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Prescription for the Planet

The Painless Remedy for our Energy & Environmental Crises

Tom Blees

CHAPTER FIVE

The Fifth Element

With apologies to Bruce Willis

THE SEARCH FOR solutions to our dependence on fossil fuels has gone down some strange roads, so it probably was inevitable that it would lead to the junkyard eventually. America is a notoriously throwaway culture. It's not too much of a stretch to think that some of what we're tossing out might be worth another look.

A researcher at Oak Ridge National Laboratory in Tennessee, Dave Beach, perhaps was thinking along these lines when he came up with the idea of grinding up the metal in our nation's scrap yards and burning it for fuel. But wait a minute, metal doesn't burn. Or does it? We all know metal can get really hot and melt, but even at blast furnace temperatures it doesn't burn. Another pipe dream?

Not so, says Beach. His team has applied for funding to build a prototype car that will burn metal as fuel. It turns out that when metal is ground exceedingly fine the resulting nano-grains become highly reactive, at which point they can be ignited and will burn quite readily. The fact that they burn at a relatively low temperature results in a reduction in the emissions of carbon dioxide, nitrogen oxides and particulates, which are formed mainly at the high temperatures in internal combustions engines. The bulk of the exhaust is mainly metal oxide. So burning steel produces rust (ferrous oxide), and if that rust is heated in a hydrogen or carbon monoxide environment the oxygen will gladly abandon the steel, which can then be used again, ad infinitum.

Unlike fossil fuels, metal fuels are not really energy sources. They, like hydrogen, are energy carriers. The good thing about fossil fuels is that we can extract them from the ground and take their energy out directly, discarding the rest. Well, as it turns out that's not such a good thing, for a couple of reasons. One is that we have to keep mining or drilling or harvesting to feed an insatiable need for more fuel. The other is that what we throw away isn't exactly environmentally benign. Hence the pickle we're in with global warming and air pollution. On top of all that the constant drilling and mining, besides being environmentally insulting, is a catalyst for wars or, at the very least, economic strife.

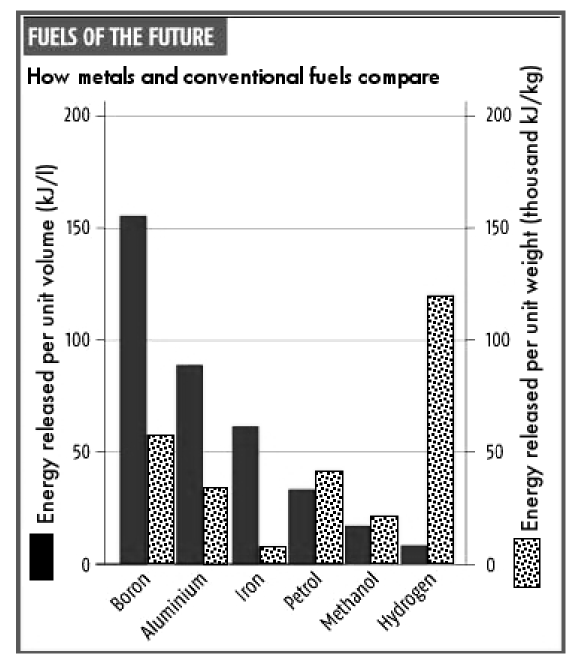
The metal-fueled car, however, wouldn't require constant sourcing of new metal aside from the amount needed to keep up with growing demand. The fuel would take its energy from the heat and the gases used to separate the oxygen from the metal oxide after it's been combined in powering the car. Whatever is the source of that heat and those gases is actually the primary energy source. As you can easily imagine, the primary energy source proposed in this book is fast reactors. Use that indirectly to drive a metal-fueled car and you're essentially driving a nuclear-powered automobile.

While the researchers at Oak Ridge are predictably enthusiastic about burning steel in cars, others aren't so excited. One of the problems is weight. Steel is mighty heavy, and the rust that would have to be carried around would be even heavier. Though the rust would be swapped out when refueling, that means there would be transportation costs two ways instead of

one way as with gasoline, plus the full weight of the fuel—or more—is always on board. On the other hand, steel and rust can be carried around in regular trucks instead of tanker trucks and both are safe to transport, so that knocks the trucking costs down a bit. But what about the weight?

Not a problem, say the Oak Ridge boys. Steel isn't the only metal that can burn. Aluminum will yield up to four times the energy per pound, and boron up to six times the energy. But aluminum costs about fifteen times as much as steel, and boron's pretty spendy too. Here's where the hydrogen guys step in again crowing about their pet fuel, because of course in terms of energy per pound hydrogen weighs nearly nothing compared to the energy it will deliver. The problem, of course, is that it's devilishly hard to store and move around.

Here's a graph[136] to help visualize the sort of energy factors we're talking about, showing the energy per unit mass on the



[136] Kurt Kleiner, "Powdered Metal: The Fuel of the Future," *New Scientist* Oct 22, 2005.

right side of each pair of bars and energy per unit volume on the other. We can clearly see both the upside and the downside of the hydrogen story there. Methanol's looking pretty iffy too. Boron—the fifth element—is clearly superior to all the others, providing far more energy per liter than any of them, and much more per kilo than all but hydrogen. So why do the Oak Ridge researchers seem to be ignoring boron in favor of steel? If it's just price, should that really be an issue if it can be 100% recycled?

Therein lies the rub. Boron just won't burn in air. The darn stuff doesn't want to light. At the nano scale that the Oak Ridge researchers are working with there might be a better chance, but the necessary venting of the exhaust would contaminate and lose some of the original boron. That would be a problem with burning steel or aluminum in air, too, for one would have to expel all the other gases in the air (mainly nitrogen, some argon, and traces of other elements). There are bound to be some minute metal particles that depart with the exhaust, as well as oxides of nitrogen, which are pollutants.

So burning metal in air—if it can be persuaded to light—thus entails at least some degree of metal loss and a resultant need for continuously replenishing the supply from outside sources—mining, ultimately. Nor is metal burning anywhere close to pollution-free. If boron (which actually isn't a metal, per se) could be made to burn in air by virtue of powdering it exceedingly fine, it's too expensive to discard even small amounts. Plus, of course, we don't want to pollute. Zero emission is the goal.

Enter a creative Canadian from a small town on the shore of Lake Ontario, Graham Cowan.[137] He has been pondering this for nearly a decade and early on came up with the inspiration of burning boron in pure oxygen. Therein lies the key. For not

[137] Graham Cowan, *Boron: A Better Energy Carrier Than Hydrogen?* (2007 [cited); available from http://www.eagle.ca/~gcowan/boron_blast.html.

only will it burn—very hot!—in oxygen, but you won't need an exhaust pipe. Inject the oxygen under pressure into a turbine or heat exchanger with boron and the result is boron oxide, which at high temperatures is a syrupy substance but which, once it cools, forms a glassy and quite non-flammable ingot. Any unburned oxygen or boron can simply be rerouted back to the intake again. Thus all the boron would eventually be captured as boron oxide, as would all the oxygen. Here's another bonus: Hydrogen, or typical fuel hydrocarbons like gasoline or diesel, require almost twice as much oxygen as boron per unit of energy produced.[138]

Precisely what form the boron should take for easiest handling and most efficient burning remains to be seen. As a hard solid substance, boron could be pelletized, or formed into long bands and wound onto spools, or perhaps powdered like the Oak Ridge researchers envision for their steel-burning engines. When a boron car driver went to refuel, she'd simply drop off the boron oxide for recycling and refill her tank (or spool) with new boron, receiving a credit for the oxide. Boron's not cheap. The amount equivalent to a 20-gallon tank of gasoline would cost somewhere in the range of a couple hundred dollars. It can be mined (as is currently done most famously in Boron, California) from the area of ancient lakebeds, or it can be extracted from seawater. There is plenty of it in the world, especially since it would only have to be extracted once for each vehicle.

Here's where that two hundred dollars becomes vanishingly cheap. The boron oxide would be hauled back to a recycling center. There it would be heated to about 700° Celsius and processed with a couple of catalysts to drive off the oxygen, which could then be released into the air (or put to any other use). The catalysts would be retrieved for reuse and the now-pure boron reformed for shipment back to the fueling point—every bit of it.

[138] Ibid. ([cited).

There are a number of marvelous aspects to this system. For one, boron is completely safe to carry around, so it can be transported by truck or train at the cheapest rates available. It's dry, odorless, and virtually inert, so it can be stored indefinitely almost anywhere: in a garage, in a basement, or in the backyard. Yet this is only one of boron's many spectacular advantages compared to hydrogen or nearly any other new fuel, for this system completely eliminates the chicken and egg infrastructure problem that can cripple the introduction of new technologies.

If you were the first person in Alaska to own a boron car and there was only one boron recycling plant in the country, in Florida, it would still be perfectly feasible to drive a zero-emission boron car economically. Just have a few totes of boron trucked up from Florida and store it in your backyard. Refueling would, unfortunately, be restricted to home, but for a long trip you could just put a bunch of boron in the trunk. For a trip all the way down the Alcan Highway—to go visit the boron supplier, perhaps—you could just fill your back seat with boron to boot, or pack a cartop carrier full of it, or even put a bunch in a trailer. But for the most likely usage patterns, home as your sole fueling station would work fine. When the boron started to run low, you'd just ship the collected boron oxide back to Florida and order some new fuel.

Of course you wouldn't be the only guy in Alaska to have a boron car for long, so fueling stations would soon be popping up all over. The investment would be about nil. The 7-11 store on the corner could sell boron. No need for underground storage tanks, hazardous materials permits, or fire suppression equipment. Rather than requiring a huge infrastructure investment to make boron practicable as a fuel, all it would take is the investment in a single boron recycling center.

Those recycling plants would be powered by IFRs. The temperature of the sodium circulating in an IFR reactor is almost hot enough to drive off the oxygen from the boron oxide. A bit of electrolysis is needed later in the process to recover the magnesium and chlorine catalysts, which are 100% reusable, and of course the IFR can also produce the electricity needed for that. By using the thermal energy straight off the reactor for preheating the boron oxide, the efficiency of the recycling process would be improved over using electrical heating for the entire process. The small temperature shortfall can be rectified with a heat boost provided electrically. Remember, the fuel for both the heat and electricity in an IFR is free.[139]

So how much would a tank (or spool, or bin) of boron cost? Well, as mentioned previously, to extract enough from land or sea for a tank of fuel would cost a couple hundred dollars. It takes about a pound and a half of boron to equal the energy of a gallon (U.S.) of gasoline, though of course how efficiently that would be converted to power would depend on the engine design. For purposes of familiarity, from here on till the end of this chapter I'll just talk about 1.5 pounds of boron as a gallon, meaning that it's equivalent in energy to a gallon of gas, though it would weigh about a fourth as much and take up less than a quarter the volume.

Once you've bought your new boron car and paid that couple hundred dollars for its first tank of boron, you'd never buy any really "new" boron again. The only costs would be the recycling, and since the IFR fuel that would power the recycling process is essentially free, that processing charge would be minimal. Then you've got shipping costs of the boron from the plant to the store on the corner, and shipping the boron oxide back to the recycling plant.

[139] Throughout this book, when I write that the IFR fuel is free that refers to the fuel alone, to which must be added the usual cost of the metal parts of the fuel assemblies (cladding, etc.). When spent thermal fuel is being used up in IFRs, there will also be the fixed cost of reprocessing it into IFR fuel. Once IFRs are all running solely on depleted uranium, all reprocessing will be done on-site at the IFR and will be part of normal operational costs. The fuel itself will, indeed, remain free.

After it burns in oxygen the weight of the boron oxide is about three times that of the original boron. So the weight and volume advantages that looked so good just a couple of paragraphs ago compared to gasoline turn out to be just about a wash. Nevertheless, in no time at all there would be boron recycling plants springing up in every state, and because boron (and boron oxide) can be shipped as cheaply as gravel because of its safety, shipment to and from the recycling centers will cost on the order of about two cents a pound each way, or about 12¢ per "gallon".[140] As for the cost of the recycling itself, the price tag to build the plant is of course a major capital expense, as it will be for all the IFR facilities. The catalysts magnesium and chlorine are part of that capital cost because they're 100% recoverable and reusable. Only the operating costs, and the amortization of the plant cost, are involved.

I will grant the reader, at this point, that I can only guess as to the ultimate cost of the recycling, since in order to figure out the amortization costs I would have to know the amount of fuel that such a recycling plant could process over its expected life span of many decades. I'll get more into the costs of building IFR plants in a later chapter, but I believe it would be safe to say that the cost of recycling a "gallon" of boron would be negligible, probably pennies. Let's say eight cents. Added to the cost of shipping you'd be looking at twenty cents to the store. The storekeeper takes a nickel; you've got your boron fuel for two bits a "gallon." If you want to quibble with my back-of-the napkin calculations here, feel free to do so. But clearly this fuel will be staggeringly cheap compared to anything you've used since the Sixties.

As for the cost of the recycling plants, even if your tax dollars pay for them it will be a bargain, considering the safety,

[140] Remember, a "gallon" of boron weighs only 1.5 pounds, but the resulting boron oxide weighs three times that much, for a total of 6 pounds that must be shipped back or forth at 2¢/lb.

economy, and — last but definitely not least — the zero emissions. Not only will we be nipping global warming in the bud, but the heretofore polluted air in our cities will soon be astoundingly clean. As energy use becomes converted wholesale to IFR-produced electricity and the cars to boron, city air will become as refreshing as country air. From the upper floors of the buildings in downtown Los Angeles you'll have a grand view of the mountains to your north and east, way across San Bernardino. Walk into the Zocalo in Mexico City and you'll once again see the windows on the palace across the block. It will be a far different, and much more enjoyable (and healthier!) world.

But how about this pure oxygen business? Is it even possible to extract pure oxygen from the air in the quantities needed with an oxygen extractor that will fit in a car? In theory, definitely, but there hasn't been much of a reason for people who need pure oxygen to work on miniaturization of the equipment. There are technologies capable of supplying pure oxygen, such as Nafion or zirconium oxide, which fuel cell researchers have been working with. A NASA researcher who's worked with oxygen extraction technologies for aircraft also told me about a system from which the oxygen exits at high pressure (which we want for the car) and very hot, about 2,000°C. Injecting it at that temperature into the engine would be like a preignition system. We want as much heat as possible, after all.

The issue of how much space we'll need for oxygen extractors is mitigated to a great degree by the lack of volatility of boron itself. Unlike gasoline-powered vehicles, there need be no shielded area in which to carry the fuel (or the boron oxide). Likewise the oxygen extraction equipment could be placed pretty much anywhere. You could even carry boron inside bumpers or quarter panels. And bear in mind that the oxygen is utilized 100% and that boron combustion only sips oxygen compared to other fuels.

Now we have to convert the heat into mechanical energy for the car, and supply the initial power to start the whole process. For this and a reason I'll explain presently, all the boron cars would be boron/electric hybrids. The batteries wouldn't have to be nearly as large as current hybrids, because they'd only have to provide power for the beginning of the trip while the oxygen extractor kicked in. As for the actual fuel ignition, there are various options.

Graham Cowan has worked on this aspect of the idea quite a bit, figuring out the potential problems with the exceedingly high temperatures in a boron turbine, the laminar flow of the hot syrupy boron oxide along the blades, the type of materials necessary, etc. Brittleness of the turbine blades is definitely an issue when you're talking about materials that can stand that kind of heat over time. While I would defer to Cowan's knowledge and inspiration in these areas over my amateur speculations, should the direct turbine approach prove overly difficult, a simple combustion chamber with a water jacket (or perhaps another liquid for moving the heat to a turbine) would likely work just fine. It will take some R&D to figure out the best configurations to extract sufficient heat to run the car, but considering the prodigious heat that boron puts out— and let's not forget the hot oxygen you're putting in there—it's a certainty that a steam turbine could easily run off it. Boron burns considerably hotter than hydrocarbon fuels, so there's quite a cushion there to compensate for a possible drop in overall efficiency. The internal combustion engines we use today aren't exactly models of efficiency anyway, converting only about 15% of the energy in their fuel to the intended purposes.[141]

As for transferring the turbine power to the drive train, there are compelling reasons to simply run a high-powered electrical generator and drive the wheels with electric motors. The reason for that has to do with the rest of the energy systems that people in the post-revolution era will be using.

Bear in mind that once all the coal plants are replaced with IFRs, the power plants burning natural gas will be the next to go, and home heating will also be converting over from natural gas and heating oil to electric heat, most probably with heat pumps to provide both heating and cooling with greater efficiency than resistance heating systems and separate air conditioners. While not the focus of this book, I would mention in passing that geoexchange heat pumps are wondrously efficient and it would constitute wise energy policy to subsidize their installation (perhaps from electricity revenues), both in new homes and retrofits. Retrofitting them is hardly more difficult than new construction, consisting mainly of digging up a section of your yard to lay out the heat exchangers, then patching your heat pump into your existing furnace and A/C system. Quiet, amazingly cheap to run, almost maintenance-free, and zero emissions (remember, the electricity to run them is coming from a zero-emission IFR plant).

Okay, so you've got a nice all-electric home and you're living in Winnipeg in the middle of winter and suddenly the power goes out. Not a problem, because your house has a fat cord in a little utility box on the side closest to your driveway, and your boron car has a plug on it that can feed power from the car's robust alternator. Put on your hat and mittens, grab your parka and the car keys, run outside, plug your house into your car, and start it up. Then hustle back into the house. Oh, but you forgot to fuel up today! Don't sweat it. Because of boron's safety and stability, every homeowner in severely cold climates would keep an emergency supply in the garage, closet, barn, or basement. Pretty nice to have that portable electrical plant when you take those summer trips to your off-the-grid cabin in the summertime, too. Honda won't be too happy when their

[141] fueleconomy.gov, *Advanced Technologies & Energy Efficiency* (US DOE/EPA, 2007 [cited); available from http://www.fueleconomy.gov/FEG/atv.shtml.

portable generator sales drop off to nothing, though. But hey, that's evolution.

Besides, Honda and all the other carmakers will be too busy to notice. They'll be in the heyday of a new automotive Golden Age, replacing an entire planet's fleet of vehicles. And who won't want a boron car? The fuel savings alone will sell them, never mind the zero emissions. Of course as boron takes over, gasoline prices will plummet, especially once OPEC becomes nothing but a distant and quite unpleasant memory. We'll explore those ramifications of the revolution a bit later.

For now, just sit back and picture how this all fits together. All over the world IFR plants, assured of hundreds of years of free fuel, are silently humming away, supplying power for not only the old uses but for steadily evolving industrial applications as well. No more coke smelters for steel production. They, like all the other coal and natural gas users, have switched to electricity. Homes and business are all electric. Even the busiest intersections on the most sweltering days have nary a hint of exhaust smell, the air is clear and fresh. Your kids grow up knowing blue skies and distant horizons even in the biggest cities, their only experience with smog being from history class. And at night those cities could be spectacular, with skyscrapers outlined in lights (LEDs or CCLs, of course).

I freely grant that there are R&D challenges ahead for the boron car, but they are most certainly surmountable in the near term. The most difficult part of it will likely be the size of the oxygen extractors, but if that took too long we could still initiate the boron engines and carry oxygen tanks on board, which we could fill up every night at home from a small extractor/compressor system outside the garage. On long trips they could be swapped out with standardized tanks at fueling stations. Given the great deal of latitude afforded us by the theoretical limits of oxygen extraction, though, it's highly doubtful that would be necessary. Already five years ago oxygen extractors were almost

small enough, even with their efficiency being barely 5% of the theoretical limit. Give that challenge to the wizards at Sandia Labs and sit back and watch the fur fly. We'll be tooling around in borocars in a heartbeat.

On the other hand, there are a lot of new electric car technologies on the horizon that seem to show great promise, from the aforementioned Phoenix to high-tech capacitor systems. And work being done on so-called flow batteries holds out the possibility of being able to simply pump out discharged electrolytes and pump in a fully charged solution, which wouldn't take much longer than fueling up with gasoline today. It's possible that by the time this book is in your hands a viable electric car will be on the road. What use for boron then? Well, you still have that home in Winnipeg, remember? And long trips in remote areas could be impossible with all-electric vehicles, though for most uses they would be just peachy. The average car trip in America is about 29 miles, so usually it would work just fine to plug in at home. If Phoenix Motorcars actually succeeds in building a car with long range per charge and a ten minute charge cycle as they're promising, admittedly the need for boron will be minimized. Nevertheless it could well be used in trucks, trains, heavy equipment, portable generators, or for safely and cheaply transporting energy in areas (such as much of the developing world) where power grids are inadequate or nonexistent. Our Winnipeg family could get by just fine with an electric car, though, as long as they kept a boron-powered generator out in the garage.

A boron/electric hybrid, however, would be the best of both worlds. Not only would you have terrific range even beyond the grid, but the charging cable that plugs into your house every night (assuming we make these plug-in hybrids) could operate in reverse if the power went out. All you'd have to do is start the car to kick in the boron power. Of course with a truly efficient boron/electric hybrid you might drive around with a tank of boron for months before ever having occasion to use it.

Would that be a bad thing? Absolutely not. From an efficiency standpoint it would be the best situation. Any time energy is converted from one form to another it incurs an energy penalty. So it would be more efficient just to use electricity straight from the IFR to charge up our cars. Dependable boron/electric hybrids would mean only that we'd need fewer boron recycling plants, saving both money (especially the high capital cost) and energy.

Yes, I am a technology optimist. But look at the challenges to boron car development compared to any other alternative energy technology. While not inconsequential, they are certainly surmountable in the near term, and a boron system virtually eliminates the chicken and egg infrastructure problem. A single recycling plant built anywhere in the country would enable boron cars to take to the road nationwide.

Graham Cowan once took a walk like Daniel into the lions' den. He presented a paper[142] at a convention of hydrogen researchers, explaining the superiority of boron as an energy carrier. Lots of stunned faces, but no fatal flaws were even suggested. Couple boron cars with IFR deployment and you've got yourself a brave new energy world.

[142] Graham Cowan, "Boron: A Better Energy Carrier Than Hydrogen?," in *11th CHC Hydrogen Research Conference* (2002).

CHAPTER SIX

A Decidedly Immodest Proposal

Always listen to experts. They'll tell you what can't be done and why. Then do it.
— Robert Heinlein