Pathway Summaries

No.	Pathway	Summary
1	Coal Gasification with CO_2 Capture	Canada has abundant coal resources; enough to meet the country's energy needs for hundreds of years. Gasification and the associated shift reaction convert coal in the presences of oxygen and steam into CO_2 and hydrogen. The hydrogen can be used for generating "clean" power, for refining oil, upgrading bitumen and for producing petrochemicals ("poly-generation") while the carbon dioxide can be captured and used in enhanced oil recovery and coal bed methane applications or sequestered in saline aquifers. Gasification economics depend on the quality of the coal and little is known about gasifying low rank (quality) Canadian coals. Canada's pathway consists of evaluating and improving known and emerging gasification technologies, and demonstrating commercial readiness for specific Canadian polygeneration applications.
2	Clean Coal Combustion	Canada has abundant coal resources. Clean coal combustion can make this resource a Canadian asset for future energy sources and remove the perception that coal is an environmental liability. Clean coal combustion will reduce emissions of NOx, SO_2, particulates and mercury to very low levels as well as capture most of the CO_2.
3	Energy Products from Agricultural & Forestry Feedstocks	On an annual basis, the renewable resource residues available from forestry, agriculture and related manufacturing industries are equivalent to approximately 25 percent of the energy Canada derives from fossil fuels. The pine beetle infestation in the forests of British Columbia, will add a substantial amount of forest bio-mass that will need to be disposed off during the next 10-20 years. Marginal agricultural land can be used to produce bio-energy crops in harmony with farming and ranching to maintain a sustainable source of biological energy feed-stocks. Proven technologies exist for converting these feed-stocks into a broad range of fuels such as wood pellets, fuel oils, bio-diesel, and ethanol from a wide variety of biological feed-stocks. Canada is well positioned to become a world leader in the production of bio-fuels.
4	Power from Agricultural Feedstocks (Straw)	Biomass is considered carbon neutral i.e. the amount of carbon released during its combustion is nearly the same as taken up by plant during its growth. This characteristic of biomass contributes enormously to the greenhouse gas mitigation. Power from straw is not economic today in western Canada, where power is generated from a large base of hydroelectric, gas fired, and coal fired plants. However, it is the "least negative cost" of any baseload large scale green power source available at large scale in Alberta. Cost of power from a large-scale straw fired power plant (more than 300 MW) is in the range of C$65- $75 per MWh. Field sourced biomass plants have a competition in cost elements between the transportation of fuel to the plant, which increases with increasing plant size, and the capital and operating cost of the plant per unit output (e.g. investment and operating cost per MWh), which decrease with increasing plant size due to economy of scale. Numerous studies, including a detailed study based on western Canada straw, confirm that the optimum size of a straw based power plant is 250 to 450 MW. Small scale power plants, e.g. 25 or 50 MW units, suffer from low thermal efficiency, due to higher heat losses, and from poor economy of scale. Straw is being used to produce heat and power in several plants in Europe on a commercial scale, and is also being cofired with coal. Technology is mature and can be implemented immediately.

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5	Power and Heat from Municipal Solid Waste	In combination with an effective municipal waste recycling program, the remaining municipal solid waste (MSW) is largely a mixture of types of biomass that can be used as a fuel in combined heat and power plants to produce electricity and heat. In the past, incinerators were used in some locations to dispose of MSW. Such incinerators were often shown to operate with excessive emissions of pollutants (such as sulfur dioxide, nitrogen oxide, carbon dioxide, mercury and especially dioxins) and generally speaking have been closed. In contrast, modern waste-to-energy facilities are essentially power plants that use MSW as their source of energy. Current technology emissions control equipment allows waste-to-energy facilities to meet or exceed European and US emissions standards. There are over 400 waste-to-energy facilities operating in Europe and there are 89 operating in the US. More waste-to-energy facilities are under construction and planned in both locations. There are also a significant number of such facilities in Japan. Advances in technology that improve the economics are desirable but are likely to be incremental as opposed to being step changes. Waste-to-energy plants can provide an environmentally friendly and low foot print means of disposing of municipal solid waste relative to local or distant landfill options. This pathway can avoid the GHG emissions from methane gas escaping form landfills and reduce the GHG emissions from long distance transportation of wastes to available landfill sites while producing marketable energy products from an essentially renewable resource.
6	Wind Farms for Grid Supply	Wind farms consist of an array of factory built wind turbines and the balance of plant infrastructure to collect the electricity and feed it into the electrical grid. Wind turbines are driven by zero-cost, non-polluting fuel, the wind. Technology development in the last 20 years for the rotor, drive train and electrical power conditioning equipment, have made wind power economically competitive and desirable as a replacement for other forms of generation that are environmentally less benign. Wide spread public support has created a regulatory environment where wind farm development is favoured through a relatively rapid permitting and environmental assessment process.
9	Solar Energy for Electricity	The supply of power to homes, and the electrical grid, by generation of electricity from photovoltaic (PV) modules installed on the roofs or facades of buildings. There are two classifications: stand-alone systems that are independent of electrical supply grids but require an energy storage to ensure an uninterrupted supply; and grid-connected systems in which excess electricity from locally installed PV panels is fed through electrical interconnects to the electrical grid for distribution. In the latter case, when there is insufficient solar energy to meet the local load, power is drawn directly from the electrical grid rather than from a battery system.
11	Low Impact Surface Mineable Oil Sands	The Canadian Oil Sands have a total in place resource of over 2 trillion barrels, of which roughly 10% can be recovered by surface mining technology. Beginning with the pioneering work of the Alberta Research Council in the late 1920s and early 1930s, followed by the Alberta Government demonstration plant at Bitumount in the late 1940s, commercial production began with the Great Canadian Oil Sands Plant in the late 1960s and the Syncrude Canada plant in the 1970s. Many other companies

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		are now involved and production of synthetic crude is expected to be about 2 million BPD of bitumen and synthetic crude in aggregate by 2012. The Oil Sands Technology Roadmap produced by the Alberta Chamber of Resources identified many of the internal and external challenges that the industry must address to achieve its long term goals.
12a	Solvent Vapor Extraction Process Heavy Oil	Solvent vapour extraction processes are less energy intensive, use less water, and are more suitable for thinner, partially-depleted reservoirs than are thermal recovery processes. In addition, these processes should reduce CO_2 emissions by 90% compared to steam injection. A major concerted effort between research organizations and industry will be required to make the solvent extraction process successful. A series of well defined laboratory studies, scaled and mechanistic physical modeling, and numerical simulations coordinated with ongoing field pilot operations will provide the technical and economical de-risking required for industry acceptance and wide-spread commercial application.
13	Alternative Hydrogen Supply for Oil Sands Development	Hydrogen is a key additive in the transformation of oil sands bitumen into synthetic crude oil (SCO). The current method of producing it is Steam-Methane Reforming (SMR), which consumes an increasingly expensive and scarce resource (natural gas) and co-produces substantial CO_2. Although other hydrogen production methods are potentially feasible (see Pathway 18 - Hydrogen Production by New Technologies, Transportation and Use), production by electrolysis is a mature technology. Hydrogen by electrolysis with the electricity produced by a nuclear reactor is now an economically attractive alternative, especially if it can be produced intermittently using off-peak electricity. It has the added benefit of long-term price stability.
14	Value-added Products from Oil Sands Development.	Alberta has very large recoverable reserves in the oil sands – more than those of Saudi Arabia. Current production levels of approximately 1 million barrels per day of bitumen and synthetic crude oil will more than triple by 2030, provided costs of recovery and upgrading can be continuously reduced through improved technology. An expanded mix of products and new markets must be developed, to avoid long term depressed netbacks on unprocessed bitumen. Canada's pathway to value-added products from oil sands bitumen will focus on improved bitumen characterization, new separation technologies, new catalysts, and integration of upgrading and refining processes, including gasification.
15	Nuclear Fission Energy for Oil Sands Development	The Athabasca region in northern Alberta includes the world's largest oil sands (crude bitumen) deposits and is the fastest growing source of crude oil in North America. Approximately 175 billion barrels of oil - comparable to the oil reserves in Saudi Arabia - are economically recoverable using surface mining and steam assisted gravity drainage (SAGD) technique for in-situ bitumen extraction. The Alberta oil sands region currently produces the equivalent of about 15% of Canadian primary energy usage and is expected to triple its output in the next ten years. The SAGD process injects medium pressure steam into an oil sand reservoir to reduce the viscosity of the bitumen in order to enable its extraction. SAGD operations currently represents only about 10% of total oil sands production but is expected to become the dominant recovery process due to large underground reserves, improving technology / recovery performance and generally lower environmental impact than surface mining. Once through steam generators (OTSG), occasionally backed up by combined-cycle gas turbines, are the most commonly used energy source to generate steam for the SAGD process. Increasing and volatile natural gas prices and

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		supply uncertainties, coupled with concerns over CO_2 emissions, will limit the future use of natural gas as a prime energy source. This pathway outlines the potential to use of nuclear energy to generate injection steam at a competitive and stable price while reducing CO_2 emissions.
16	Alternative Energy Systems for Road Vehicles	This pathway would use electricity as the main energy carrier for light and medium duty road vehicles, by using " plug-in hybrid", or "grid-connected" hybrid vehicles. A vehicle range of up to 100 km would be obtained using the energy stored in a battery which has been charged from the electricity grid. A small, efficient, engine would be used to extend the range when required, and to provide power "assist" on steep hills, for example. The primary energy could then be obtained from any zero greenhouse gas source, including renewable energy and nuclear power.
18	Hydrogen Production, Transportation and Use	The vision of the hydrogen economy is based on two expectations: (1) that hydrogen can be produced in a manner that is affordable and environmentally benign, and (2) that applications using hydrogen—fuel cell vehicles, for example—can gain market share in competition with the alternatives. To the extent that these expectations can be met, Canada, and indeed the world, would benefit from reduced vulnerability to energy disruptions and improved environmental quality, especially through lower carbon emissions. However, before this vision can become a reality, many technical, social, and policy challenges must be overcome. This pathway outlines the fundamental transformation that is required both on the supply side (technologies and resources for hydrogen production) and the demand side (technologies and devices to convert hydrogen to energy) of the hydrogen economy.
19a	Geothermal Borehole Thermal Energy Storage (BTES) System	A Geothermal Borehole Thermal Energy System (BTES) is an energy storage system that stores energy in an underground rock formation contiguous to targeted buildings. Waste heat energy produced from cooling in the summer is stored below ground and used in the winter for heating; in the winter, the waste cold energy produced for heating is stored for use in the following summer for cooling. A BTES is most economically attractive for larger scale installations (such as blocks of buildings), with installation in conjunction with original construction.
19b	Mid-depth and Deep Geothermal Energy	This pathway will not consider shallow geothermal, as this is a well developed technology and is available commercially. Mid-depth (< 6000 M) and deep hot rock (> 6000 m) geothermal energy resources are potentially very significant sources of moderate temperature (40°C to 180°C) and higher temperature (>180°C) heat. This heat can be used directly for heating or commercial and industrial processing, including potentially oil sands processing and district heating, or for electrical power generation from facilities ranging in size from a few kilowatts to potentially hundreds of megawatts. The key features on non-hydrothermal (i.e. geyser) type sources of geothermal heat is that they will require the creation of new or utilization of existing reservoirs for heating water (or potentially other carriers), transporting the hot fluid to the service, extracting the heat and recycling the spent fluid back to the reservoir. The surface technologies are typical of power generation currently in use.
20	Natural Gas Hydrates	Methane hydrates exist in large quantities below permafrost and in sub-sea sediments. Estimates of Canadian natural gas volumes in hydrate form range from 1,540 to 28,500 trillion cubic feet (45 to over 800 trillion m^3). If methane can be efficiently extracted from this resource, it provides a vast new source of natural gas. Hydrate deposits which are found in Arctic gas formations in conjunction with free

No.	Pathway	Summary
		gas are likely to be developed first and are already in production in Russia simply by producing the free gas and depressuring the reservoirs so that the hydrate will dissociate.
21	Development of Coal Bed Methane	According to PTAC's Unconventional Gas Roadmap, Canada has over 1,500 trillion cubic feet (43 trillion m^3) of coal bed methane in place, vs. about 370 Tcf (10.5 trillion m^3) of remaining conventional natural gas potential. At a projected production rate of up to 7.5 Tcf/yr to meet on-going exports to the U.S., and increasing domestic demand for power generation and oil sands development, new sources such as CBM will be required to compensate for declining rates of conventional gas production. CBM production in the U.S. already provides almost 30% of the domestic gas production, is already underway in Alberta, and being considered in other provinces.
23	Tidal and Wave Energy for Electrical Power	Canada has 40,000 MW of identified tidal stream energy, and countless irrigation channels, inflows, spillways (and instream river flow) opportunities for energy harvest. The east and west coast deepwater wave energy may exceed 200,000 MW with nearshore resources exceeding 30,000. A dozen Canadian technology companies are working with concept, prototype or pilot approaches. Ten leading international technology companies are actively looking to work in Canada because of resource availability. Canada has excellent research capacity and infrastructure to support the sector and its ocean technology, marine, and power industry capacity can readily deploy in this market. This is an emerging energy opportunity.
24	Carbon Dioxide Capture, Transportation, Storage and Use	Canadian greenhouse gas (GHG) emissions to the atmosphere could be significantly reduced by extracting CO_2 from gas streams in large industrial, oil sands and power plants, then compressing and transporting it to geological storage sites, such as depleted oil and gas reservoirs, deep coal seams and saline aquifers in the Western Canadian Sedimentary Basin. This is (perhaps the only) 'win-win' pathway that would minimize the impact on our economy and ensure the sustainability of our energy sector, while effectively addressing the climate change challenge.
25	Advanced Fission Reactors for Electrical Power	Generation IV reactor systems are being developed with the aim of advancing fission reactors in the following areas: 1) Sustainability, 2) Safety, 3) Economics, and 4) Proliferation Resistance and Physical Protection. Six reactor systems are currently being developed under the GenIV initiative. Theses reactor systems differ in the degree of enhancement in the above four metrics and range from reactors that are highly economic for nearer term application (i.e., supercritical water cooled reactors) to reactors that would extend the Uranium supplies almost indefinitely (e.g., fast breeder reactors).
26	Magnetic Confinement Fusion for Electrical Power	A thermonuclear fusion power plant is based on high temperature magnetic confinement of hydrogen isotopes of deuterium and tritium. Fusion of one deuterium and one tritium atom produces one alpha particle (ionized helium atom) that carries 20% of the energy produced and one neutron that carries the remaining 80%. One gram of deuterium and tritium in equal numbers will produce an energy equivalent to almost 100,000 kwh. The alpha particles give up their energy to the plasma thereby maintaining its temperature. The neutrons, carrying most of the energy, are captured in a lithium 'blanket' surrounding the reactor vessel where they provoke further reactions with lithium to produce tritium and give up their energy to the coolant. The coolant in the closed coolant cycle in turn gives up its energy via a

No.	Pathway	Summary
		heat exchanger to the external coolant cycle, which drives conventional turbines and thus produces electricity.
27	Inertial Fusion Energy for Electricity	Fusion of isotopes of hydrogen (D, T) offers the potential of virtually unlimited, universally available, environmentally clean energy. Successful energy production, however, requires heating the fuel to 100 million degrees and confining it for sufficient time to provide net energy gain. The high density, short confinement time approach - inertial fusion energy (IFE) - is based on using laser (or ion) beams to compress and heat fuel pellets to ignition conditions. In a power reactor, the fusion reaction energy resulting from pellet burn (primarily in neutrons) would be captured in a circulating lithium blanket (used for both producing more tritium fuel and carrying heat to an external thermal-electric generation cycle). Attributes include: a) no greenhouse gas emissions, b) no long-term radioactive waste storage, c) no possibility of reactor runaway.
28	Recovery of Bitumen from Carbonate Deposits	While bitumen is generally associated with oil sands, 71.1 billion m^3 or 26% of Alberta's bitumen resources are contained in carbonates rather than sand formations. The "Carbonate Triangle" deposits have been identified as being the most technically challenging. This is not a new realization, as carbonates were originally targeted for technology development by AOSTRA in the 1970's and 1980's, and did see the development of production pilots but with mixed success. However, the problems encountered 20 years ago during the pilot trials could be solvable today. The industry now has mining and drilling technologies such as continuous miner, horizontal wells and well completion technologies that would increase the likelihood of successful recovery of bitumen from carbonates. (Peachy, B.; Heidrick, T.; et al., May 31, 2006)
29	Increased Conventional Oil Recovery	While Canadian conventional oil has been reported to be in decline, this is only from primary production from established and mature basins. Over 70% of the oil in those basins is known to be still in the reservoirs, and is awaiting enhanced oil recovery methods to be more extensively applied to increase recovery. A recent PTAC report "Ramping up Recovery" indicates that there is still over $1 trillion of conventional oil that might be produced with proven methods. At the same time additional new deposits will eventually come on-stream from the Arctic and offshore which will require unique production technologies to match the unique environments.
29b	Enhanced Oil Recovery by Air Injection Processes	Air injection technology could potentially be applied to several types of petroleum reservoirs ranging from deep light oils to heavy oils, with an increase of perhaps a few percent (2 to 10%?) in the recovery of conventional oil in Canada. The incremental oil would be refined, some of it after upgrading, into liquid fuels for ultimate use in engines within the agriculture, industrial and transportation sectors. Transportation would be conducted primarily by pipeline or tanker truck, depending on the volumes being transported along specific routes.
30	Increased Natural Gas Recovery	Canadian natural gas from conventional mature basins is expected to begin a decline sometime in the next 5-10 years. Conventional gas recoveries are considered to be anywhere from 59-72% of the gas in place, depending on the pool, economics during production, etc. The recent PTAC report "Ramping up Recovery" estimated that besides the current reserves there is likely to be an additional 12-13 TCF of conventional gas, valued at over $400 billion dollars that could be recovered with better application of existing technology in Alberta and B.C. Frontier gas resources are still relatively unknown and unexploited, but would also benefit from technology advancements.