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Deep Dive Topic: Choosing between ablators

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Choosing Between Ablators[*]

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Criteria are:
- X-ray ablation rates (rocket efficiency) and ablation pressure, the relative merit of different materials in this respect, for a fixed x-ray drive, is essentially known from theory and experiment.[1]
- Interaction with the hohlraum (ablator filling the hohlraum beyond the ¼-critical electron plasma density, net energy coupling to the ablator)
- Predictability of the ablator (known EOS over all material phases and opacity)
- Material microstructure (seeds for instability growth)
- Manufacturability to within required physics specifications
- Compatibility and manufacturability with tailored high-Z dopant materials (for pre-heat and fuel-ablator interface Atwood number control)
- Chemical reactivity with the environment
- Acceptable behavior at cryogenic temperatures
- Acceptable instability control

Recent data on implosions using identical hohlraums and very similar laser drives[2] underscores the conundrum of making a clear choice of one ablator over another. Table I shows a comparison of Be and CH in a nominal length, gold, 575 μm-diameter, 1.6 mg/cc He gas-fill hohlraum while Table II shows a comparison of undoped HDC and CH in a +700 length, gold, 575 μm diameter, 1.6 mg/cc He gas fill hohlraum. As can be seen in the tables, the net integrated fusion performance of these ablators is the same to within error bars. In the case of the undoped HDC and CH ablators, the hot spot shapes of the implosions were nearly indistinguishable for the experiments listed in Table II.

High ablation pressure does allow access to shorter laser pulses, which in turn allows easier access to vacuum/near-vacuum hohlraums – that have a potential advantage in predictability, lower hot-electrons, and improved energy coupling.[3] It is in fact the integrated hohlraum-ablator coupling performance in the hohlraum *that is best suited for the ablator/pulse-shape combination* that has the best chance of distinguishing net ablator performance. For example, HDC ablators are best suited for shorter laser pulses that allow access to low gas-fill hohlraums. Beryllium's high rocket efficiency can be used to utilize lower radiation temperature hohlraums either through lower laser drive or large surface area hohlraums.

Key physics metrics that all ICF implosions depend upon are: 1) the ability to produce high implosion velocities (>360 km/s) with obtainable radiation temperature drives, 2) ability to work with a pulse-shape that minimizes ablator instability while also minimizing fuel adiabat, 3) is compatible enough with the chosen hohlraum that shell (DT fuel + remaining ablator) and hot-spot shape control can be maintained throughout the implosion to bang-time. These three physics requirements roll-up into maximizing the implosion stagnation pressure, which is key to getting to ignition. To some degree, these three key performance criteria (high enough velocity, low enough adiabat with no mix, and good enough shape control) can be traded against each other and furthermore the trade-space grows with increasing laser energy since the ignition energy scales as $E_{ign} \sim (1/p_{stag})^2$.

Ablator	Power(TW)	Energy(MJ)	Yield(13-15)	Tion(keV)	DSR(%)
Be	350	1.42	7.8e14±1.7e13	3.65±0.13	2.92±0.19
CH	351	1.27	7.7e14±1.6e13	2.96±0.2	2.95±0.14

Table I: Be (shot N150617) and CH (shot N130501) ablator DT layer implosion performance using identical hohlraums and laser pulse-shapes (both 3-shock high-foot pulseshapes).

Ablator	Power(TW)	Energy(MJ)	Yield(13-15)	Tion(keV)	DSR(%)
HDC	430	1.48	3.7e14±8.3e13	3.38±0.15	2.08±0.15
CH	430	1.5	4.8e14±9.0e12	2.85±0.17	2.84±0.29

Table II: HDC (shot N140722) and CH (shot N130802) ablator DT layer implosion performance using identical hohlraums and similar laser pulse-shapes (both 3-shock high-foot; shorter duration for HDC)

It is possible that a fundamental property of one of the ablators – such as its crystal structure of its equation of state – could preclude its use in high compression implosions. For example, local melting and re-freezing of crystals after shock transit could result in density perturbations that grow by the Rayleigh-Taylor instability. Such a problem would manifest itself in high-convergence implosions. The best way to find such a problem would be "native" hydrogrowth radiography experiments;[4] these are planned for all three ablators in FY16. Known issues with current ablators such as oxygen uptake in CH and crystal defects in Be are related to fabrication techniques and are not fundamental properties of the ablator. At this point, there are no known fundamental reasons to reject a candidate ablator material.

It is difficult to state a quantitative criteria for rejection of an ablator, but we do have a strategy: (1) Namely, use CH, because of its large database and some demonstrated surrogacy (Tables I and II above) to the other ablators, to scope different hohlraum platforms with the pulseshape adapted as needed; (2) Test HDC and Be in their more optimal hohlraum configurations; (3) Test the ablator/hohlraum combinations to high-convergence and determine if they exhibit any deleterious behavior. Additionally, consideration of alternate ablators other than HDC or Be is ongoing at a low level (because of the long materials engineering lead time and costs), e.g. boron-carbide has been studied in planar geometry in both

Omega and NIF experiments and has so far been determined to not have sufficient surface finish control at present.

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[1] R.E. Olsen, et al., Phys. Plasmas, **18**, 032706-1 (2011); T. Dittrich, et al., Phys. Plasmas, **6**, 2164, (1999); S. Haan et al., Fusion Sci. Technol., **49**, 553 (2006).

[2] Note tests of ablators in planar geometries have also been carried out: e.g. A. Moore, et al., "Off-Hugoniot characterization of alternative inertial confinement fusion ablator materials," to be submitted to Phys. Plasmas (2015).

[3] A.J. Mackinnon, et al., Phys. Plasmas, 21, 056318-1 (2014); L.F. Berzak Hopkins, et al., 22, 056318-1 (2014); N.B. Meezan, et al. Phys. Plasmas, 22, 062703-1 (2015).

[4] K. Raman, et al., Phys. Plasmas, 21, 072710 (2014).