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1. Check Fusion Power Associates Website (http://fusionpower.org), plus 2 other websites. Who has the best explanation of what fusion is & why we should expedite its development? (limit to 2 paragraphs)

    - Of the three websites I reviewed, I believe the General Atomics Fusion Education website (1) most effectively explains the science behind fusion and why scientists are working so hard to make it viable on a large scale. The other websites address these two components, but do so by leaving out practical knowledge of the technology and the broad history of its development. These websites also do not always define technical terms that an ordinary viewer might not understand.
    The GAT website, however, breaks down its summary into an easy-to-follow "what, how, why, when" format that succinctly covers the basics of fusion power. When the article does use technical jargon, it defines the words in understandable terms. This website's balance of depth and breadth make it appealing to many audiences, and make it my top choice.

Other websites: (1) http://fusioned.gat.com/images/pdf/what_is_fusion.pdf
(2) https://lasers.llnl.gov/science_technology/fusion_science/

Excellent

2. As energy Czar, you are to develop a future (~30 year) program using fusion vs. clean coal. Discuss figures of merit for comparison using a table. Make a decision and justify.
Ex. Assume fusion plant is by Fusion Studies Lab in Illinois. Assume ITER type.

	Fusion	**CC**
Cost of construction	High: ITER ≈ US$ 5B[1]; NIF Project ≈ US$ 3.5 B[2]	Med: FutureGen ≈ US$ 1.5 B[3]
Cost of output power	High/Med: Similar to power from other "responsible" electricy generation techniques (ex. Wind, solar)[4]	High at first/Low later?: Argument that clean coal electricity in 2020 will be cheaper than today's electricity from coal w/o CCS[5]
Time for construction	High: ITER, from breaking ground to first plasma ~10 yrs[6]	Med: FutureGen, from breaking groud to first operations ~ 4 yrs[7]
Lifetime of plant	ITER: 30 yrs[8]	Linden, NJ Clean Coal Plant: expected 50 yrs[9]
Environmental Impact	High: rxn. releases no CO_2 and rxn. products can be recycled as fuel for more rxns.	Reduce emissions through deep subterranean storage of liquified CO_2, but there is potential for leakage & impacts on geology, H_2O quality. Also likely some emissions of NO_x, SO_x, particulates.[10]
Security of supply	High/Med: Supply of deuterium nearly inexhaustible. Natural tritium rare but can be bred via the fusion process.	Med: US land has 200 yrs of resources[11], but any fossil fuel is exhaustible at some point.

Decision: We will proceed with development of a fusion-based energy economy. Though the initial cost and ramp-up time of the clean coal plant are lower, as fusion research progresses, fossil fuel technology will likely become more obsolete and less socially desirable. In the long term, the indirect costs of choosing coal – such as healthcare, exploration for new resources, and geological management of sequestration sites – will bring the financial and environmental costs of CC to a higher level. Because of its technical novelty, fusion research may also promote technological innovation with a more diverse array of applications (this is speculation only). In summary, fusion carries lower long-term costs and environmental impact, and is a more secure supply. For these reasons we choose a fusion program.

3. From textbook: 1.2, 1.5. Compare to 1lb TNT (joules), 1.8. (Hint: for 1.8: see ~3.9, relation between CMS and lab angles)

   **See hand-written pages

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4. **Optional Extra Credit, 20%:** Carbon cycle: How is the carbon created to begin with? Is the creation energetically favorable (i.e. what are the Q-values of the reaction you prepare)?

The following reaction describes the formation of ^{12}C:

$$^4_2\alpha + {}^4_2\alpha \rightarrow {}^8Be\ (unstable), + {}^4_2\alpha \rightarrow {}^{12}C$$

The reaction occurs mainly in stars in the red-giant stage and later[12].

Analysis of Q-value: $Q = -(\Delta m)c^2$

$$\Delta m = m_f - m_i = m_{12C} - 3m_\alpha = (1.9927\cdot10^{-26}\,kg) - 3(6.64455\cdot10^{-27}\,kg) = -6.71\cdot10^{-30}\,kg$$

$$\hookrightarrow Q = -(\Delta m)(3\cdot10^8\,\tfrac{m}{s})^2 = 6.044\cdot10^{-13}\,J \approx 3.77\,MeV$$

$\therefore$ Since $Q > 0$, process is exoergic + favorable

[1] http://www.ofes.fusion.doe.gov/News/ITERCostReport.pdf
[2] https://lasers.llnl.gov/education/faqs.php#cost
[3] http://www.futuregenalliance.org/faqs.stm
[4] http://fusion.org.uk/techdocs/isfnt6_cook.pdf, p.1
[5] http://www.cleancoalusa.org/docs/affordable/
[6] http://www.iter.org/PROJ/Pages/ITERAndBeyond.aspx
[7] http://www.futuregenalliance.org/about/timeline.stm
[8] http://www.iter.org/Pages/FactsFigures.aspx
[9] http://newlygreens.com/_content/green/blog/linden-clean-coal-plant-82709-public-hearing/
[10] Same as Ref.3
[11] http://www.cleancoalusa.org/docs/abundant/
[12] http://www.nature.com/nature/journal/v433/n7022/full/433117a.html

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out whereas fuel for fusion will be abundant for a very long time. It is my opinion that coal should continue to be a part of the energy plan as almost a crutch until fusion technology can become as established as fossil fuel use. Therefore as Czar I would continue to fund clean coal but sink more resources into fusion to establish the technology so it can phase out production of energy from coal and other fossile fuels.

1.2) ① $d+d \rightarrow p+t + 4.1\,MeV$
② $d+d \rightarrow n+h + 3.2\,MeV$

atom mass

① $Q = [2m_d - (m_p+m_t)]c^2 = [(2)(3.3446\times10^{-27}kg) - (1.6726\times10^{-27} + 5.0085\times10^{-27})](2.9979\times10^8 m/s)^2$

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$= 7.2798\times10^{-13}J = 4.54363\times10^6 eV = 4.54363\,MeV$

② $Q = [2m_d - (m_n+m_h)]c^2$
$= [(2)(3.3446\times10^{-27}kg) - (1.6749\times10^{-27} + 5.0084\times10^{-27})](2.9979\times10^8 m/s)^2$
$= 5.30257\times10^{-13}J = 3.30955\,MeV$

1.5) @ 25°C pure water 55.3457 mol/L
$\Rightarrow$ in 1 L $(55.3457\,mol)(6.022\times10^{23}\,molecule/mol)$

10/10

$= 3.333\times10^{25}$ molecules $\Rightarrow 6.66584\times10^{25}$ D+H atoms
$(1/6700)(6.66584\times10^{25}) = 9.94902\times10^{21}$ D atoms
① $d+d \rightarrow p+t$ ½ of reactions
② $d+d \rightarrow n+h$ ½ of reactions
Energy from ① ½ atoms used; 2 atoms/reaction $\Rightarrow (1/4)(Q)(\#\,atoms)$
$(1/4)(7.2798\times10^{-13}J)(9.94902\times10^{21}) = 1.81067\times10^9 J$
Energy from ② $(1/4)(5.30257\times10^{-13}J)(9.95\times10^{21}) = 1.31888\times10^9 J$

Total Energy ①+② $\Rightarrow$ $3.12955\times10^9\,J/liter$ ✓

1 kg TNT = 4.184×10^6 J

$\Rightarrow (4.184 \times 10^6 \text{ J/kg})\left(\frac{1 \text{ kg}}{2.2 \text{ lb}}\right) = 1.898 \times 10^6$ J/lb

Thus 1 L of water has over 1600 times the energy as 1 lb of TNT

1.8) a) $(E_{k,Li} + m_{Li}c^2) + (E_{k,p} + m_p c^2) = 2(E_{k,\alpha} + m_\alpha c^2)$

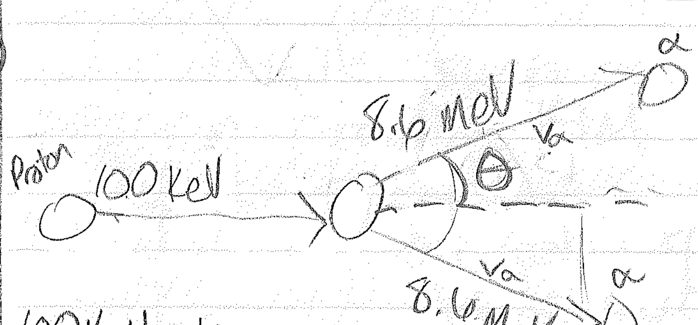
$Q = E_{k,Li} + E_{k,p} - 2E_{k,\alpha} = [(m_{Li} + m_p) - 2m_\alpha]c^2$

10/10 $Q = [(11.6443 \times 10^{-27} \text{ kg} + 1.6726 \times 10^{-27}) - (2)(6.64455 \times 10^{-27} \text{ kg})]$

$(2.9979 \times 10^8 \text{ m/s})^2$

$= 2.7798 \times 10^{-12}$ J $=$ **17.3499 MeV** ✓

b)



8.6 MeV = 1.37789×10^{-12} J

100 keV = 100000 eV

$= 1.6022 \times 10^{-14}$ J

$V_p = \sqrt{\frac{(1.6022 \times 10^{-14})(2)}{(1.6726 \times 10^{-27})}} = 4.4371 \times 10^6$ m/s

$V_\alpha = \sqrt{\frac{(1.37789 \times 10^{-12})(2)}{(6.64455 \times 10^{-27})}} = 2.03653 \times 10^7$ m/s

$m_p V_p = 2 m_\alpha \cos\theta \, V_\alpha$

$\cos^{-1}\left(\frac{m_p V_p}{2 m_\alpha V_\alpha}\right) = \theta = \cos^{-1}\left(\frac{(1.6726 \times 10^{-27} \text{ kg})(4.4371 \times 10^6 \text{ m/s})}{(2)(6.64455 \times 10^{-27} \text{ kg})(2.03653 \times 10^7 \text{ m/s})}\right)$ ✓

$\theta = 88.43$

$\theta_{diverge} = 2\theta = 176.857$

c) $E_{^4_2He} = \left(\frac{M_{^3_2He}}{M_{^4_2He} + M_{^3_2He}}\right) Q$

from equation 1.24a : $^1_1H + ^6_3Li \rightarrow ^3_2He + ^4_2He + 4.0\,MeV$

$\Rightarrow Q = 4.0\,MeV$

$E_{^4_2He} = \left(\frac{5.0084 \times 10^{-27}\,kg}{6.64467\times10^{-27} + 5.00844\times10^{-27}}\right)(4.0\,MeV) = 1.71887\,MeV$

The velocity that would be obtained for this reac[tion] by ^4_2He is much less than the 8.6 MeV observed in the experiment.

Even if the ^4_2He had all of the 4.0 MeV from the re[action] transferred to it, it would still be less than the 8.6 Me[V]

✓

Bonus

① $^4_2He + ^4_2He \longrightarrow ^8_4Be + \gamma$ 10/10

② $^8_4Be + ^4_2He \rightarrow ^{12}_6C + \gamma$

① $Q = [(2)(6.64467\times10^{-27}\,kg) - 1.329360\times10^{-26}](2.9979\times10^8\,m/s)^2$

$= -1.8842\times10^{-14}\,J$

$= -117.601\,KeV$

$\Rightarrow$ Creation of ^8_4Be Not energetically favorable

② $Q = [(6.64467\times10^{-27} + 1.329360\times10^{-26}) - 1.99272\times10^{-26}](2.9979\times10^8\,m/s)^2$

$= 1.17822\times10^{-12}\,J$

$= 7.35375\,MeV$

$\Rightarrow$ Creation of $^{12}_6C$ is energetically favorable

$\Rightarrow$ overall favorable

✓