The Hydrogen Economy

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Treading Carefully…

"The two most abundant things in the universe are hydrogen and stupidity."

Harlan Ellison

"There is more stupidity than hydrogen in the universe -- and it has a longer shelf life."

Frank Zappa

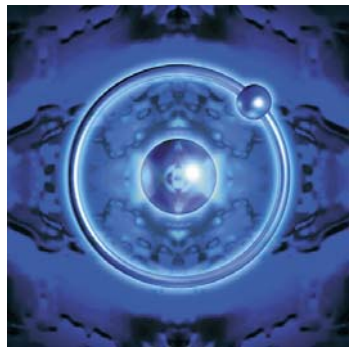
Presentation Overview

- Defining Terms
- The Hydrogen Vision
- Energy Policy Context
- Hydrogen Value Chain
- Industry Characteristics
- Barriers
- A Farm Energy Perspective
- Where To From Here

Terminology

Hydrogen

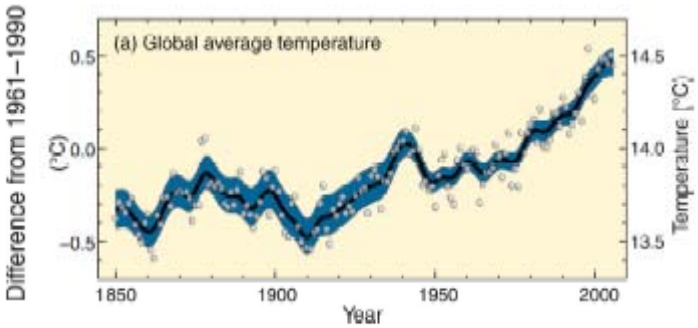
- The lightest and most abundant element in the universe (approximately 75% of all matter)
- Largely present on earth in hydrocarbons and water
- A unique and attractive energy storage medium



“The Hydrogen Economy”

- “A hypothetical state of advanced technology and resource allocation in which the energy to produce motive power and stationary electricity is derived from the efficient reaction of hydrogen molecules”
- Consistent with a sustainable and emissions-free vision of the natural environment

The IPCC: Sober Science on Global Warming

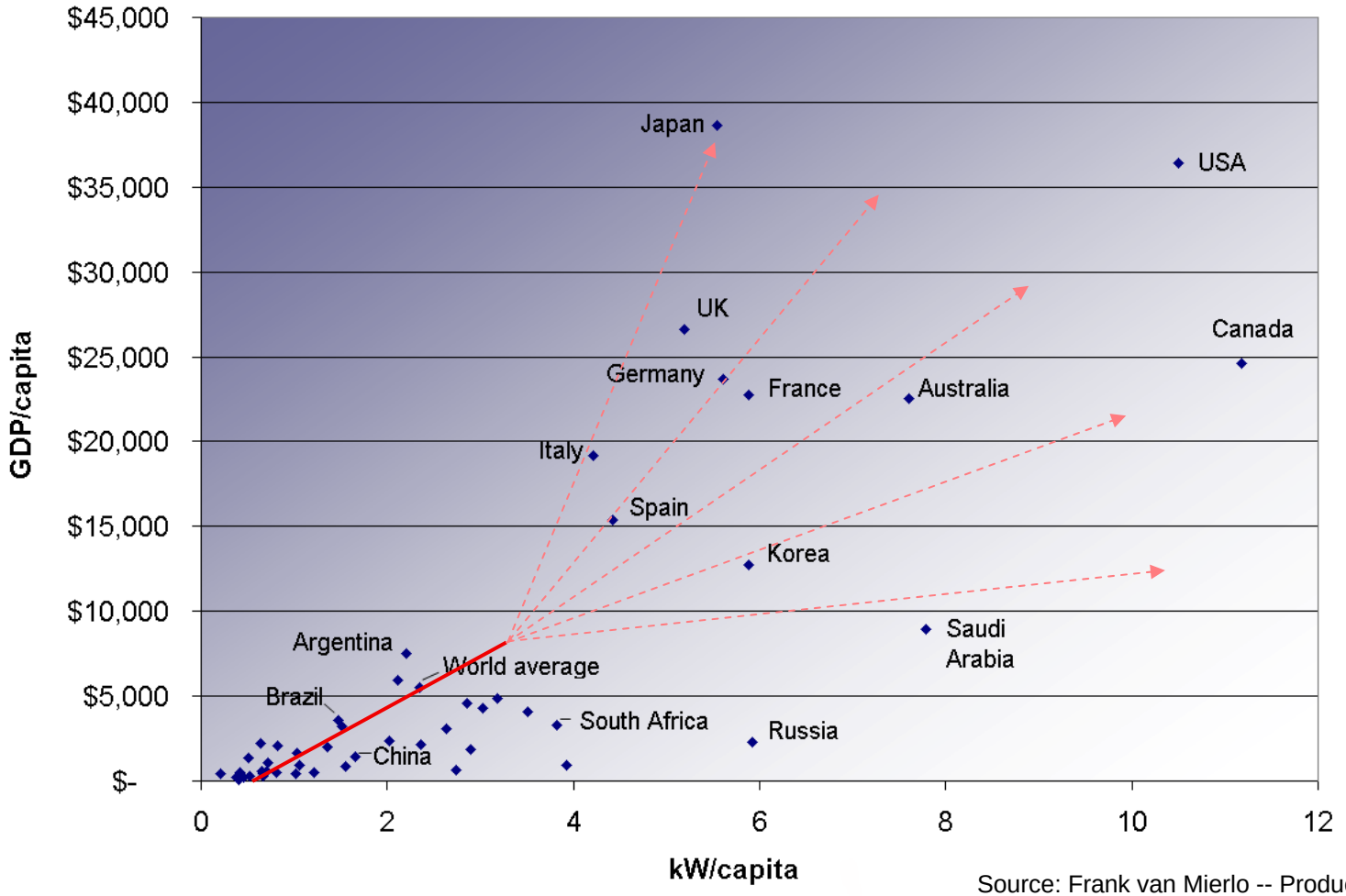


- Amounts of carbon dioxide and methane measured in the atmosphere in 2005 far exceed the natural range found in well preserved samples of the last 650,000 years:
  - CO2: 180-300 → 379 ppm
  - Methane: 320-790 → 1,774 ppb
- The primary source of the increase in carbon dioxide is fossil fuel use
- The primary source of the increase in methane is likely a combination of human agricultural activities and fossil fuel use

Category	CO_2 concentration at stabilization (2005 = 379 ppm) [6]	CO_2-equivalent Concentration at stabilization including GHGs and aerosols (2005 = 375 ppm) [5]	Peaking year for CO_2 emissions [A, c]	Change in global CO_2 emissions in 2050 (% of 2000 emissions) [A, c]	Global average temperature increase above pre-industrial at equilibrium, using "best estimate" climate sensitivity [d], [e]	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only [f]	Number of assessed scenarios
	ppm	ppm	Year	Percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

Fourth Assessment Report: 2,500 scientific expert reviewers, 800 contributing authors, 450 lead authors from 130 countries.

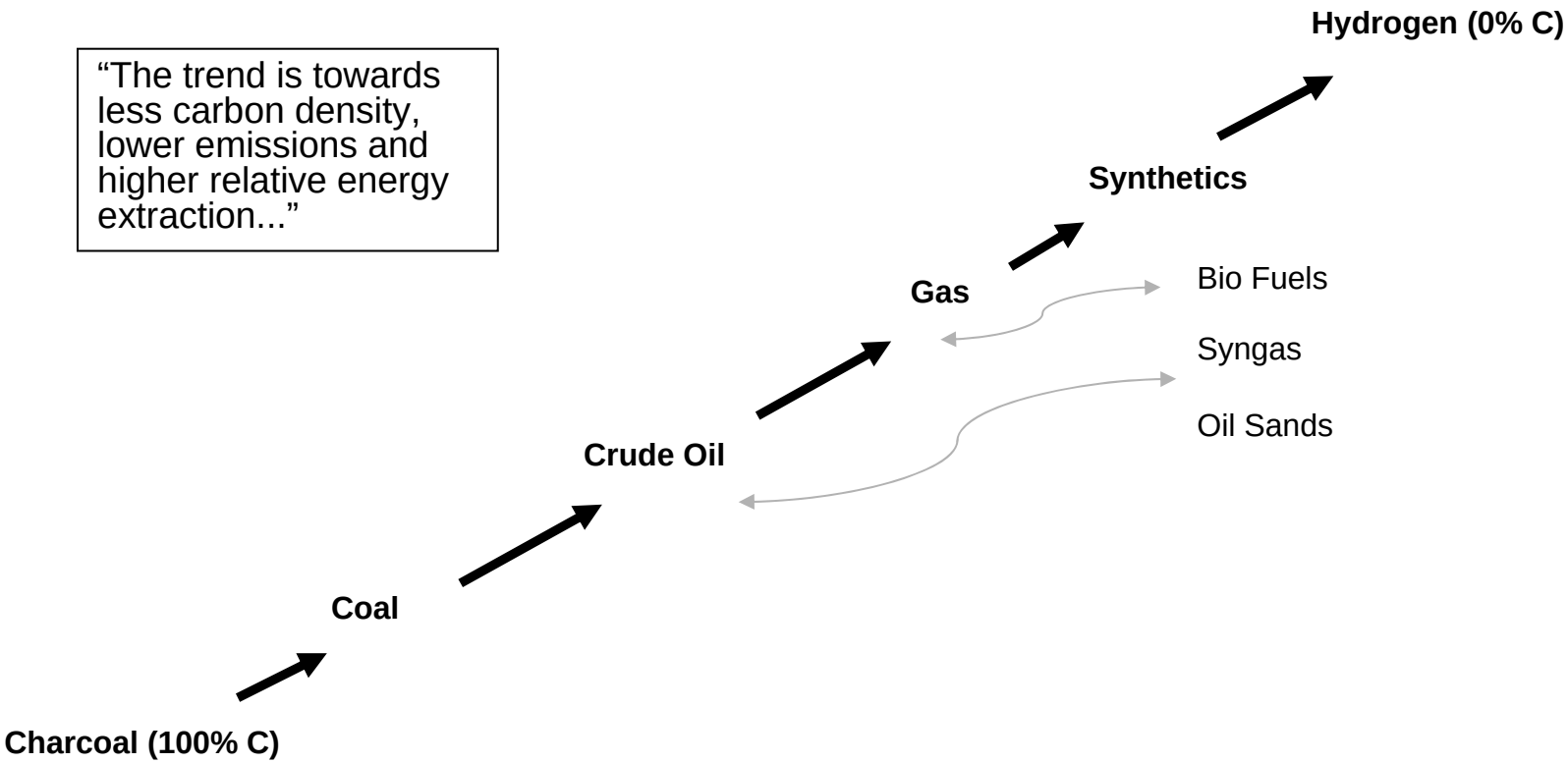
Choosing a Future Energy Path…



Source: Frank van Mierlo -- Produced from data in the 2006 "'Key World Energy Statistics"' from the International Energy Agency

Away from Carbon and Towards Hydrogen

"The trend is towards less carbon density, lower emissions and higher relative energy extraction..."



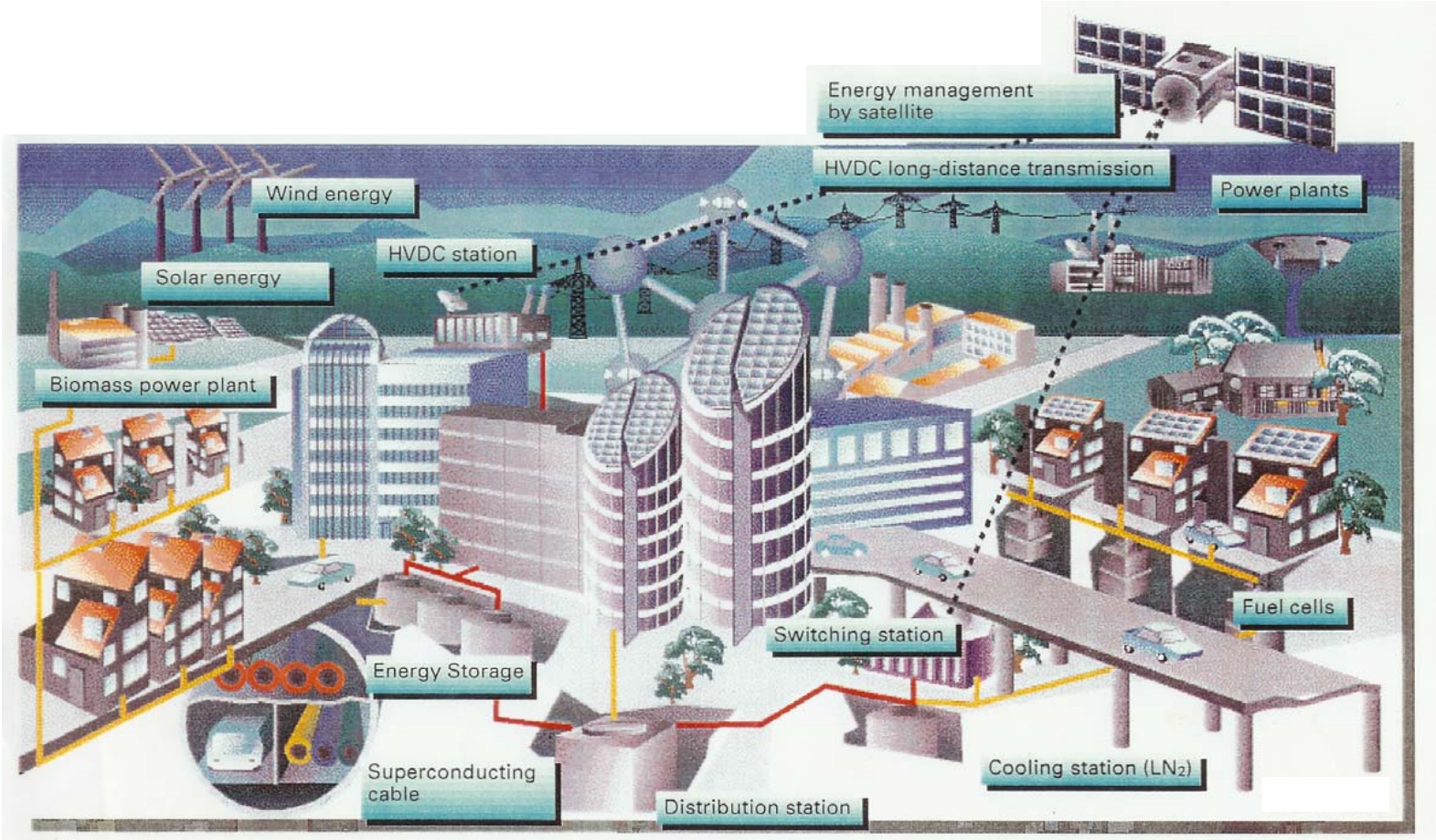
Source: Arthur J. Carty, National Science Advisor, Government of Canada

"The Hydrogen Economy" – What it Means

- ***Not soon!***
- Technology + Flexibility + Sustainability + Economics = Transformation
- Customer-driven solutions continue trend to decentralized infrastructure
- Emerging production, storage and FC products are "disruptive technologies" – i.e. they have the potential to transform economic and social systems far beyond their market:
  - Distributed storage and usage of electricity and heat using modular products
  - Hydrogen-fuelled vehicles as a replacement for internal combustion engines
  - Stationary power systems to provide cost-effective inputs to the electricity grid

Notwithstanding the uncertain timing of commercialization, hydrogen and fuel cell technology development continue to be robust. Future paths are still unclear, but Ontario has key assets and expertise.

A Green and Futuristic Vision!



Source: Siemens, 1997

Ontario Energy Context

- About 80% of Ontario's electricity infrastructure requires rehabilitation or replacement in the next 20 years
- Key policy drivers have been provided by Ministerial Directive:
  - Ensure reliable supply
  - Create a conservation culture
  - Develop more renewable energy
  - Strengthen transmission infrastructure
- Regulations are now in place to cease burning of coal by 2014
- Conservation is defined to include: energy efficiency, load shifting, fuel switching and self generation (e.g. distributed energy)
- Government initiatives lead North America:
  - 6,300 MW of conservation targeted to 2025 (1,350 to 2007 and 2010)
  - Net metering, renewable and clean energy standard offer programs
  - Enabling regulations for connections and technical standards
  - Incentives for renewable installations and energy efficient products

Value Chain

- About 80% of Canada's hydrogen production originates in the western provinces, and is primarily used for oil refining, heavy oil upgrading and chemicals
- The growth of oil production from Alberta tar sands will significantly increase the demand for H2 capacity: current production of 3.5 million tonnes/year is expected to increase to more than 6 million tonnes/year by 2030
- In Ontario, the bulk of H2 is produced for oil refining and chemicals, though smaller quantities are produced for merchant uses

Production

- Steam reformation of natural gas is the most common production method
- Electrolysis, including on-site devices, is a small but growing production segment
- Chemical processes using steam heat and water are developing

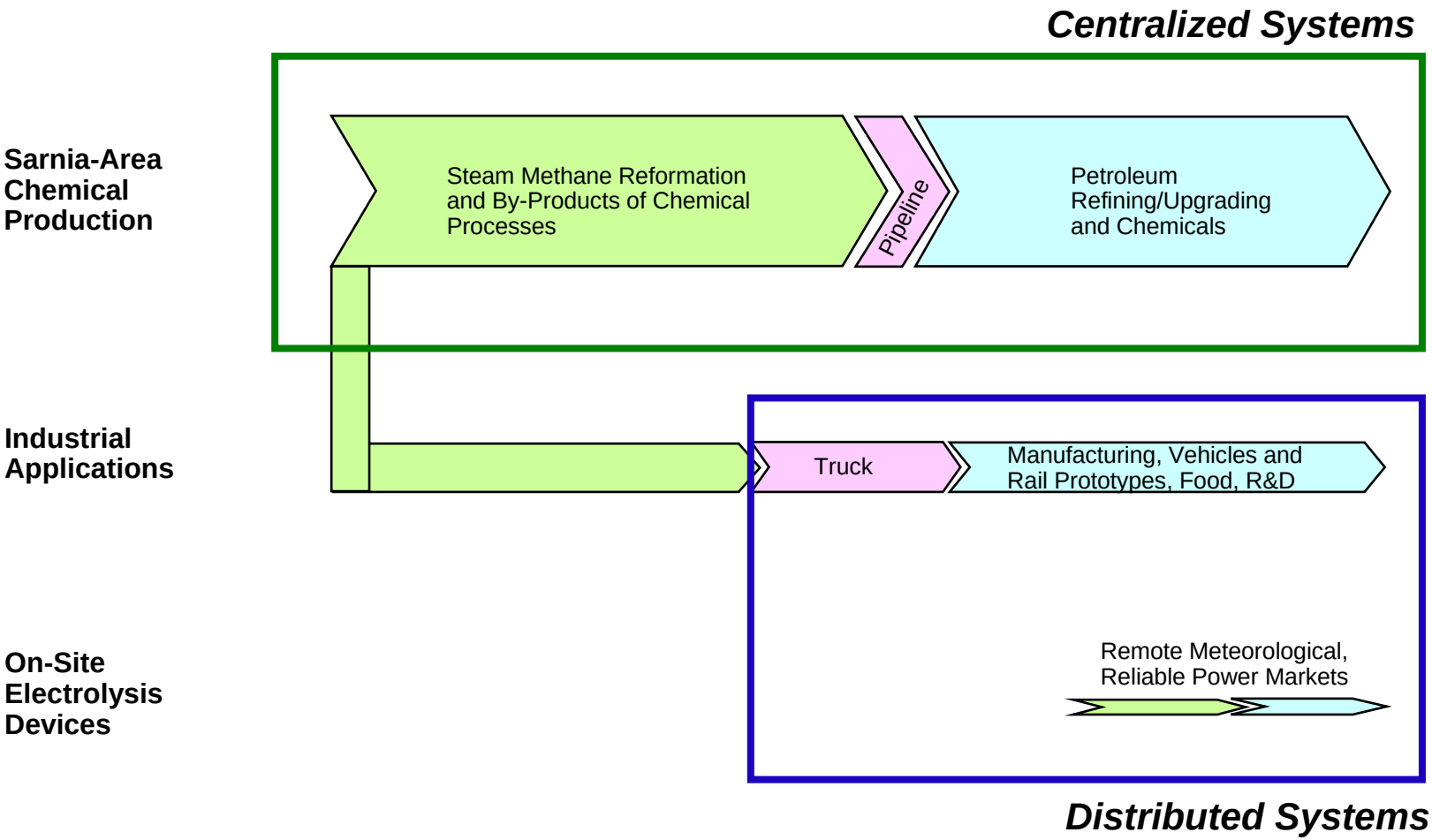
Distribution/Storage

- Pipeline networks deliver most of Alberta's and Sarnia's H2
- Refrigeration trucks distribute liquid H2
- Distributed technologies focus on containers, cartridges and refueling
- On-board storage for vehicle use consumes significant R&D

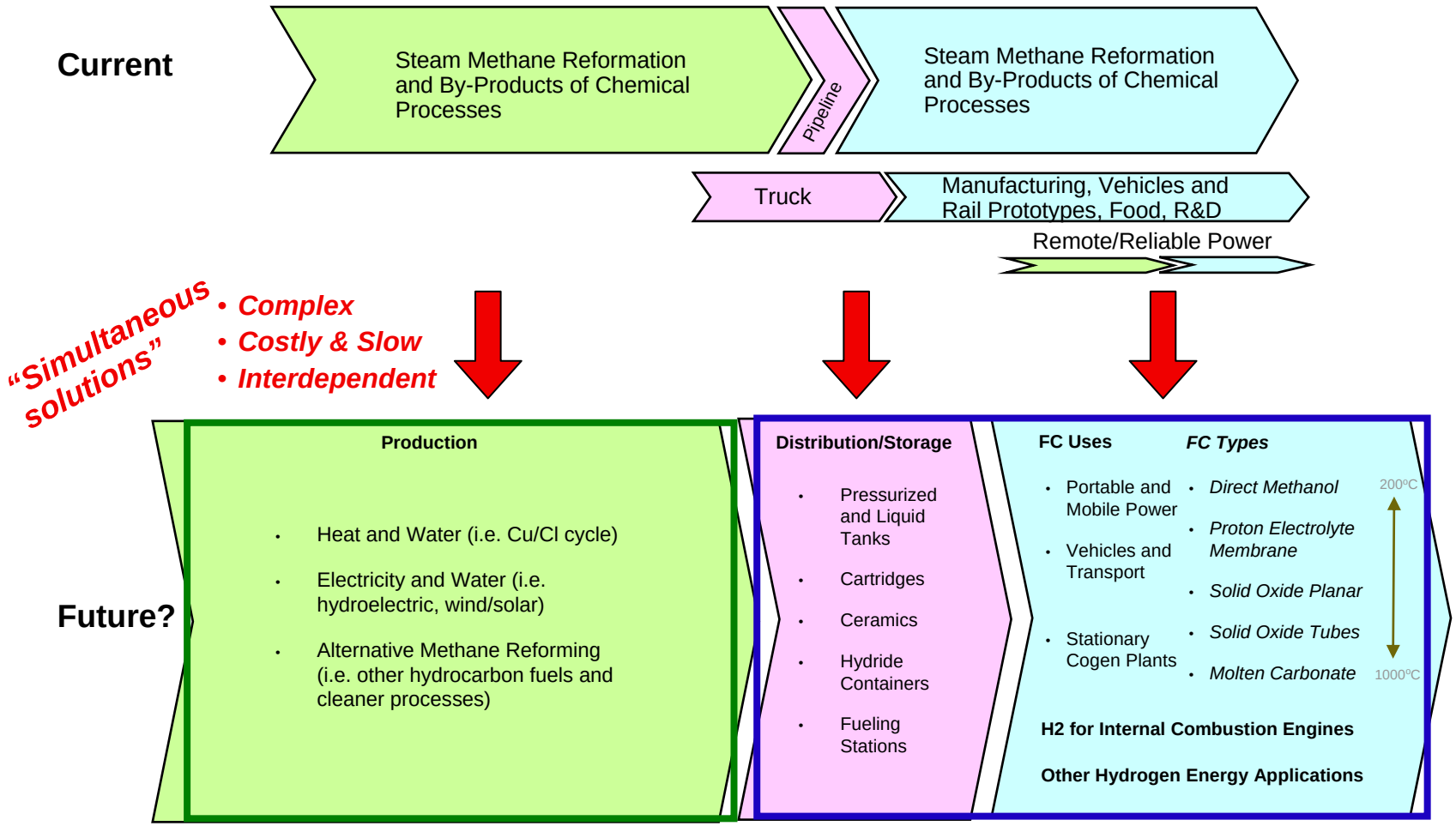
End Use Applications

- H2 is largely used in oil refining/upgrading and chemical production, and can also be used in manufacturing, food processing and FC prototype R&D
- Fuel cell applications offer tremendous growth potential
- Internal combustion engines can also utilize H2

Ontario's Current Hydrogen Value Chain



Potential Future Paths to Innovation



Technology innovations to produce, store and distribute hydrogen for fuel cell and other end use.

Global Landscape

Hydrogen Supply

- 2006 characteristics of the global hydrogen market:
  - 55 million metric tonnes of hydrogen supplied
  - Estimated value of $135 billion
  - Key producers are Air Products, Praxair, Air Liquide
- Virtually all supply is from steam methane reformation
- Two key end-use sectors:
  - chemicals (60%)
  - refining (30%)

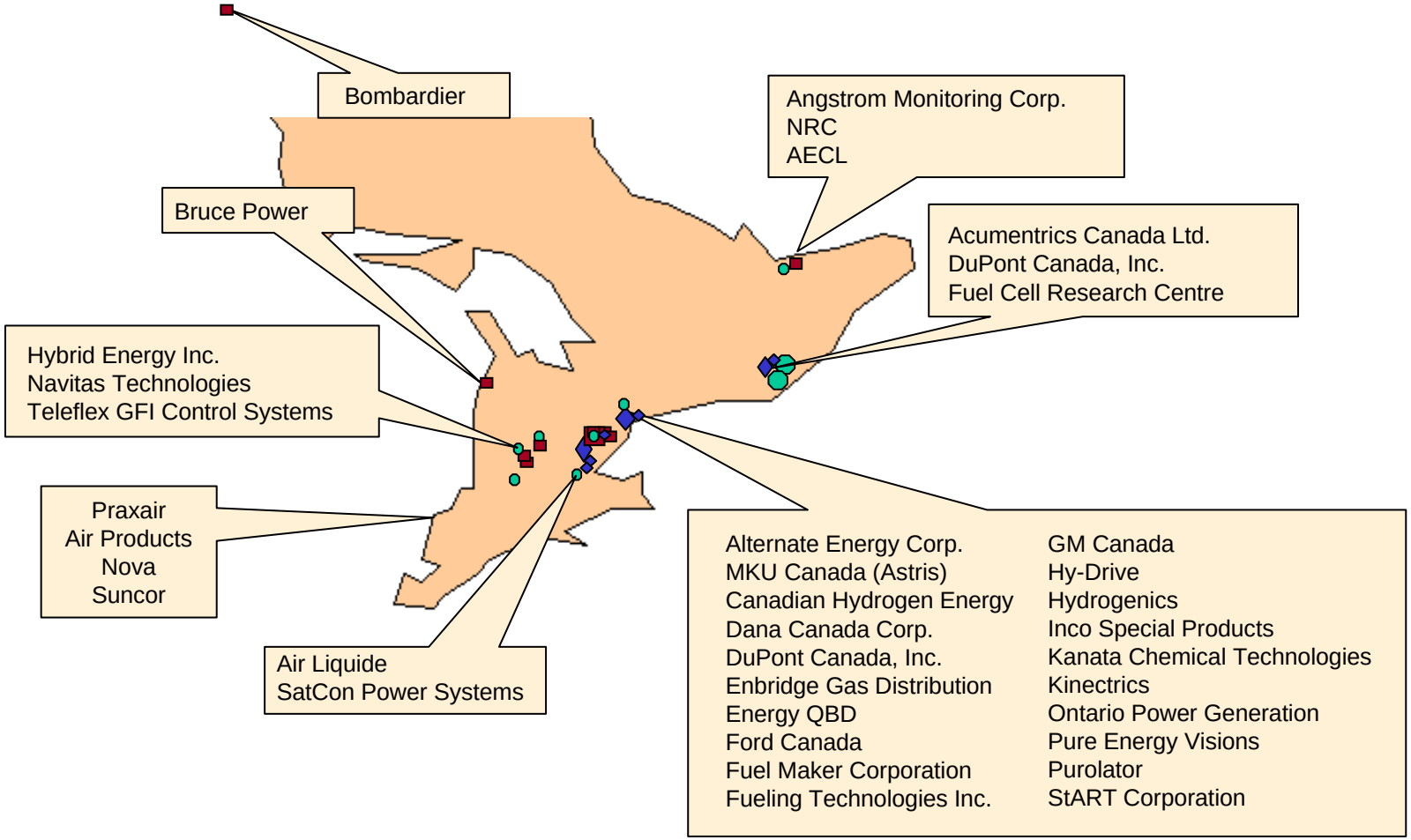
Fuel Cells

- 2006 status of global publicly traded FC companies:
  - Annual revenue rose 59% to $415 million
  - R&D investment was $215 million
  - Losses were $645 million
- Direct methanol FC's seem poised for market entry
- Massive automotive R&D, pilots and demonstrations
- Stationary power markets limited to niches (i.e. UPS)

The industrial world is investing in these technologies!: USA: DOE 2008 Hydrogen program budget is $309 million; in the European Union, the Hydrogen Joint Technology Initiative is $690 million; Japan is committing $4 billion over next 5 years.

Source: FC Survey by PriceWaterhouseCoopers, plus preliminary data compiled by Ministry of Energy from published and industry references

Hydrogen/FC Industry Participants



Source: Preliminary data compiled by Ministry of Energy

Ontario – Preliminary Industry Summary

	Hydrogen Supply	Distribution/ Storage	Fuel Cells and Other Uses	TOTAL (Approximate)
Number of Companies	20		Fuel cells = 15 H2 & FC = 5-10	40
Annual Capital Investment (Including Government Funding)				R & D investment = $50+ million Demo = $5.5 million
Annual Revenues	$1.5 billion (H2 production value)	$40 million		
Direct Employment	115+		215 H2 & FC = 125	450

Source: Preliminary data compiled by Ministry of Energy from industry references

Ontario Government Initiatives

Ministry	Program Name	Key Elements
Ministry of Research and Innovation	Ontario Fuel Cell Innovation Program	$3 M in annual funding with a focus on commercialization and moving products to the manufacturing stage
Ministry of Research and Innovation	Ontario Research Fund -- Ongoing	Keeping Ontario's researchers at the leading–edge in priority economic sectors. Focus on operational and capital costs.
Ministry of Research and Innovation	Innovation Demonstration Fund – Ongoing	Commercialization and initial demonstration of globally competitive, innovative technologies, processes and/or products
Ontario Centres of Excellence – Centre for Energy	Breakthrough Clean Energy Technologies	$5.5 M from OCE for two projects focused on hydrogen-fueled systems development.
Ministry of Research and Innovation	Strategic Assessment of Hydrogen Train Development	Multi-stakeholder feasibility assessment of an Ontario-based hydrogen train demonstration.

Barriers

- **Technology**
  - "Simultaneous solutions" to innovation requirements throughout the value chain; are solutions near for clean and renewable supply, safe and reliable storage/distribution, dependable and practical applications for transport and stationary power?
- **Economics**
  - The lowest conventional motive and stationary power products are hundreds of dollars per kW or less; can fuel cell technologies find a log-scale improvement in delivered cost?
- **Regulations**
  - Do production, handling, transportation and usage regulations reflect best practice?
- **Policies**
  - Are environmental and other externalities captured in current policy development – and how can government resources best incent innovation/remove barriers?
- **Expectations**
  - Do society/industry/other stakeholders appreciate the scope of the challenge?

Needs and Enablers

	Hydrogen Supply	Distribution/Storage	Fuel Cells
"Technologies need to…"	• Demonstrate economic viability of heat and water electrolysis	• Develop alternatives to pressurized H2 • Establish dense hydrogen storage at room temperature	• Increase stack densities • Size FC's to vehicles • Improve speed and range • Improve reliability
"Sectors need to…"	• Find strategic partners among upstream electricity and heat providers • Demonstrate waste or off-peak energy as input to H2 production cycle	• Demonstrate pilot refueling infrastructure • Find strategic partners among downstream vehicle makers to define required storage parameters	• Generate profits from increasing revenues (find near-term niches) • Maintain R&D levels • Establish a dependable supply chain for volume production

Farm Energy Perspective

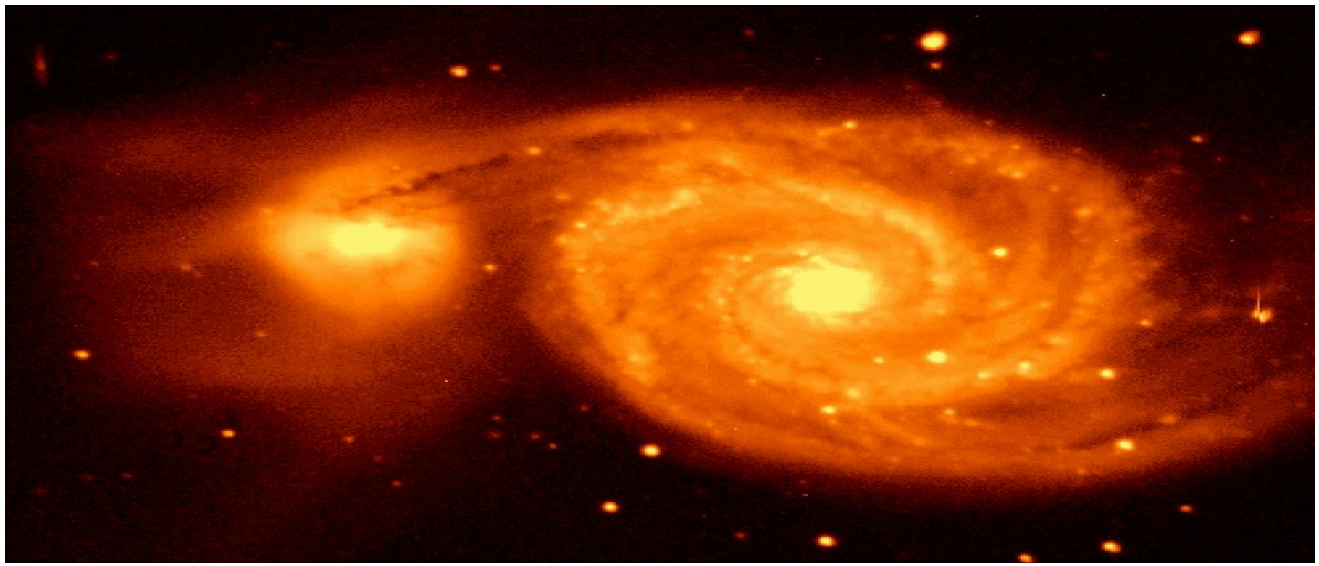
- Hydrogen Usage:
  - H2-fuelled internal combustion engines
  - Fuel cell-based heavy machinery where depth/emissions are concerns
- Hydrogen Production:
  - Wind-based electrolysis:
    - A potential solution for carbon-free and renewable supply
  - Anaerobic digestion:
    - Increasing research into accelerating H2 production/storage during hydrolysis and acidogenesis/acetogenesis stages of the AD process
    - 2006 demonstration at AA Dairy (500-cow operation in Candor, NY)
    - Almost 12,000 Google hits: "hydrogen production" anaerobic digestion -- including 1,200 Ontario references

Where To From Here

- "Global investments in building the hydrogen economy are expected to represent a CAGR of 27.0% over the next 5 years." – BCC Research, USA
- FC development is an important high technology niche, which is expanding among key industrial centres globally; innovation clusters in New England, the West Coast, Europe and Japan are likely to be the catalysts for new products, processes and infrastructure
- Aggressive climate change and industrial development initiatives in Ontario compliment H2/FC R&D, demonstration and commercialization
- Ontario H2/FC technology accomplishments and initiatives are substantial
- The Ontario automotive sector has invested large sums in FC development, and has gained unique industry expertise
- Ontario's Next Generation Jobs Fund focuses on transformative projects that will establish leadership positions for Ontario-based organizations

“Fortune befriends the bold.”

John Dryden



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