University of Waterloo

A Vision of a Hydrogen Economy

Design of a Hydrogen Power Park

2005 H2U Design Contest

National Hydrogen Association, U.S Department of Energy, and ChevronTexaco

Team Members: Allison Mendes, Shirley Leung, Hani Fadali, Gordon Graff, Bryan Icyk, Bartosz Lomanowski, Abhay Patel

Advisor: Michael Fowler

Project Goal

To design a feasible, innovative & safe *Hydrogen Power Park* that will refuel fuel cell vehicles and produce electricity

Team Vision

To generate greater demand for a *Hydrogen Fuel Economy*

Today's Topics

- The Team
- Park requirements
- Park Design
- Safety
- Economics
- Environmental Analysis
- Marketing Plan

Human Resources

Allison Mendes

Chemical Eng.

Shirley Leung

Chemical Eng.

Bartosz Lomanowski

Mechanical Eng.

Hani Fasali

Electrical Eng.

Bryan Icyk

Business/Marketing

Abhay Patel

Chemical Eng.

Gordon Graff

Architect

The Team!

Dr. Michael Fowler, P.Eng.

Faculty Advisor

Chemical Eng

Your Energy Source

Hydrogen Power Park

Park Requirements

- The park will commence service in 2010 for a ten year service life

- Generated and stored hydrogen on-site
- Increase capacity from 50 kg/day to 250 kg/day at 5 kg/car
- Maximum footprint: 21000 sq ft
- Provide a minimum of 100 kW of electrical power using green energy
- Use commercially available equipment

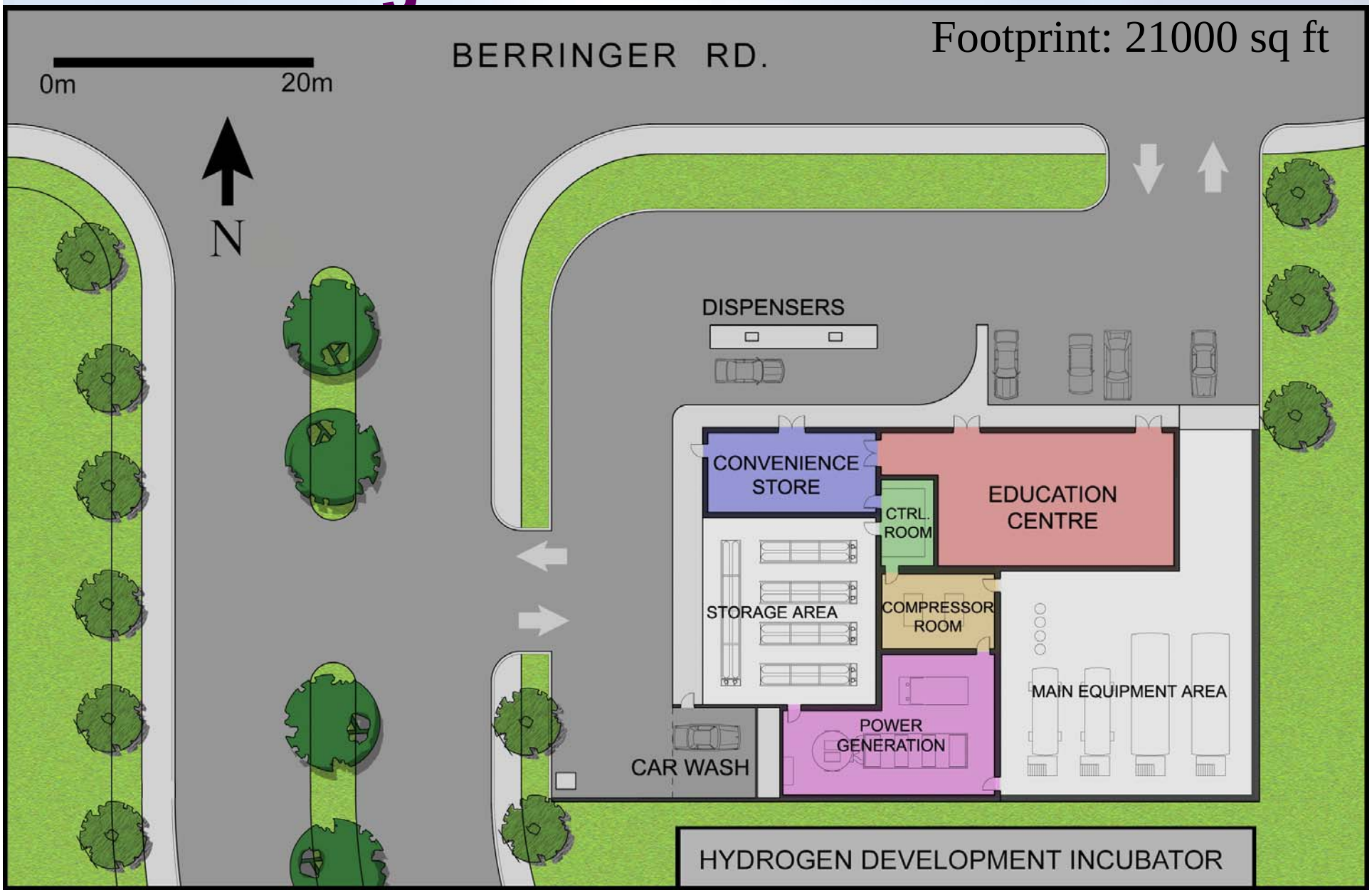
Park Design – Waterloo is A Perfect Location !

- Become one of the pit stops along the Hydrogen Corridor between Windsor-Montreal
- Affiliation with the University of Waterloo
  - *Education tool for university research*
  - *Encourage evolution of hydrogen technology*

Location:

Waterloo Research and Technology Park

Park Design – 2D Site Plan



Hydrogen Development Incubator

Aims:

- **To develop and promote hydrogen production and distribution**
- **Enhance the developmental and research efforts by serving as a 'think tank'**

Public Education Centre

- Located in the Power Park for students and public to learn about hydrogen production and its advantages

Features of Educational Facility

- Cut-away models of hydrogen vehicles and equipments
- Posters

Park Design- Renewable Feed Source

- Renewable and relatively cheap feed source
- The process feed will be composed from a landfill gas from the Waterloo Landfill site in Southwest Ontario
- Landfill gas cost $0.045/m^3 compared to $0.315/m^3 for Natural Gas!

Waste Disposal Site

Methane

$$CH_4 + H_2O \leftrightarrow 3H_2 + CO$$

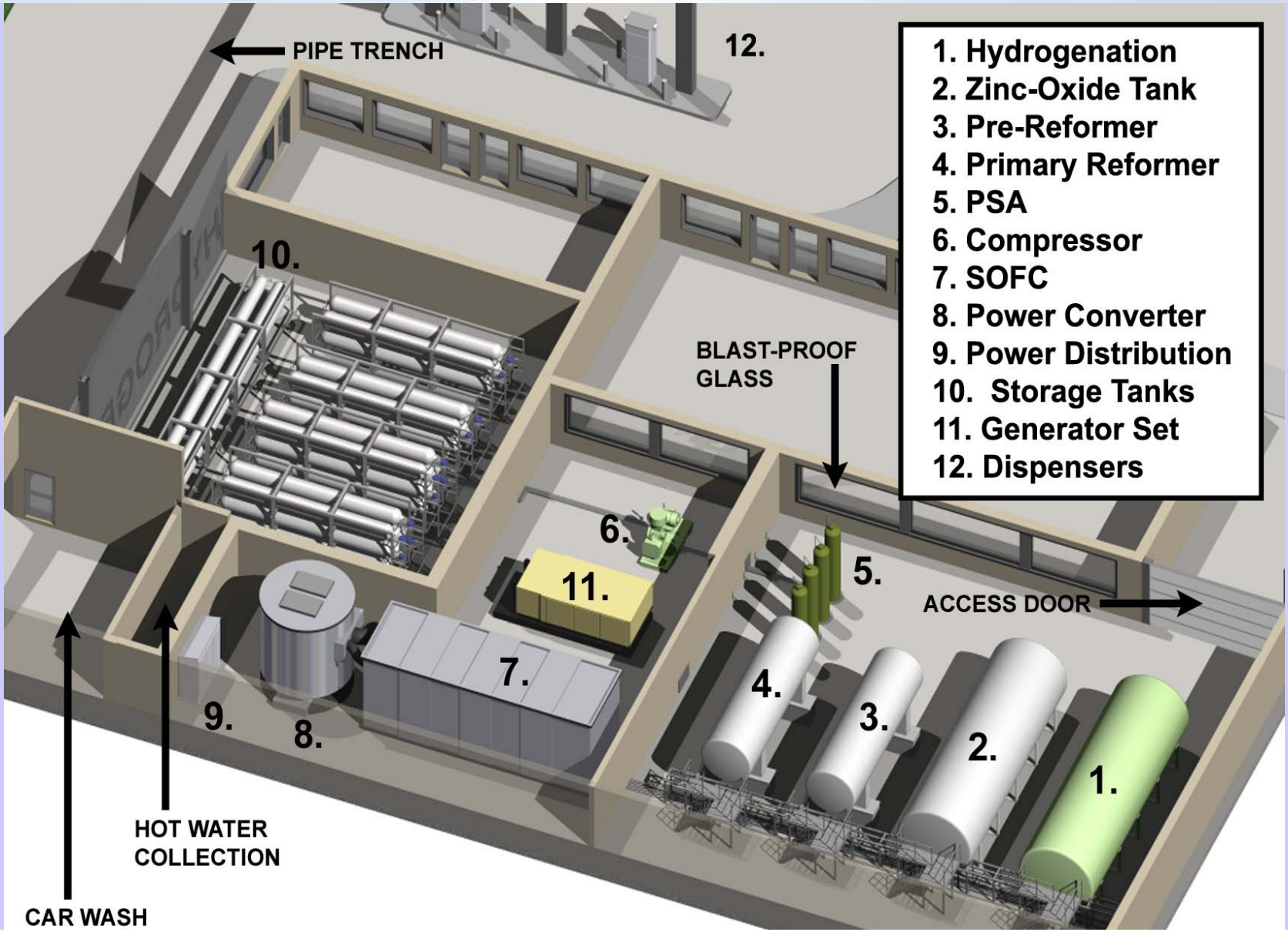
Waterloo Power Park

H_2

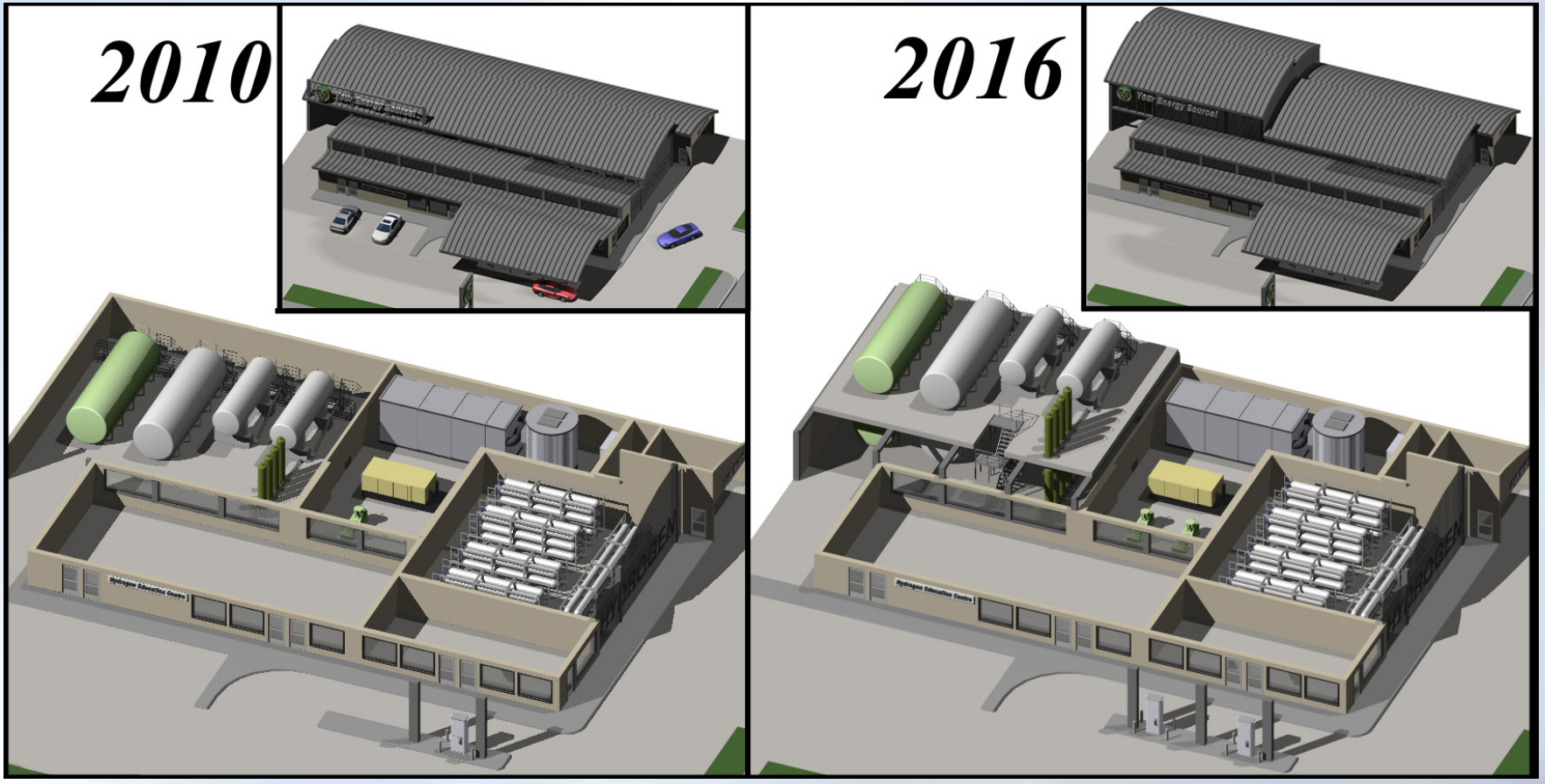
Park Design – 3D Rendering [Side View]

Park Design – 3D Rendering (Top View]

Park Design – Process Equipment (3D)

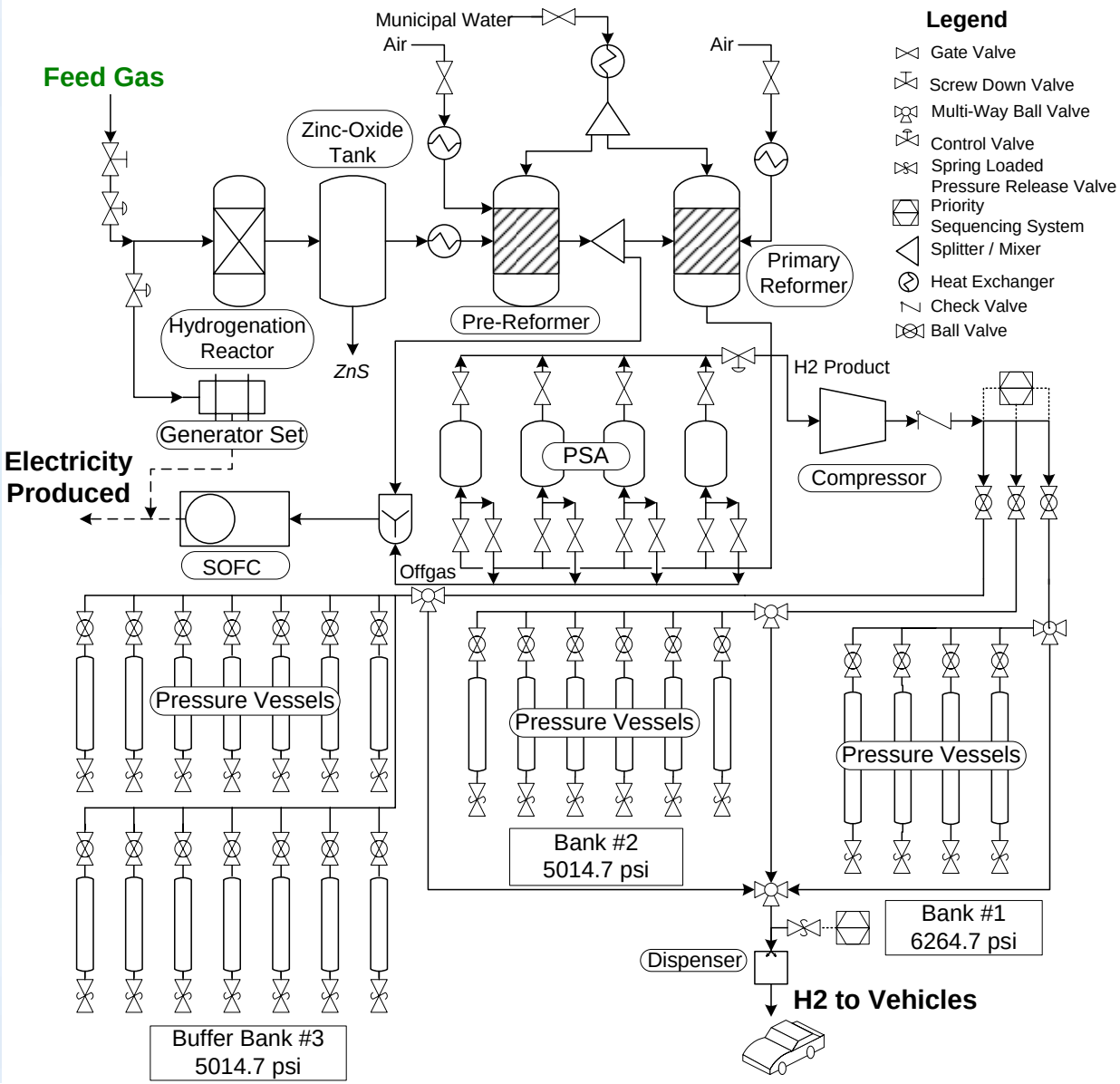


Park Design – Expansion in 2016



Process Flow Diagram

- Conditioned landfill gas (≈ natural gas) is supplied by pipeline to power park
- The gas is reformed, compressed and stored onsite at high pressures and finally dispensed to FCVs.
- Electricity is generated by a 125 kW SOFC using a mix of partially reformed gas and PSA waste gas.



Park Design- Rational for Equipment Selection

Pre-reformer - Hydrogenics Corp.

- Increases % conversion of methane to hydrogen in SMR due to increased steam to carbon ratio (S:C).
- Act as a sulphur guard (extends life of expensive SMR & SOFC)

SMR (Steam methane reformer) - Hydrogenics Corp.

- Significantly less expensive than an electrolyser
  Based only on energy and capital costs:
  - *electrolyser $555 US/kg*
  - *reformer $1.6 US/kg*

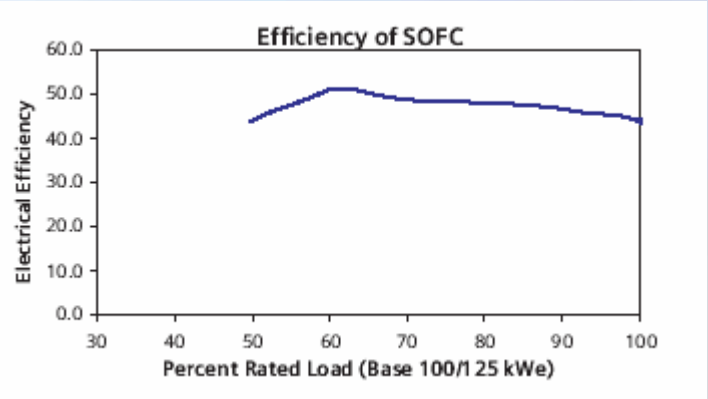
PSA (Pressure Swing Adsorption) - Hydrogenics Corp.

- Purity of product stream yields 99.95% H_2

Park Design- Rational for Equipment Selection

125 kW Solid Oxide Fuel Cell (SOFC)

– Siemens Westinghouse Power Corp



- Lowest emissions of any power plant using natural gas
- Incorporates a power conditioning system to convert DC to AC
- High electrical efficiency even at part load

2-Stage Diaphragm Compressor - Products Industries Inc.

- Completely isolates process gas (pure H_2) from contamination
- Relatively low maintenance

Park Design- Rational for Equipment Selection

Compressed Gas Storage System - CP Industries

- 3 storage banks under 2 different pressures
- Cascade filling system to minimize hydrogen storage capacity
- 1-day buffer storage capacity (load flexibility)

Bank1: 4x764.6 L (6264.7 psi)

Bank2: 6 x 968.4L (5014.7 psi)

Bank3: 14x 968.4L (buffer)

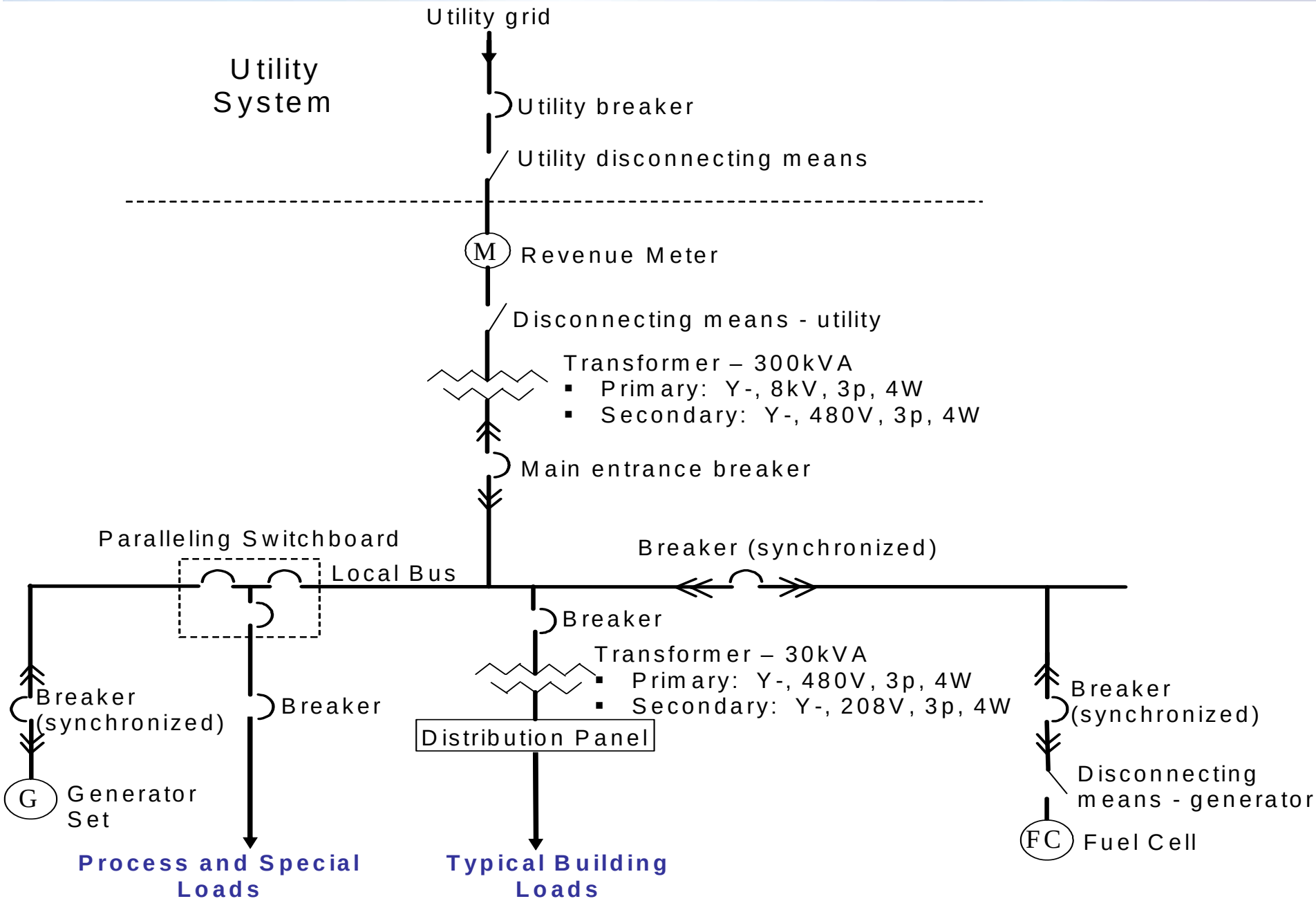
H_2 Dispenser - Fueling Technologies Inc.

- One dispenser with a single, side oriented, nozzle
- Provides temperature compensated fills (safety feature)

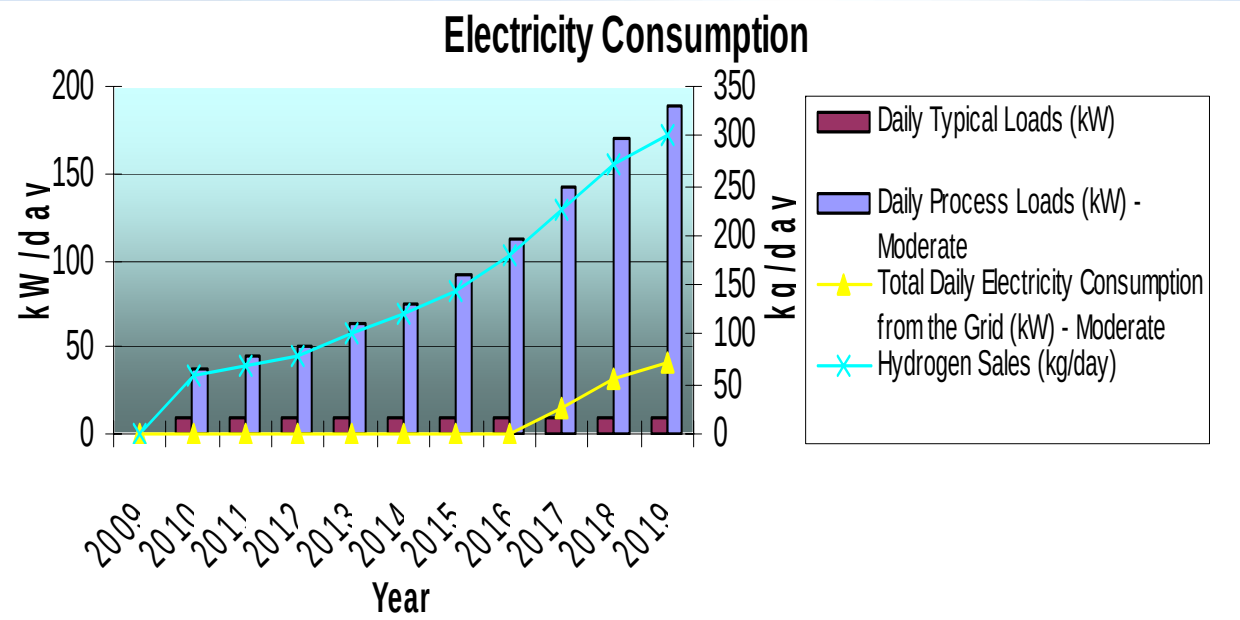
Park Design-Electrical System

- A safe, realistic and practical design that adheres to all applicable codes and standards
- SOFC operates in parallel with the grid
  - *Reduce the need to purchase electricity*
  - *Supplies critical site power in case of power outage*
  - *Selling power to grid is unprofitable*
- 100 kW generator set for stand-by operation in case of an outage on the supply utility system

Interconnection Diagram of Power Production Sources with Loads



Electrical Requirements



The SOFC produces less CO_2 emissions than grid power.

SOFC: 440g of CO_2 per kWh

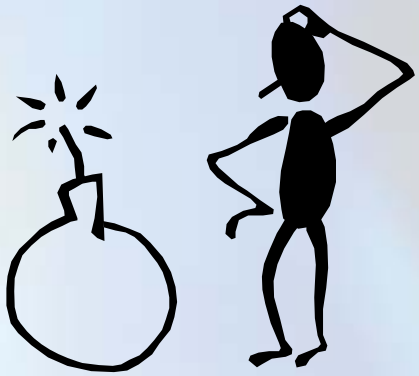
Grid: 453g of CO_2 per kWh

SOFC: Able to produce 3000kWh/day and will only produce energy as required.

As the energy consumption increases beyond 3000kWh/day, the difference is drawn off the local power grid.

Safety Considerations in the Park Design

4 major failure modes and their preventive measures:

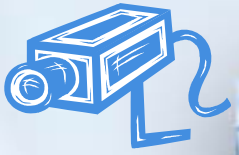


1. **Human Error**
   adequate employee training
   visible warning signs and instructions

2. **Gas Leakages**
   built according to standards, regular inspections

3. **Equipment Failure**
   scheduled maintenance as suggested by manufacturers

4. **Terrorism**
   security cameras,
   card-accessed entrances



Safety Considerations in the Park Design

When there is hydrogen Fire /Leakage:

- Infrared/UV sensors, smoke detectors, flow sensors → audible alarms + red flashing light + emergency fail-safe shutdown → emergency dispatcher → fire department

Hydrogen Properties 1

- Flammable
- Non-toxic
- Odourless
- Colorless gas
- Small molecular size
  - *prone to leakage*

- Compare to natural gas
- Diffuses in air 3.8x faster
- Rise 6x faster

- Invisible flame (unless coloured by impurities)
  - *significantly less radiant heat than hydrocarbon fire*
    - reduce the risk of secondary fires
    - but less warning as one approaches the invisible flame

Hydrogen Properties 2

Combustion

- Hydrogen → water vapour
- Natural gas (incomplete combustion) → toxic CO & CO2, water

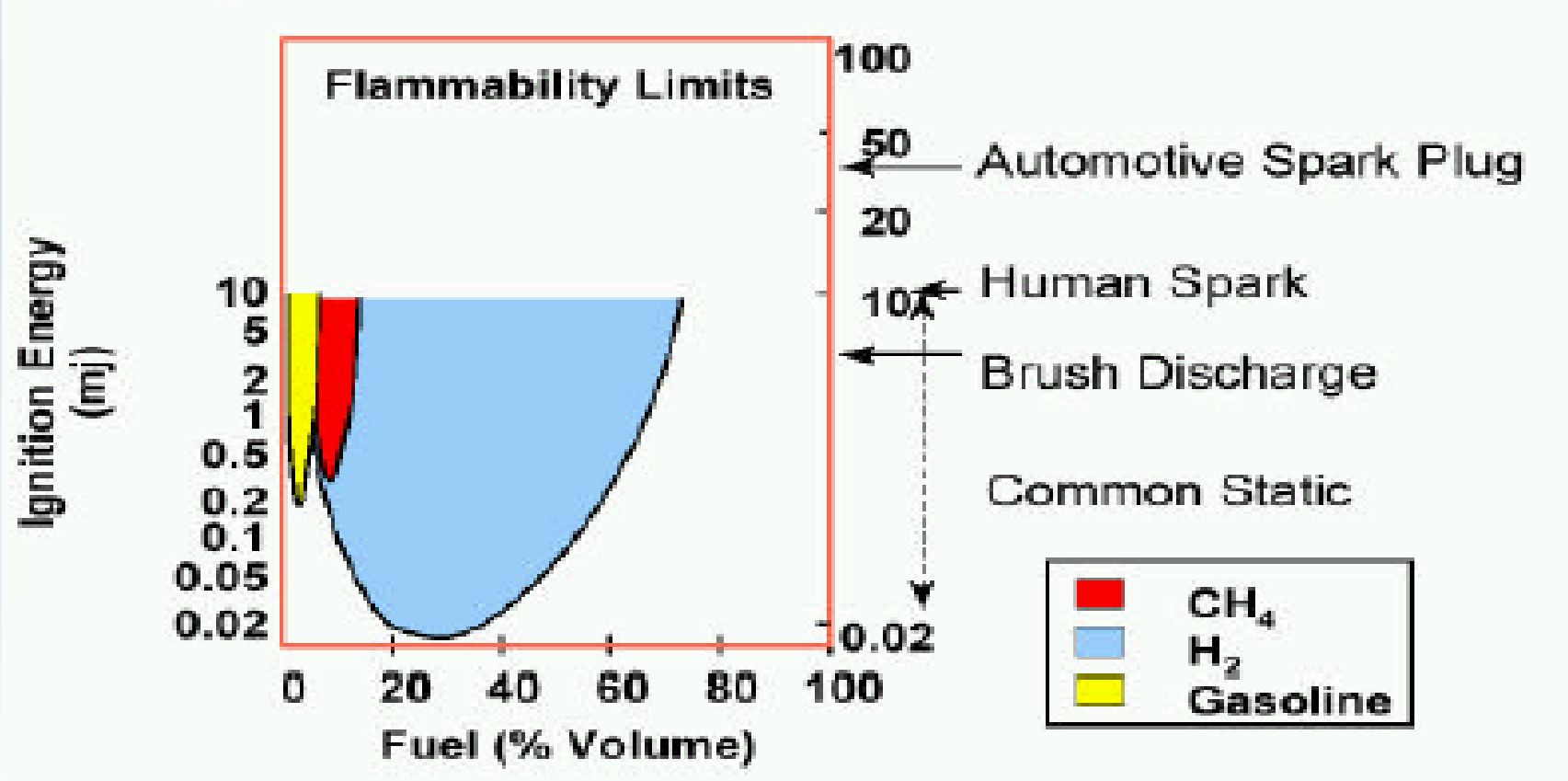
Flammable mixture

- As long as ventilation is adequate, the probability of hydrogen forming a flammable mixture with air is very low

Leak

- Large leak → flammable cloud + ~~ignition source~~ → fire/explosion
  - *strict prohibition of open flames (e.g. smoking) and cell phone usage*

Hydrogen vs Natural Gas vs Gasoline



Flammability limits and ignition energy of H2, CH4 and gasoline with air

Flammability range of hydrogen is 7 times wider than methane

Safety Analysis

Advantages

- **Safety analysis at conceptual stage:**
  - ***opportunity for inherently safer design solutions***
  - ***more cost-effective to operate the power park***

- **Reduce chance of:**
  - ***process safety related incidents***
  - ***downtime and financial losses***
  - ***losing public confidence***

HAZOP (Hazard and Operability)

Process Section	Parameter	Deviation	Causes	Consequences	Safeguards/Mitigations

HAZOP Methodology

- **Logical & systematic approach for identifying potential hazards**
- **Creates deviations from the process design intent**
- **Only warrants qualitative analysis; not quantitative**
- **Conventional group approach discarded**
  - ***Lack of experienced human resources***

GUIDE WORDS: more, higher, longer, less, lower, shorter, as well as, also, part of, reverse, other than, sooner, lower. ….

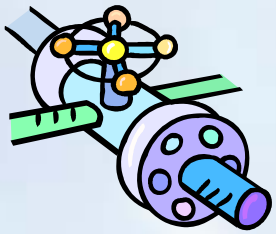
HAZOP Results Summary

Equipment of the highest risk:

- Dispenser

Human error preventions:

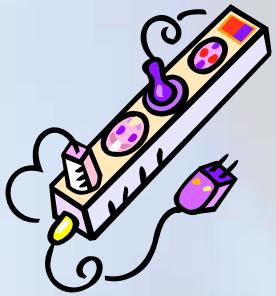
- Trained operator to refuel vehicles
- Clear labels / instructions:
  - *Manual emergency shutoff valves labelled with direction of turning*
  - *Pipelines labelled with direction of flow*



HAZOP Results Summary

Sparks generation preventions:

- Permanent bonding and grounding of equipments
- Grounding of person doing maintenance work
- Use tools that do not generate sparks



Sabotage/terrorism preventions:

- Surveillance/security system
- Remote manual emergency shutdown system

High Risk Situations

1. **Maintenance, start-up and shut-down of equipment**
   - *Venting or bleeding device to depressurize gas before dismantling*
   - *Start-up procedures (e.g. purging with an inert gas)*

2. **Control system fault**
   - *Cause: grid power outage*
     - **SOFC & generator set can supply power to control system.**
   - *Cause: virus/hacking*
     - **Anti-virus and firewall softwares**
   - *Watchdog timer to monitor status of the control computer*

Essential Safety Components

Instruments

- Flammable gas detectors
- Smoke detectors
- UV/infrared hydrogen flame detectors
- Manual + automatic safety shutoff valves
- Pressure relief valves
- Grounding/bonding

Systems:

- Redundant fail-safe shutdown (automatic and manual)
- Emergency ventilation
- Emergency power
- Security

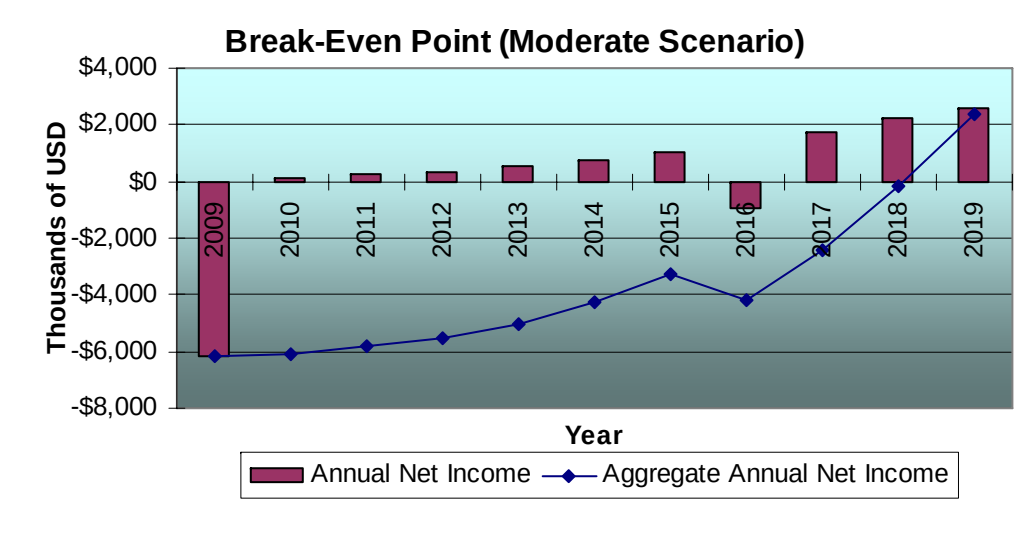
Economics – Purchase Costs

Dispenser	$62,988
Compressor	$97,660
Storage System	$198,000
100 kW SOFC	$200,000
Primary Reformer (2)	$1,600,000
Pre-Reformer (2)	$1,400,000
Control System	$200,000
Hydro-desulf. unit (2)	$200,000
Zinc-Oxide Bed (2)	$200,000
PSA	$50,000
piping, etc.	$50,000
Land	$1,000,000
Building	$1,000,000
Construction Costs	$200,000

Total Purchase Cost

$6,458,648 US

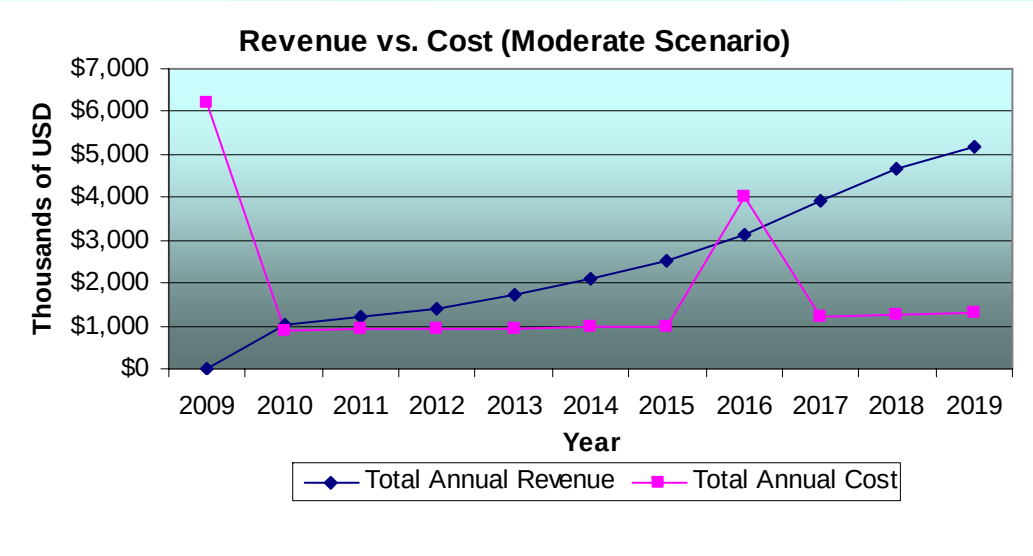
Economics - Profitability



Break-even point: 2018

Payback period: 9 years.

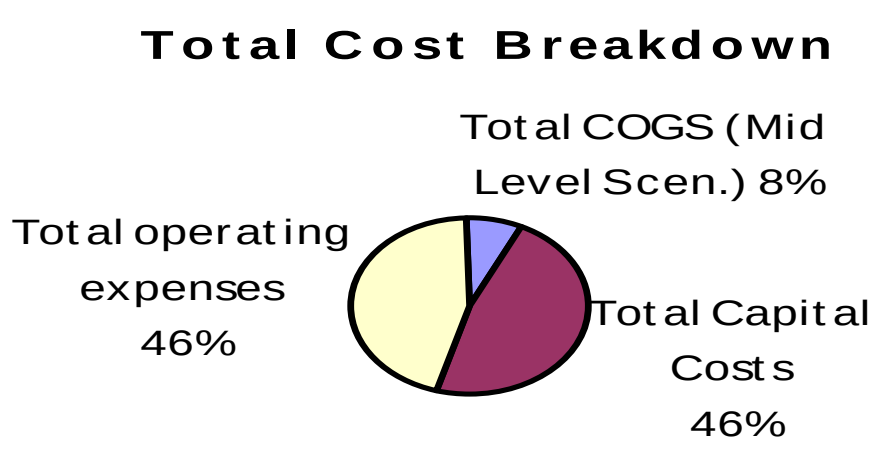
Average production cost of H2: $33.95/kg



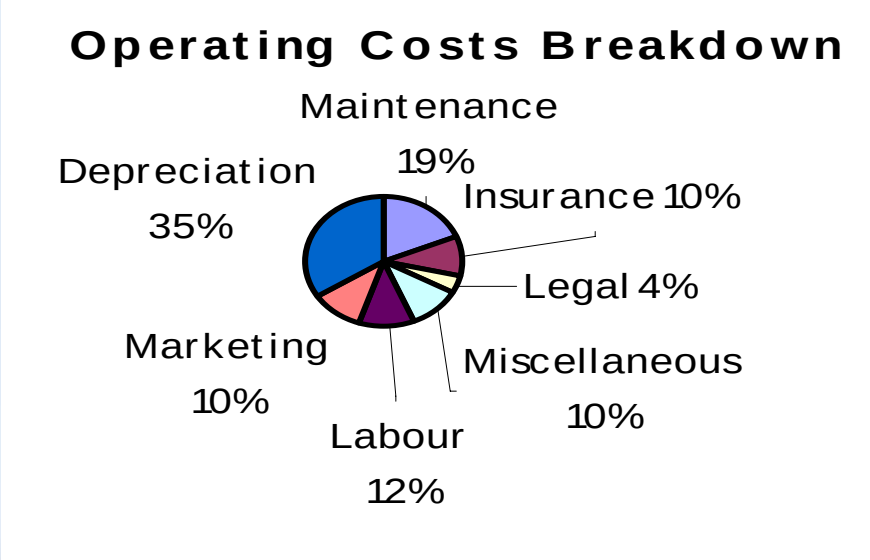
Total revenue: $26.9 M

- **Mostly from hydrogen sales ($22.6 M, $53.38/kg)**
- **Other sources: convenience store, carbon emissions credits**

Economics – Cost breakdown



Operating costs: start at $846K in 2010 and rise with the projected rate of inflation



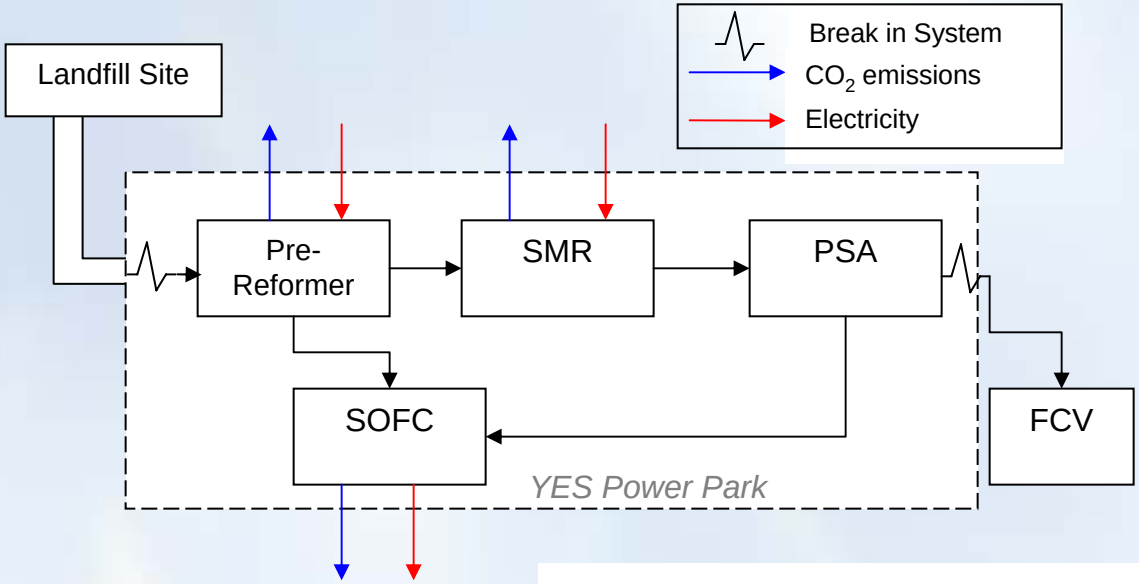
Total capital costs: $9.1M

- Purchase cost
- Applicable taxes (15%)
- Installation and transportation (2% of purchase cost)

Average cost of goods sold: $138K

- Electricity consumption
- Feed gas
- Convenience store

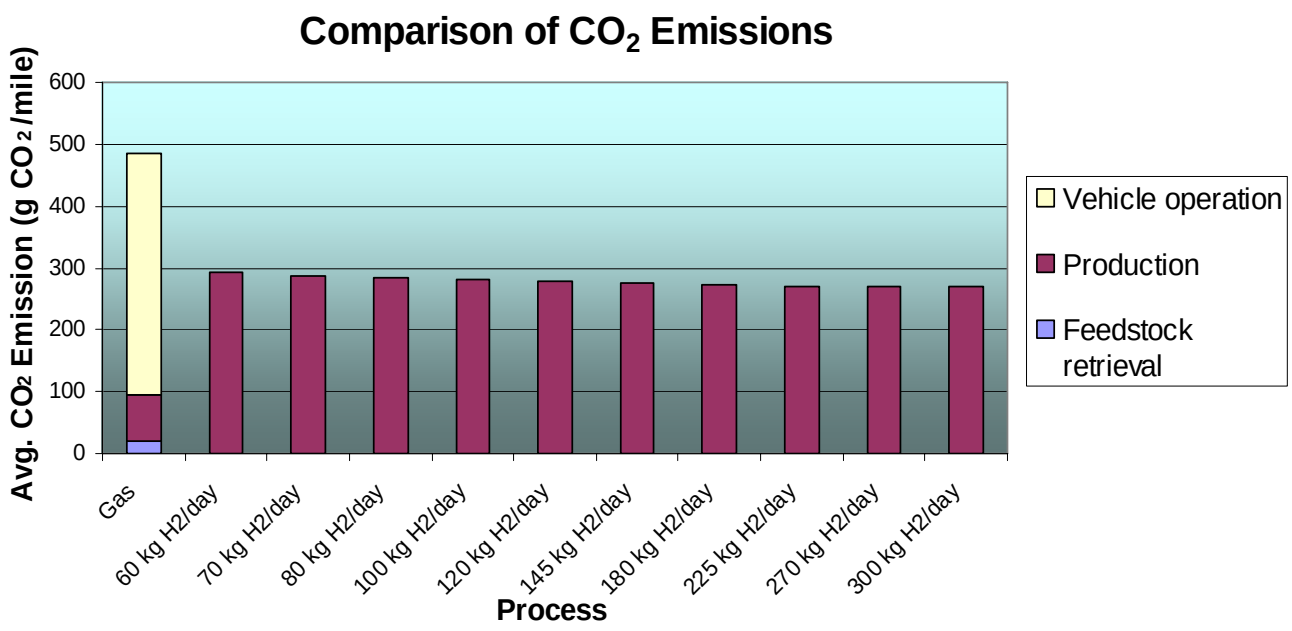
Environmental Analysis



Adopting hydrogen process reduces automobile-related emissions by at least 40%

As more hydrogen is produced per year, the average grams of CO_2 per mile decrease.

The major CO_2 emissions are localized at the power plant which makes CO_2 capture achievable.



Marketing Plan

Targets

1. **Fuel cell vehicle owners:**
   i. ***Businesses operating FCV fleets***
   ii. ***Early adopters.***
2. **Waterloo community**

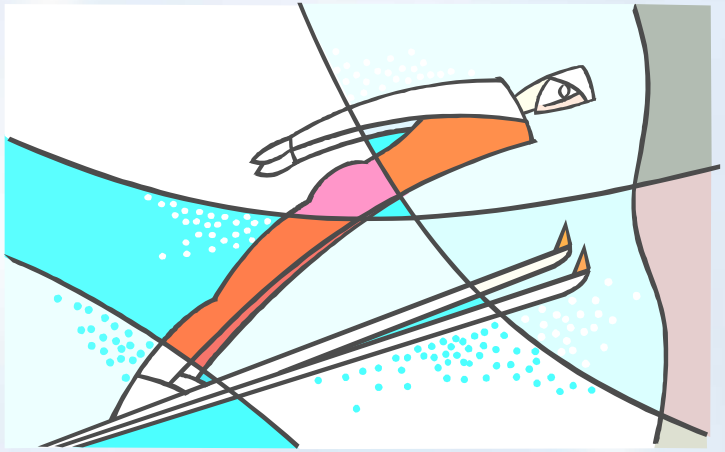
Marketing Strategies

- ✓ **Promote and support early adopters (e.g. ChallengeX Vehicle)**
- ✓ **Position hydrogen as an attractive fuel source (e.g. use of education center)**
- ✓ **Accelerate commercialization of the hydrogen economy**

- ➢ ***Looks and behaves like a gasoline station***
- ➢ ***Align the park with the Toronto Hydrogen Village***
- ➢ ***Located next to a Hydrogen Development Incubator***

Marketing Plan - Implementation

- ✓ **The launch of the marketing campaign will corresponds with the 2010 Winter Olympic Games in Vancouver, British Columbia**
  - ➢ ***Anticipated that hydrogen and related technologies will receive a significant amount of national and international exposure***



Summary

- ✓ More than just a hydrogen refuelling station
- ✓ Development Incubator + education center to promotes the adoption of hydrogen technology
- ✓ Feasible, innovative & safe
- ✓ Reduce and localize emissions
- ✓ Marketing plans to achieve hydrogen acceptance

Driving Clean?

A fuel cell vehicle that runs on hydrogen is a clean, environmentally friendly alternative to gasoline. Hydrogen reduces the impa of air pollution and global warming because it does not emit any of the harmful pollutants found in gasoline. **YES** hydrogen statio provide fuel that is as safe and as reliable as conventional gasoline, plus the only by-product generated by **YES** hydrogen is pu water. So, do yourself and the environment a favour - fill up with **YES** hydrogen and start driving clean today.

For more information about fuelling your vehicle with **YES** hydrogen, call 800-YESINFO or visit yeswaterloo.ca

Questions?