theoretical basis for the lattice enthalpy:

HL = |*z*1*z*2| *N*A*e*2 / (4***d*) (1 - *d*\* / *d*) *A*

Where *z*1 and *z*2 are the charges on the cations and anions, *N*A is Avagadro's constant (6.02214 ×1023), *e* is the elementary charge (1.602177 ×10-19 C), ** is the vacuum permittivity (8.85419 ×10-12 J-1C2m-1), *d* is the distance between the ions, *d*\* is an empirical parameter taken to be 34.5 pm, and *A* is the **Madelung Constant**which varies in a range from ~1.7 to 2.4 depending on the material.  The most important aspect of the equation is that HL is proportional to *z*1*z*2/*d*  meaning that the largest lattice enthalpies will be in solids with large charges and small ions.  This can be seen in the following table. 

|  |  |  |  |
| --- | --- | --- | --- |
| **Lattice Enthalpies of common solids** | | | |
| Compound | HL  kJ/mol | Lattice Spacing   A | Madelung   Constant |
| Al2O3 | 15916 |  | 4.1719 |
| Mn2O3 | 15146 |  |  |
| Fe203 | 14774 |  |  |
| SiO2 | 15135 |  | 2.2197 () |
| TiO2 | 12150 |  | 2.408 |
| Mn(OH)4 | 10933 |  |  |
| CeB6 | 10083 |  |  |
| VN | 8283 |  |  |
| TiN | 8130 |  |  |
| MgO | 3850 |  |  |
| CaO | 3461 |  |  |
| MgS | 3406 |  |  |
| SrO | 3283 |  |  |
| CaS | 3119 |  |  |
| BaO | 3114 |  |  |
| SrS | 2974 |  |  |
| BaS | 2832 |  |  |
| LiF | 1037 | 2.014 (200)   1.424 (220) |  |
| NaF | 926 |  |  |
| LiCl | 852 |  |  |
| KF | 821 |  |  |
| LiBr | 815 |  |  |
| NaCl | 786 | 2.820 | 1.74756 |
| LiI | 761 |  |  |
| NaBr | 752 |  |  |
| KCl | 717 | 3.14 |  |
| NaI | 705 |  |  |
| KBr | 689 | 3.29 |  |
| KI | 649 |  |  |

Sources: [Atkins, P. (1997)](file:///C:\Users\Todd\Desktop\MatrioshkaBrainsPaper_files\PlntDssmbly.html#AtkinsP1997), pg 366-370;   
[Lide, D. R. (1992)](file:///C:\Users\Todd\Desktop\MatrioshkaBrainsPaper_files\PlntDssmbly.html#LideDR1992), Chp. 12..

For our purposes, we will use a generous 20,000 kJ / mol as the energy required to break the chemical bonds binding together the elements of the planets.

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**Other Notes:**

From: *Solar Cells and Their Applications*, Chapter 13, pp 285-299.

Solar Cells for space usage have parameters as follows:

Si: 2.40 g/cm3, GaAs/Ge, 5.46 g/cm3 (from 50-200 m thick)   
Coverglass 2.2-2.6 g/cm3 (from 75-700 m thick)   
Coverglass is necessary to protect the cells from radiation.

A concentration to 10,000 suns and produces 3,300 K and is equivalent in power to a megawatt.

Solar absorbers, such as the [porcupine](http://www.weizmann.ac.il/solar_energy/Avi/DIAPR/Porcupine_Avi.html) can work up to 5,000 suns

**WWW Sources:**

* Photovoltaic Information
  + [National Center for Photovoltaics](http://www.nrel.gov/ncpv/) @ [National Renewable Energy Laboratory](http://www.nrel.gov/)
  + [Photovoltaic and Space Effects Branch](http://powerweb.grc.nasa.gov/pvsee/) @ NASA [Glen Research Center](http://www.grc.nasa.gov/)
  + [Rocketdyne](http://www.boeing.com/space/rdyne/index.html) discussion of [solar power and Solar Two power station](http://www.boeing.com/space/rdyne/library/th13/tower.htm).
  + [SpaceDaily](http://www.spacer.com/) discusses [Photovoltaics & Solar Cells](http://www.spacer.com/spacecast/news/solarcell-99c.html)
  + [Weismann Institute](http://www.weizmann.ac.il/) [Solar Energy Page](http://www.weizmann.ac.il/solar_energy/)
  + Univ. of Florida [Solar Energy and Energy Conversion Laboratory](http://www.me.ufl.edu/SOLAR/welcome.htm)
  + [Entech, Inc.](http://www.entechsolar.com/)
  + [Seimens Solar](http://www.solarpv.com/)
  + [The Solar Concentrating Website](http://www.users.globalnet.co.uk/%7Eblootl/trackers/index.htm)
  + [The ConSolar Homepage](http://www.weizmann.ac.il/consolar/consolar.html)
  + [Solarcell Concentrator Hits 36% Energy Conversion Rate](http://www.spacedaily.com/news/solarcell-03c.html), [SpaceDaily](http://www.spacedaily.com/) (29 Jul 2003).
* Solar Furnace Information (1 sun = 1 kW/m2)
  + [NREL](http://www.nrel.gov/) and [Sandia](http://www.sandia.gov/) collaborate on [EREN](http://www.eren.doe.gov/)'s [SunLab](http://www.eren.doe.gov/sunlab/) . Sandia hosts [National Solar Thermal Test Facility](http://www.sandia.gov/Renewable_Energy/solarthermal/nsttf.html) with a peak power of 5 MW (~50,000 suns) at a flux density of 2,600,000 W/m2 providing 2480o K peak temperatures.  NREL hosts the 10 kW High-Flux Solar Furnace which typically achieves 2000 suns (~20,000-50,000?). NREL pages document their [Solar Industrial Research](http://www.nrel.gov/lab/pao/solar_industrial.html) and [Solar powered laser](http://nrelinfo.nrel.gov/hot-stuff/press/solar.html).  Research is conducted with the [Univ. of Chicago](http://www.uchicago.edu/) [High Energy Physics](http://hep.uchicago.edu/)[Nonimaging Optics](http://hep.uchicago.edu/solar/NIoptics.html) group.
  + [OIT](http://www.oit.doe.gov/) [High-Flux Solar Furnace](http://www.oit.doe.gov/Research/Projects/469.htm)
  + [Polytechnical College](http://rhlx01.rz.fht-esslingen.de/) of Esslingen, Germany: [High-Flux Solar Furnace](http://rhlx01.rz.fht-esslingen.de/projects/alt_energy/sol_thermal/flux.html)
  + [University of Minnesota](http://www.umn.edu/) [Dept. of M.E.](http://www.me.umn.edu/) has a [Solar Furnace](http://www.me.umn.edu/biennial/pp.html) that can achieve 7,000 suns and temperatures from 1,000-3,000 K.
  + [Paul Scherrer Institut](http://www1.psi.ch/) has a [70 kW parabolic concentrator](http://www1.psi.ch/www_f5_hn/Solar/solar_home.html) which produces  4,000 suns
  + ANUTECH has produced [400 m2 350 kW parabolic concentrators](http://www.anutech.com.au/physci/opps/bigdish.html)
  + [Plataforma Solar de Almería](http://psaxp.psa.es/)
  + [Red Rock Energy](http://www.redrok.com/main.htm): Heliostats & Links
  + Circa 1960 [photo](http://www.caltech.edu/%7Ematsci/duwez_furnace.html) of Dr. Pol Duwez Solar Furnace at [Caltech](http://www.caltech.edu/)
  + [STL](http://www.p3.org/stl/hp1.html) [Solar Energy Units](http://www.p3.org/stl/hp6.html)
* Lattice Energy Information
  + Purdue review of [Lattice Energy](http://chemed.chem.purdue.edu/%7Egenchem/topicreview/bp/ch7/lattice.html)
  + [Correlation of Melting Point with Lattice Energy for Cubic Ionic Solids](http://www.tulane.edu/%7Ebmitche/book/mptab.html)
* Gravitational Binding Energy Information
  + [rec.arts.sf.science](news:rec.arts.sf.science) [FAQ](http://www.treitel.org/Richard/rass/qdfaq.html)
  + Star Wars - Technical - [Death Star Firepower](http://www.stardestroyer.net/Empire/Tech/Beam/DeathStar.html) (has discussion of gravitational binding energy)

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