Ottawa research scientist Bruce Clements

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CANADA GETS A SHOT AT CHANGING THE WORLD

Canadian scientist Bruce Clements and U.S. inventor Alex Fassbender can make coal behave itself – by keeping it under constant pressure, writes **Neil Reynolds**. The technology could restore the reputation of the world's most abundant fossil fuel.

Bells Corners, Ottawa

Approach the compound on an overcast day in spring and you can't escape the sense that you are entering a classified place in a prohibited time. You are 10 minutes from downtown Ottawa, passing through vaguely inhospitable terrain – scrub land, stunted cedars and hardwoods. Even in the distance, beyond the fences and fields, you can for a few minutes see no evidence of human habitation.

You reach a security gate that divides the roadway, exit your car and enter a guard house that looks like Checkpoint Charlie. Uniformed personnel trade a plastic security card for your driver's licence. On the wall, a map sites 19 buildings that form an imperfect semi-circle around an old quarry. In the old days, they used its sandstone to build the Centre Block on Parliament Hill – though they went to Ohio and Vermont for the decorative stone. Another wall sign prohibits cameras. Through the windows, you glimpse distant concrete towers rising windowless above the trees.

You go to Building 3, the numerical manner in which all the fortress structures are identified. Here you meet Bruce R. Clements, the federal scientist responsible for research into advanced combustion technologies, the efficient burning of things for prime energy. Mr. Clements leads you to Building 4, next door, where a rambling series of high-ceiling rooms are connected by narrow walkways and filled with pipes, wires and tubes that incoherently service experimental furnaces. They're as small as parlour stoves and as large as a four-storey house. Building 4 is explosion-proof.

Here is an odd-shaped furnace used to burn muck for the analysis of the infamous Sydney tar ponds. Here is a hori-

zontal furnace used to calculate the impact of cross-current winds on the distribution of flue gases from oil wells, a memento of Wiebo Ludwig, the evangelical Alberta farmer who declared war on the oil patch for poisoning his soil and killing his cattle. Here is Canada's only experimental high-pressure gasifer, a cylindrical furnace 10 inches in diameter, five feet in height, surrounded by a thick tube of stainless steel. It subjects coal to extraordinary pressure, turning it into gas, forcing it to release its energy in ways it never has before – notwithstanding the fact that humans have burned coal for thousands of years.

Forbidding as it looks from the outside, the sprawling research compound here at the federal government's Canada Centre for Mineral and Energy Technology in Bells Corners is one of the finest in the world. It has some of the best pilot-plant facilities in North America and it houses most of the advanced coal research done in Canada. It has laboratories capable of breakthrough advances in technology. It has scientists capable of making them happen.

We're back at Building 3. It was here that Natural Resources Minister Gary Lunn discreetly discussed in mid-January, with Environment Minister John Baird at his side, a breakthrough in clean-coal technology that could change Canadian history and perhaps world history, too.

"There's exciting promise in coal," Mr. Lunn said. "They're doing research [here], right now, today, where they can remove 90 per cent of the pollutants from coal-fired electricity generation. You combine that with carbon capture and storage to take out all of the greenhouse gas emissions – there's enormous promise here.

"When you speak to the scientists, they believe that we can get to zero-emissions coal-fired technology. We should be open to that. Carbon capture and storage has enormous potential in places like the oil sands where there are high concentrations of greenhouse gases, where we can take those gases, capture them, put them into a pipe and put them deep down in the earth's crust where they came from.

"This is an opportunity where we really want to focus our research money."

Mr. Lunn could not have more precisely described the dramatic advance in clean-coal technology proven here at the federal lab – a revolutionary coal-fired combustion process code-named TIPS (Thermo-energy Integrated Power System). In the lab, TIPS delivers clean coal. It delivers CO_2, coal's greenhouse gas emissions, cleansed and ready for underground sequestration. It delivers this perfect package at a price that blows away the competition. And it does it in a furnace only one-tenth the size of conventional coal furnaces.

Judging by all the analysis and tests so far, a TIPS coal-fired electrical generation plant could fit comfortably into urban or suburban streetscapes. It sounds too good to be true. But Bruce Clements, a classically understated Canadian scientist, says it's for real. "This is huge," he says. "This is a step change."

Trust the scientist to be precise. In colloquial language, a "step change" means an important change. In scientific language, it means a paradigm shift. It means a quantum leap. It means going forward and never going back. Mr. Clements chooses his words very carefully. He repeats them. "This is huge," he says. "This is a step change."

He reflects on his 16 years as a research scientist in what his business card calls "combustion optimization" with Natural Resources at the Bells Corners compound. "I've had my share of achievements," he says. "I've never had anything like this. This is a life's work."

Mr. Clements, 50, is a hometown Ottawa boy who earned his engineering degrees at the University of Ottawa and who has spent his entire 27-year career working around Ottawa. He's a family man, married to Diane, with three children, Carolyn, Brian and Eric. He has a dog, a black Lab named Kobi. In his pitifully cramped office in Building 2, the screensaver on his computer rotates pictures of his family and his cottage on Black Lake near Perth. He knows that wood stoves in the country aren't environmentally correct these days but he occasionally burns wood anyway. He's more than science. He's romance, too. He used to have his own band that played Ottawa Valley hotels. Rock. Jazz. Lounge music. He played piano and sax.

Mr. Clements works with two young

Inventor of a revolutionary advance in coal-fired power generation, U.S. chemical engineer Alex Fassbender has teamed with Natural Resources Canada to test and evaluate the new technology. Last year, Mr. Fassbender toured the Maritime provinces on his BMW motorcycle.

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Research scientists Bruce Clements, Richard Pomalis and Ligang Zheng form the team that tested and assessed breakthrough coal-combustion technology at the secluded Bells Corners laboratory compound operated by Natural Resources Canada.

engineers whom he describes as brilliant – Richard Pomalis and Ligang Zheng. The three scientists are together, along with three other men, in a photograph taken last year at a signal moment for TIPS in Boston (see page 10). The Canadians had driven down together – taking eight hours, yes, but saving travel money – to meet three Americans: Alex Fassbender, Herman De Meyer and Gregory McRae. Mr. Fassbender is the scientist and inventor who devised the basic TIPS process and who holds the patents on it. He teamed with Mr. Clements when he found that Bells Corners was the only research lab in the world that could properly test his innovations.

Mr. Fassbender, 53, is an interesting and imposing character. At 6′ 2″, he towers over his companions in the photograph. In early March, he drove his limited-edition 2003 eight-cylinder silver Volkswagen through fierce snowstorms from Boston to Bells Corners to meet with Mr. Clements. Why drive? Because it cost him less than flying – thrifty people, these scientists – and because he loves to drive his very-rare car. Now executive vice-president of a company called ThermoEnergy Corporation, based near Boston, he started his career at Pacific Northwest Laboratories, a U.S. national research lab near Seattle. He loves Vancouver. He's thinking of moving north permanently.

Mr. Fassbender got his degree in chemical engineering at the University of California at Berkeley in 1976 – a time and place where he could catch such lecturers as Edward Teller of hydrogen bomb fame, and Glenn Seaborg, Nobel Prize winner (chemistry) in 1951 and later science adviser to several U.S. presidents. Mr. Fassbender has an MBA among his post-graduate degrees.

Herman De Meyer and Gregory McRae, the other two men in the Boston photograph, are scientists with international reputations who spent a full day grilling Mr. Clements and Mr. Fassbender on the TIPS technology. For Mr. Clements and Mr. Fassbender, it was a kind of final exam. Dr. McRae was a member of a panel of scientists at the Massachusetts Institute of Technology which, in mid-March, published a definitive report on the future of coal – where it's going and how it's going to get there. Headed by chemical engineer John Deutch (a former director of the CIA in the 1990s) and physicist Ernest Moniz (an undersecretary of energy in the 1990s), the MIT team concluded its report succinctly: "Coal use will increase under any foreseeable scenario because it is cheap and it is abundant."

Dr. De Meyer and Dr. McRae grilled Mr. Fassbender, Mr. Clements, Mr. Pomalis and Mr. Zheng for hours. When they finished, they gave the team and the technology a thumbs-up. TIPS had aced its final exam. All that remained now was to build the demo plant and find out if TIPS functions in real-life as it does in theoretical modeling and in experimental testing.

THE TECHNOLOGY USES PRESSURIZED OXYGEN TO ACHIEVE HIGH COMBUSTION EFFICIENCY, NEAR-ZERO EMISSION OF POLLUTANTS AND CARBON CAPTURE. IT CAN HANDLE A WIDE RANGE OF FUELS, INCLUDING HIGH-MOISTURE COAL AND BIOMASS. THE TECHNOLOGY DOWNSIZES THE COAL AND VENTS NOTHING INTO THE ATMOSPHERE.

Mr. Clements wasn't surprised by the passing grade. He and his team had analyzed the technology thoroughly – and independently. He had calculated more

efficiencies than Mr. Fassbender himself had conceived. Further, he had concluded that no significant technical barriers existed to building a demonstration plant. Based on Mr. Clements' findings, Mr. Fassbender expects to have a large-scale, carbon-capture commercial power plant under way within two years, preferably in Canada – which really means Bells Corners. Mr. Clements' exhaustive 200-page report on Mr. Fassbender's technology identifies TIPS as potentially the most competitive new power plant (with CO_2 capture) in the world.

The technology uses pressurized oxygen to achieve high combustion efficiency, near-zero emission of pollutants and carbon capture. It can handle a wide range of fuels, including high-moisture coal and biomass. Coal is inherently dirty and big. With Mr. Fassbender's technology, it gets cleaned, squeezed and compacted. In the end, the technology downsizes the coal and vents nothing into the atmosphere.

In basic ways, Mr. Fassbender's model uses the same methodology that James Watts used in the 18th century. You pulverize coal into particles as fine as talcum powder, then burn it in a furnace surrounded by pipes filled with water. You direct the steam into off-the-shelf turbines that spin to produce electricity. In conventional coal furnaces, though, you captured the pollutants – or not – as they exited the smokestack. In TIPS technology, there's no smokestack.

In other ways, TIPS introduces unique adaptations. First, you begin to cleanse the coal before you burn it. In a separate facility alongside the furnace, you take room-pressure air and put it under pressure. Lots of pressure. Air pressure in a car tire is 30 pounds per square inch (psi). Air pressure in Mr. Fassbender's entry chamber is 1,250 psi. You separate the pressurized air into its basic components, oxygen and nitrogen, then direct the pure oxygen into the furnace to drive the combustion.

Then you burn the coal under pressure – again, 1,250 psi. You keep the steam under pressure, too, inside tubes, typically between 2,500 psi and 3,700 psi. In the end, you have nothing left in the furnace except ash (used commercially in concrete.) You have captured the pollutants – sulphur oxides, nitrogen oxides, mercury, particulate matter – in the hot exhaust from the furnace. You pass these fumes through a condensing heat exchanger "where," as Mr. Fassbender puts it, "the magic happens." From this condensation, you get very hot water – the water content of the coal itself, the water produced by combustion. At 400 degrees Fahrenheit, the water is a significant energy source of its own. "It's what the [high] pressure buys you," Mr. Fassbender says. "It means that the pressure pays for itself."

When the exhaust fumes release the water, they release the rest of the pollutants with it. You direct some of the CO_2 back to the furnace to exploit the residual energy left in it. You cool the rest of the CO_2, still under pressure, to 87 degrees Fahrenheit – when it turns into a liquid. You further cleanse the liquid CO_2, an easy process now because it's so compacted. Think of a CO_2 cartridge for an air gun, Mr. Fassbender says. Then think of a garbage can. The cartridge holds under pressure the same volume of gas as the garbage can.

BECAUSE OF THE EXTREME ATMOSPHERIC PRESSURES USED IN THE PROCESS, MR. FASSBENDER'S GENERATING PLANT CAN BE 10 TIMES SMALLER THAN CONVENTIONAL PLANTS. MR. FASSBENDER THINKS THAT IT CAN FIT COMFORTABLY INTO LARGE CITIES

Because of the extreme atmospheric pressures used in the process, Mr. Fassbender's generating plant can be 10 times smaller than conventional plants. Mr. Fassbender thinks that it can fit comfortably into large cities – any place, actually, served by a railway line. "A conventional 500 megawatt plant has to be built in the hinterland," Mr. Fassbender says, "and you lose four per cent of your electricity from the transmission lines." He says the CO_2 can be moved to its sequestration site either as a compressed liquid or as a compressed gas. Mr. Clements, on the other hand, says the TIPS generating plants should be built near sequestration sites – moving the electricity rather than the CO_2, which stays buried because it's heavier than air.

Clean-coal furnaces have existed for a decade or more, some more sophisticated than others. In its earliest form, chemical "scrubbers" captured pollutants – some quite successfully – as they vented from smokestacks. In advanced form, the furnace converts coal into a synthetic gas ("syngas"), which gets directed into a giant turbine to make electricity. The heat generated in this process gets recycled and powers a second turbine. In this technology, known as IGCC (for integrated gasification combined cycle), most pollutants never reach the smokestack. They are retrieved from the syngas, processed and packaged for commercial uses. The first of these IGCC power plants went into production in 1996 in Florida's Polk County – and has powered the Pirates of the Caribbean at Disney World in Orlando with clean electricity ever since.

The IGCC power plants are impressive things, and are widely considered the best bet of the clean-coal technologies that are already operational. Mr. Clements and Mr. Fassbender hold different opinions on them. Mr. Clements supports the technology, notwithstanding his conviction that TIPS is superior. "I am more of a believer," he says, "in a diverse power-generation portfolio." Mr. Fassbender thinks that IGCCs will soon become anachronisms. They can capture CO_2, he says, only if you turn them into "chemical factories." The scientists agree, though, that IGCCs are complex, expensive to build and costly to operate.

CANMET scientists have worked for years on IGCC technologies and will continue to do so. Mr. Clements observes that the IGCC technology can turn coal into either a liquid fuel (which can run cars) or a gas (which can turn turbines and make electricity). "In the U.S., this could be very important," he says, "in decreasing the country's dependence on foreign fuel supplies." Mr. Fassbender's design produces electricity. Its contribution as a vehicular fuel would probably be for gas-electric hybrids. In its favour, TIPS doesn't need the giant turbines that the IGCC plants require, a huge saving in capital and operating costs, and uses off-the-shelf turbines instead. And it captures the CO_2 without incurring extra expense.

A snapshot from the "final exam" for inventor Alex Fassbender (third from right), Ottawa research scientist Bruce Clements (right) and team members Richard Pomalis (second from right) and Ligang Zheng (left). The examiners: Gregory McRae (second from left) and Herman De Meyer (third from left). Dr. McRae is a professor of chemical engineering at MIT, an adviser to the U.S. clean-coal research program and a member of two Environmental Protection Agency review panels and the U.S. Department of Energy's science advisory board for advanced scientific computing. Dr. De Meyer is a process simulation expert with a British company, Reaction Systems Engineering. He was once chief process development engineer with Bayer Chemicals in Belgium. The "exam" took place in Boston shortly before Christmas.

It was the Clements team that discovered the magnitude of Mr. Fassbender's innovations. "They had never been quantified," Mr. Clements says. "Therefore, the significance [of the TIPS process] had been underestimated." Mr. Clements finished this "quantification process" just before Christmas 2006. "It was then that we started to get excited," Mr. Clements recalls. "We hadn't realized what we were sitting on." At almost the last moment, they recognized that a TIPS furnace could indeed be one-tenth the size of a conventional furnace, "which excited us even more." Coal-fired power plants, as now constructed, are bigger than high-rise apartment buildings; small power plants would represent a huge economy.

Mr. Clements and his team have confirmed that the TIPS steam cycle operates with a boiler efficiency eight per cent better than conventional systems. It incurs much less thermal loss. It increases power output by eight per cent. It eliminates the need for auxiliary power required by other sequestration technologies, saving an additional 10 per cent of power output. The list of incremental cost-savings goes on. Add it all up and TIPS promises clean coal at a bargain price, compared to conventional coal plants, with CO_2 capture thrown in free.

By Mr. Clements' calculations, TIPS can deliver pollution-free electricity for less than eight cents per kilowatt hour – and ultimately, for a large-scale commercial operation, by significantly less than eight cents. In comparison, Ontario (which markets electricity for less than it costs to produce) sells electricity for as little as 5.8 cents per kWh and as much 9.7 cents for peak-demand consumption. New Brunswick sells electricity for 9.2 cents per kWh. The U.S. sells electricity – this is the national average in 2006 – for 9.8 U.S. cents per kWh. (New York State charges 14 cents per kWh.)

These prices illuminate the economic difference that this technology can make. In a special report on clean energy, *Canadian Business* magazine reported in February that today's cost of producing clean-coal electricity runs as much as 50 per cent more than conventional methods. Malcolm Wilson, director of CO_2 management with the University of Regina-based Energy Innovation Network, observed that the technology existed to develop clean-coal electricity at a competitive price. He added: "What we need now is the next step."

Or the next step change.

Fossil fuels provide as much as 80 per cent of the world's supply of primary energy – and coal (25 per cent) isn't far behind oil (35 per cent). Natural gas provides 20 per cent. All the other fuels, together, supply 20 per cent – nuclear, 6.5 per cent; hydro, 2.2 per cent; biomass, 11.1 per cent; solar, wind and geothermal, 0.4 per cent. The MIT report says these percentages aren't going to change anytime soon.

Canada and the U.S. have coal reserves that will last for hundreds of years. China and India have comparable levels. As a result, coal will probably provide twice as much energy in 2100 as it does now, the MIT report says – regardless whether it's dirty or clean. Thus the fundamental energy challenge of the 21st century is to make it clean, at an economic price.

Bruce Clements first encountered Alex Fassbender six years ago. Intrigued by his concepts but skeptical, he analyzed them on his own initiative. One by one, the Fassbender concepts checked out. A year ago, the two men and their respective organizations formed a partnership – the public/private model that Natural Resources Canada research labs use all the time. (Mr. Fassbender's ThermoEnergy Corporation is based in the Massachusetts town of Hudson, population 20,000). Mr. Clements is now ready to build a demo plant on the Bells Corners compound. He needs four or five years and $12 million, a pittance in terms of the energy-research expenditures now under way in Canada and around the world.

It is possible that the Fassbender-Clements coal-fired generating station won't work as the two men think it will. It is reasonably possible, though, that it will. As Mr. Clements observes, Mr. Fassbender can take his aspirations back south of the border whenever he hits a dead end in Canada. With the Fassbender-Clements partnership, Canada has a good shot at introducing a world-changing technology. It would be a shame to let it slip away – though not, regrettably, an unprecedented shame.

Right here in Building 4, Minister Lunn, is a good place to invest a small part of the research money you mentioned the other day. And right now. Bruce Clements believes that Alex Fassbender's radical clean-coal technology could put Canada in the forefront of clean-energy technology, carbon dioxide capture – and cheap power. Deep down, he's convinced. All he needs is a chance to prove it.

Award-winning journalist Neil Reynolds is publisher of *Diplomat*.