LA-UR-08-1805

GREEN FREEDOM

Green Freedom™ *(Patent Pending)*
Synthetic Fuels and Chemicals Production

Presentation to:

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Dr. F. Jeffrey Martin

Dr. William L. Kubic

Los Alamos National Laboratory

Los Alamos, New Mexico

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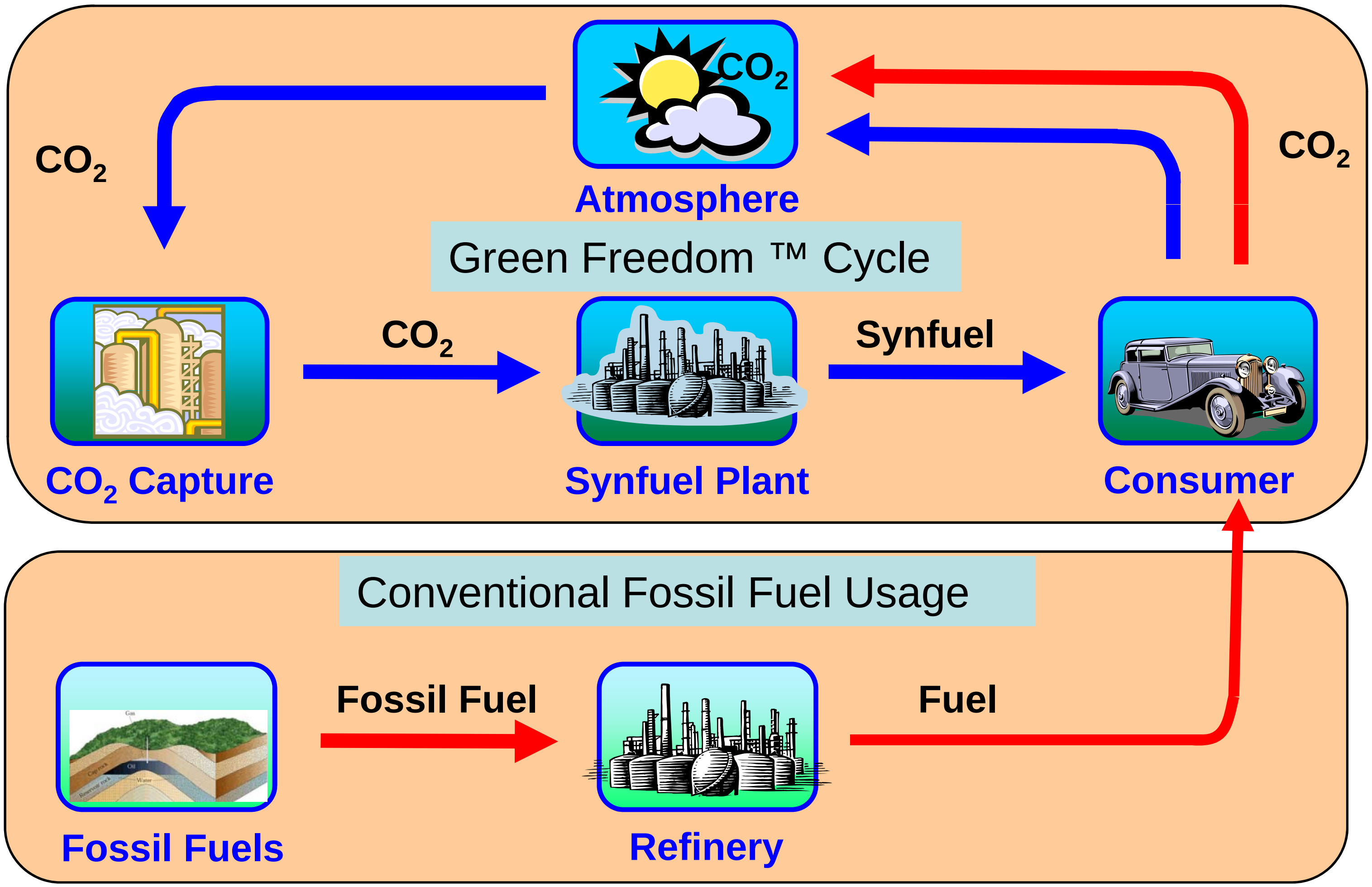
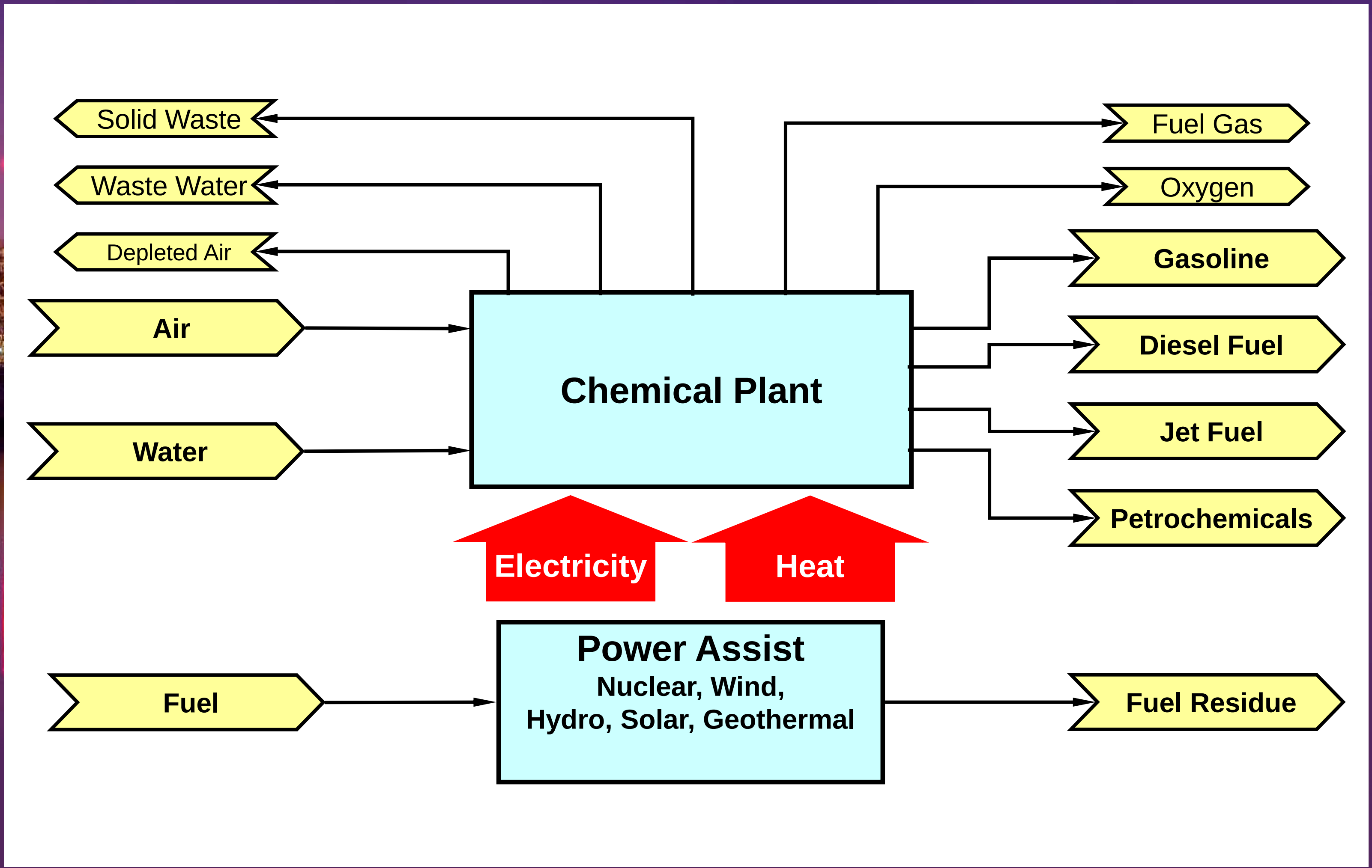
Green Freedom™

- *A concept for large-scale production of sulfur-free, carbon-neutral synthetic fuels and chemicals from air and water using power assist*

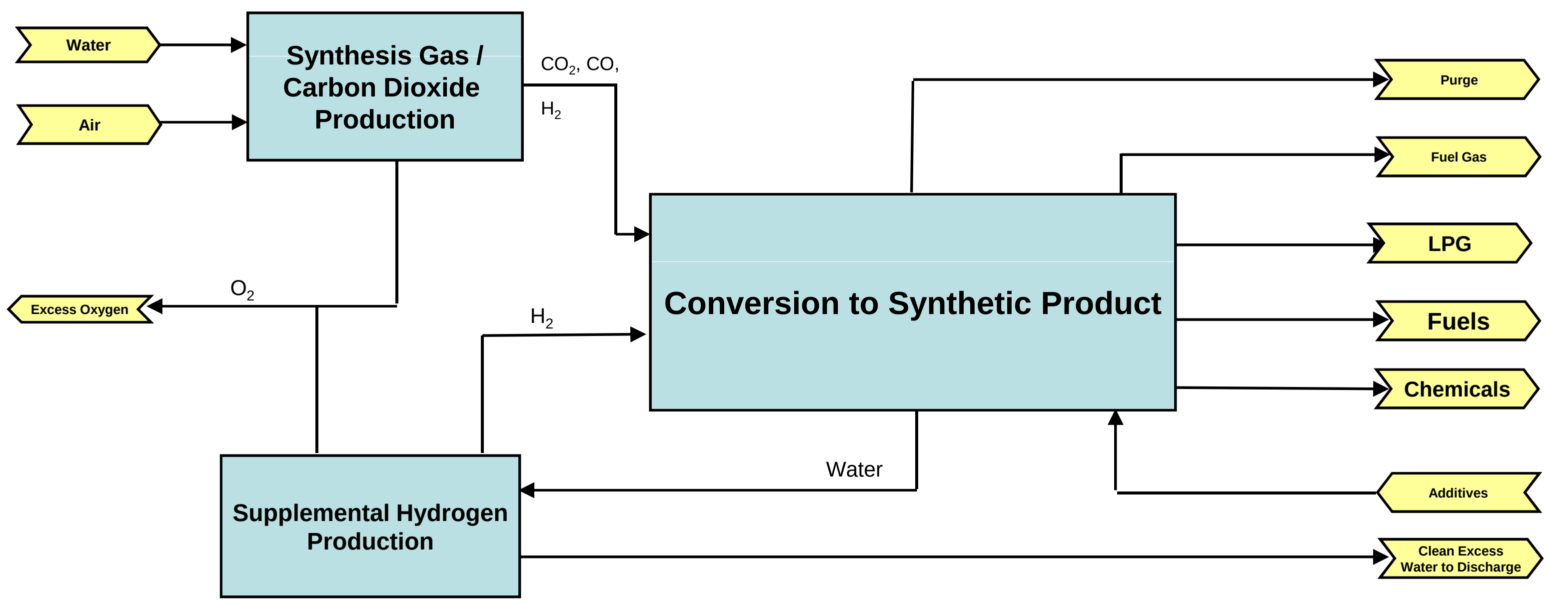
Green Freedom™ Recycles Carbon Dioxide



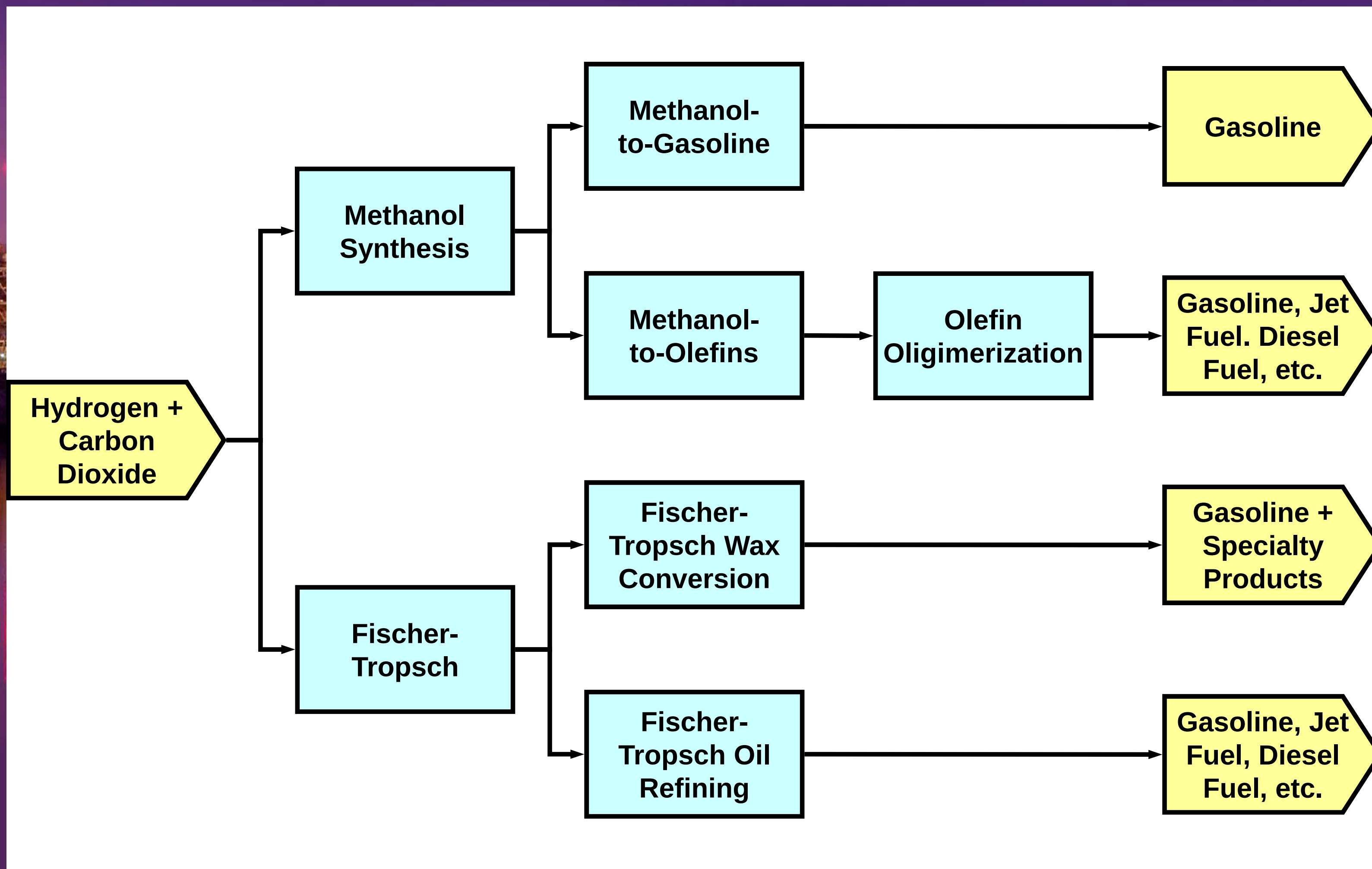
Carbon-Neutral Power Assist



Synthetic Fuels and Chemicals Production



Common Paths for Converting Synthesis Gas into Useful Products

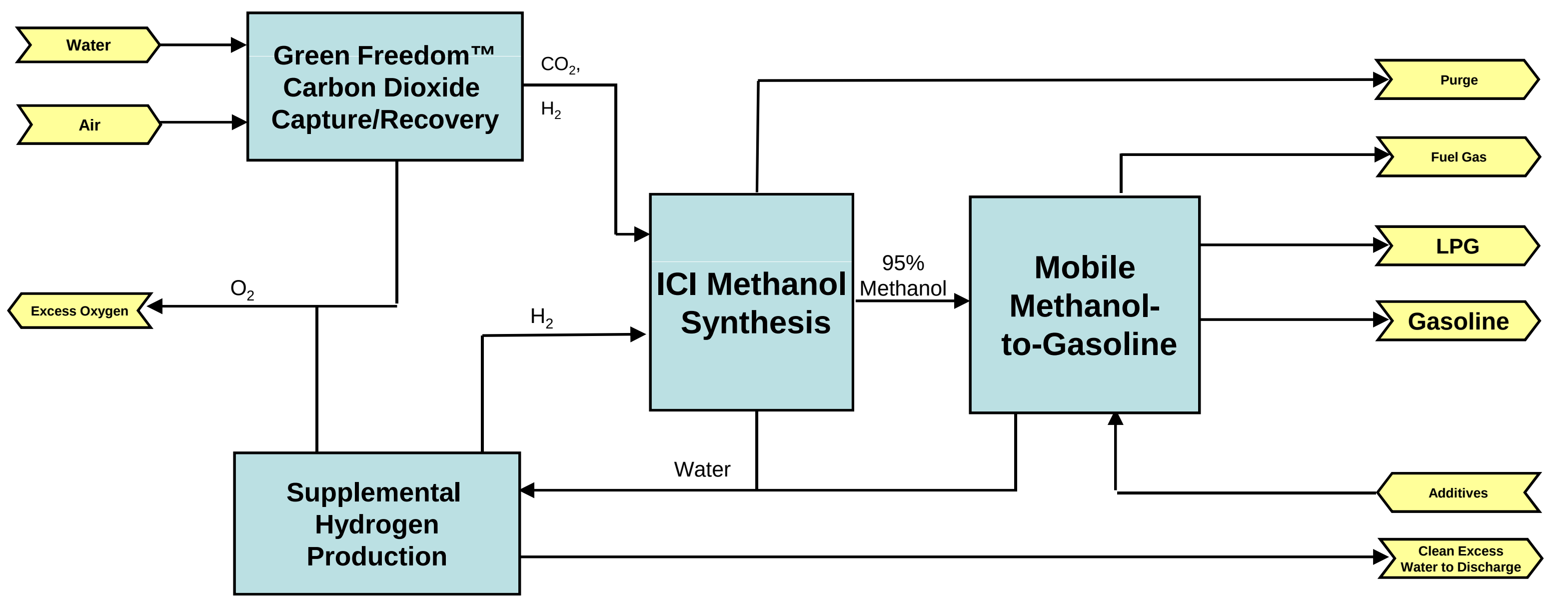


Green Freedom™ Approach

- **Base the design primarily on proven technology. For example:**
  - **Pressurized water reactors**
  - **Water electrolysis**
  - **ICI low pressure methanol process**
  - **Mobil's methanol-to-gasoline (MTG) process**

- **Enabling Features**
  - **Practical CO_2 capture**
  - **Green Freedom CO_2 recovery technology**
  - **Co-location of power assist and chemical plants**
  - **Integrated system and energy management of all major processes**

Evaluation Case for Green Freedom™ Gasoline Production (17,000 bbl/day)

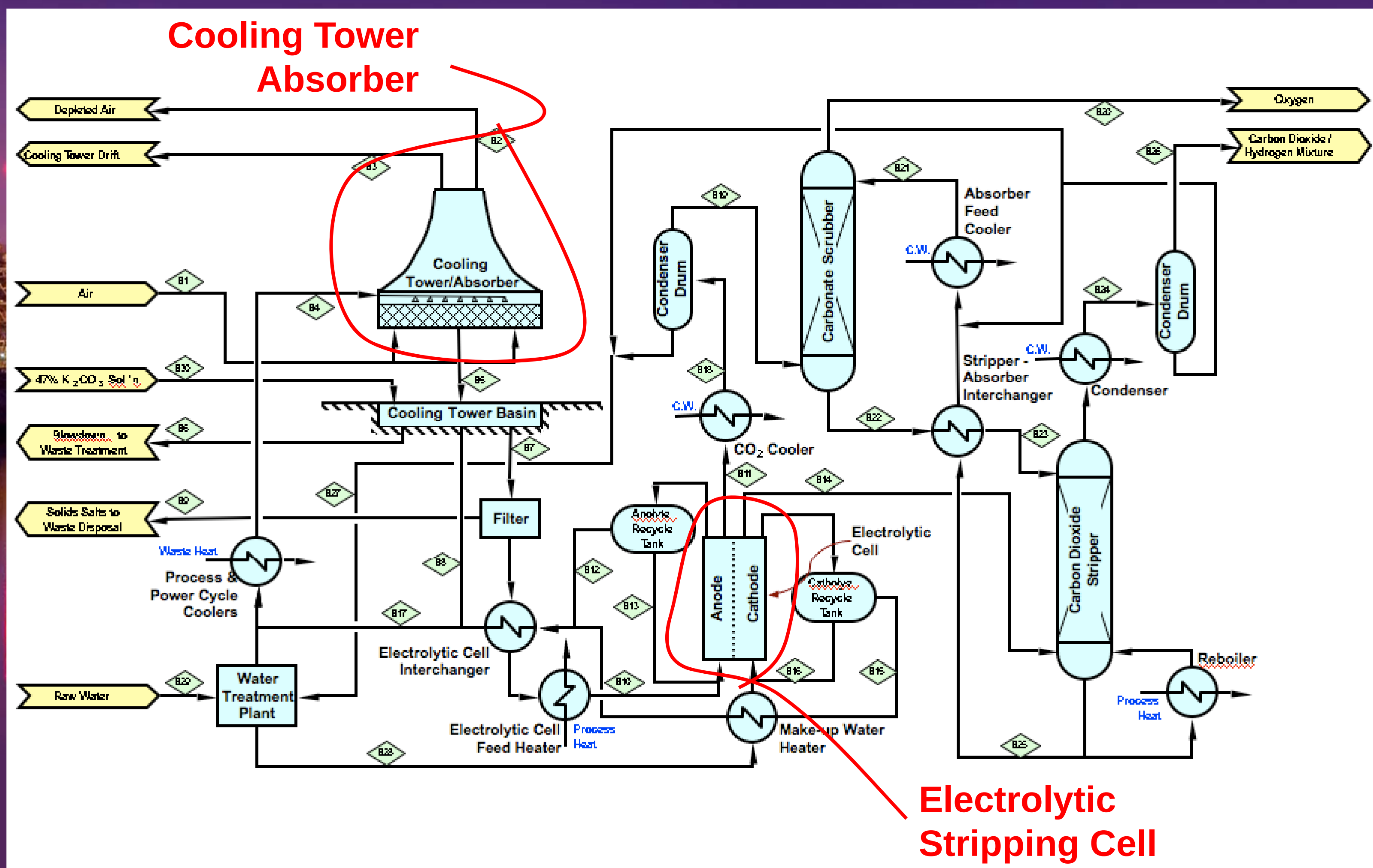


Carbon Dioxide Capture from the Atmosphere

A field of switch grass removes CO_2 from the air at a net rate of ~15 ton per acre per yr

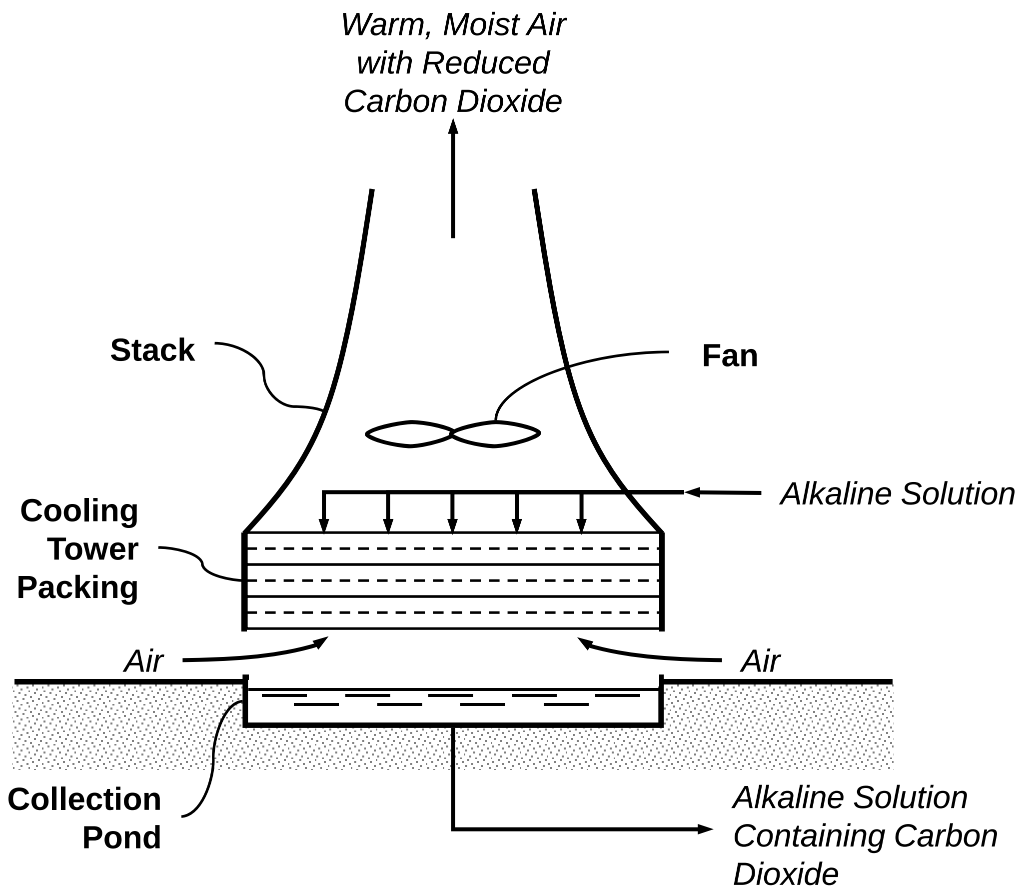
An alkaline lake absorbs CO_2 at an estimated rate of ~450 ton per acre per yr

Process Flow for CO_2 Capture and Recovery Process

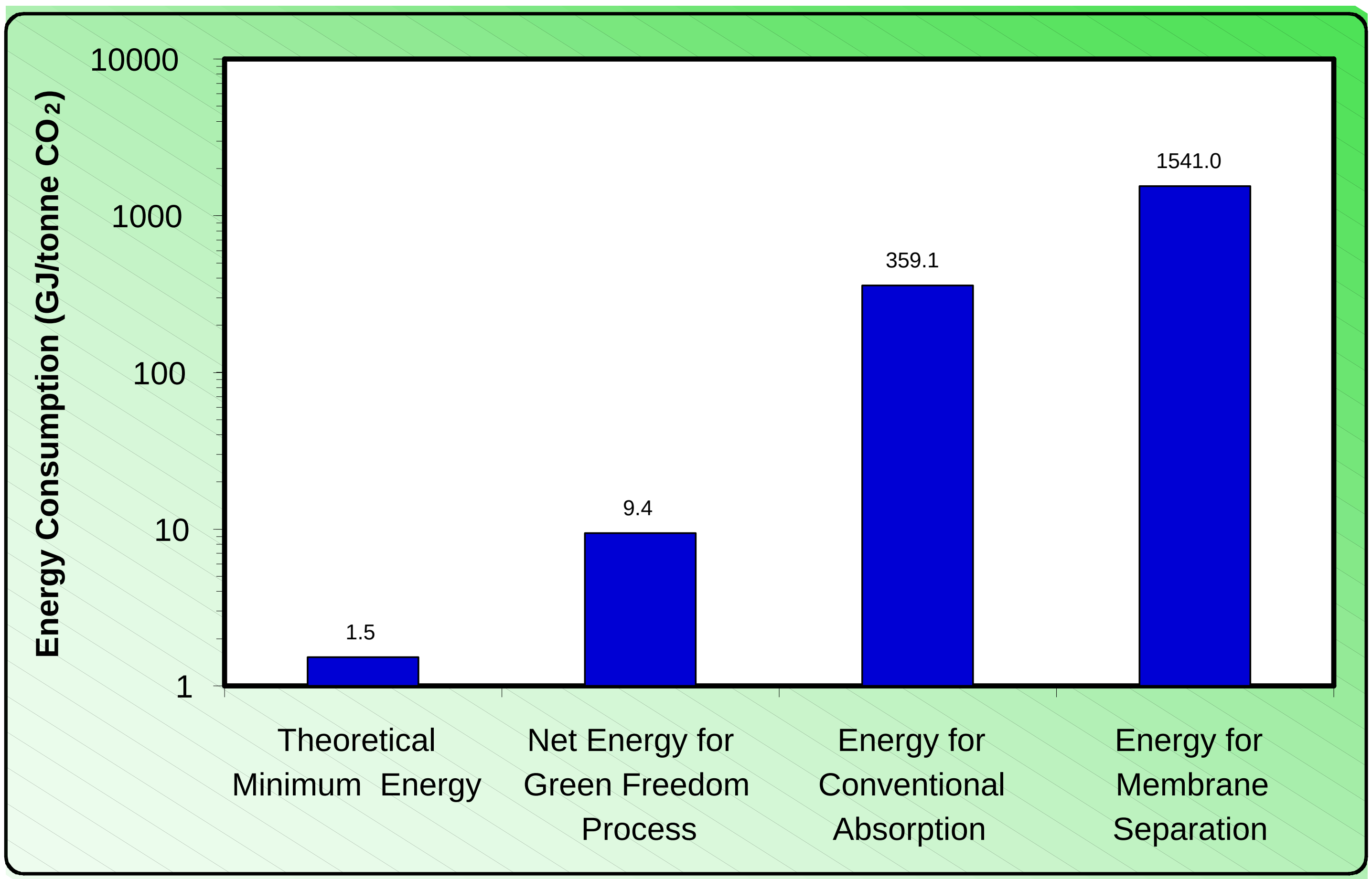


Unclassified

Counter-Current, Assisted-Draft Cooling Tower/Absorber



New Capture and Recovery Process Drastically Reduces Energy Consumption



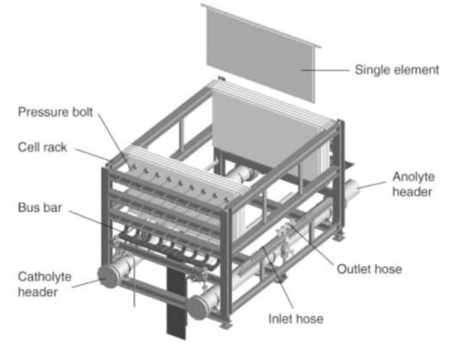
Carbon Dioxide Capture

- **Cooling towers modified to capture Carbon Dioxide - serving double duty**
  - **Cooling for the power and chemical plants**
  - **Capturing carbon dioxide from the atmosphere**
- **Cooling requirements**
  - **4 cooling towers for two power plants**
  - **2 cooling towers for the chemical plant**
- **Absorption requirements**
  - **6 cooling towers for CO_2 capture**
  - **Potassium carbonate solution to enhance absorption**

Green Freedom™ CO_2 Recovery Cells

- The CO_2 recovery cells are similar to chloralkali cells
- Typical cell capacity as estimated from chloralkali cell data
  - Commercial chloralkali cell produces 29 - 82 ton NaOH/day
  - Corresponds to a carbon dioxide recovery of 30 - 86 ton CO_2/day
- A 5000 tonne/day methanol plant requires 7800 tonne CO_2/day
  - Requires 90 - 260 cells
  - Installation would be three times larger than the chloralkali plant shown on the right

Kruppe-Uhde BM-2.7 Electrolyze



Chloralkali Plant with 36 Kruppe-Uhde BM-2.7 Electrolyzes

Supplemental Hydrogen Production

- **Proven water electrolysis technology**
  - **Used for applications requiring small amounts of H_2 with very high purity**
  - **Current commercial units are smaller than chloralkali cells**
  - **Largest are produced by Norsk Hydro and produce 485 Nm^3/hr of H_2**
- **Process requires 45,000 Nm^3/hr of H_2**
  - **15,000 Nm^3/hr is produced by the Green Freedom™ recovery cells**
  - **Additional 30,000 Nm^3/hr needed**
  - **Requires 620 Norsk Hydro electrolyzers**

Norsk Hydro Electrolyzer

Older Norsk Hydro Hydrogen Plant

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Methanol Production and Methanol-to-Gasoline Process

- **Established processes for producing <u>methanol technology</u>**
  - **Single-train plants with a capacity of 7500 tonne/day are possible**
  - **Evaluation case is based on a 5000-tonne/day plant**
- **Proven <u>MTG technology</u> is well suited for smaller scale gasoline production**
  - **14,500-bbl/day operated successfully in New Zealand**
  - **A large plant is being planned in China**
  - **Baseline process requires a 17,000 bbl/day plant**

5,000 tonne/day Methanol Plant

New Zealand MTG Unit

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Power Assist

- **Nuclear reactors power the process @ 6600MW thermal:**
  - **2000 MW of electricity**
  - **470 MW of steam**
- **Base Case uses two Westinghouse AP1000 pressurized water reactors (PWR)**
  - **Two AP1000 reactors generate 6800 MW thermal power**
  - **PWRs are proven technology**
  - **The AP-1000 reactor is a NRC certified design**

Artistic Rendering of an AP1000 Reactor

Feeds

- **Primary Feeds**
  - **Air ……………………………………… 450,000,000 Nm^3/hr**
  - **Process Water ……………………………… 130,000 L/hr**
  - **Potassium Carbonate Make-up ……………… 3,000 kg/hr**
- **Utilities for Chemical Plant**
  - **Electricity …………………………………… 2,000 MW**
  - **High-Pressure Steam ………………………… 260 MW**
  - **Low-Pressure Steam ………………………… 210 MW**
  - **Uranium Fuel ……………………………………60 tonne/yr**
  - **Cooling Water Make-up …………………… 7,400,000 L/hr**
- **Other chemicals and consumables**
  - **Gasoline additives**
  - **Catalysts**
  - **Membranes and diaphragms**

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Yields

- **Intermediate Products**
  - **Carbon Dioxide ………………………. 7,800 tonnes/day**
  - **Hydrogen ………………………... 11,000,000 Nm³/day**
  - **Methanol ……………………………….. 5,000 tonnes/day**
- **Primary Products**
  - **Gasoline …………………………….… 17,000 bbl/day**

  OR
  - **Diesel …………………………………. 10,000 bbl/day**
  - **Jet Fuel ………………………………. 4,500 bbl/day**
- **Byproducts**
  - **Fuel Gas ………………………………. 5,500 GJ/day**
  - **Liquid Petroleum Gas (LPG) ………. 510,000 L/day**
  - **Pure Oxygen ……………………….. 5,500,000 Nm³/day**

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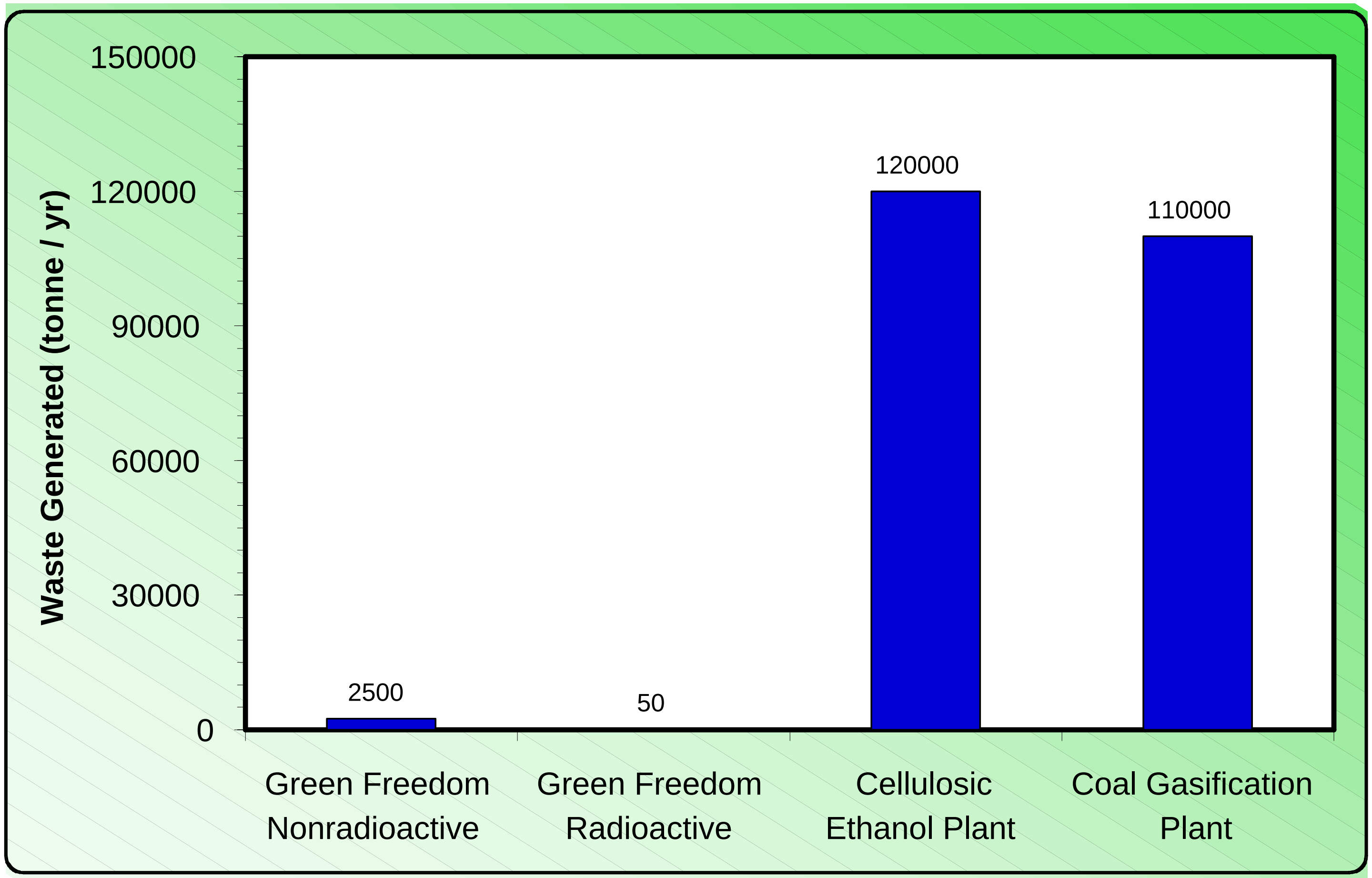
Foot Print Needed to Capture Equivalent CO_2 per Year

Approximate Solid Waste Generation by a Green Freedom™ Plant

- **Non-radioactive waste**
  - **Waste water sludge ……………………………….. 1000 tonne/yr**
  - **Membranes, diaphragms, etc. …………………. 500 tonne/yr**
  - **Construction / maintenance waste …………..** **1000 tonne/yr**
  - **Total ……………………………………………. 2500 tonne/yr**

- **Radioactive waste**
  - **Total …………………………………………….…. 50 tonne/yr (6 m^3/yr)**

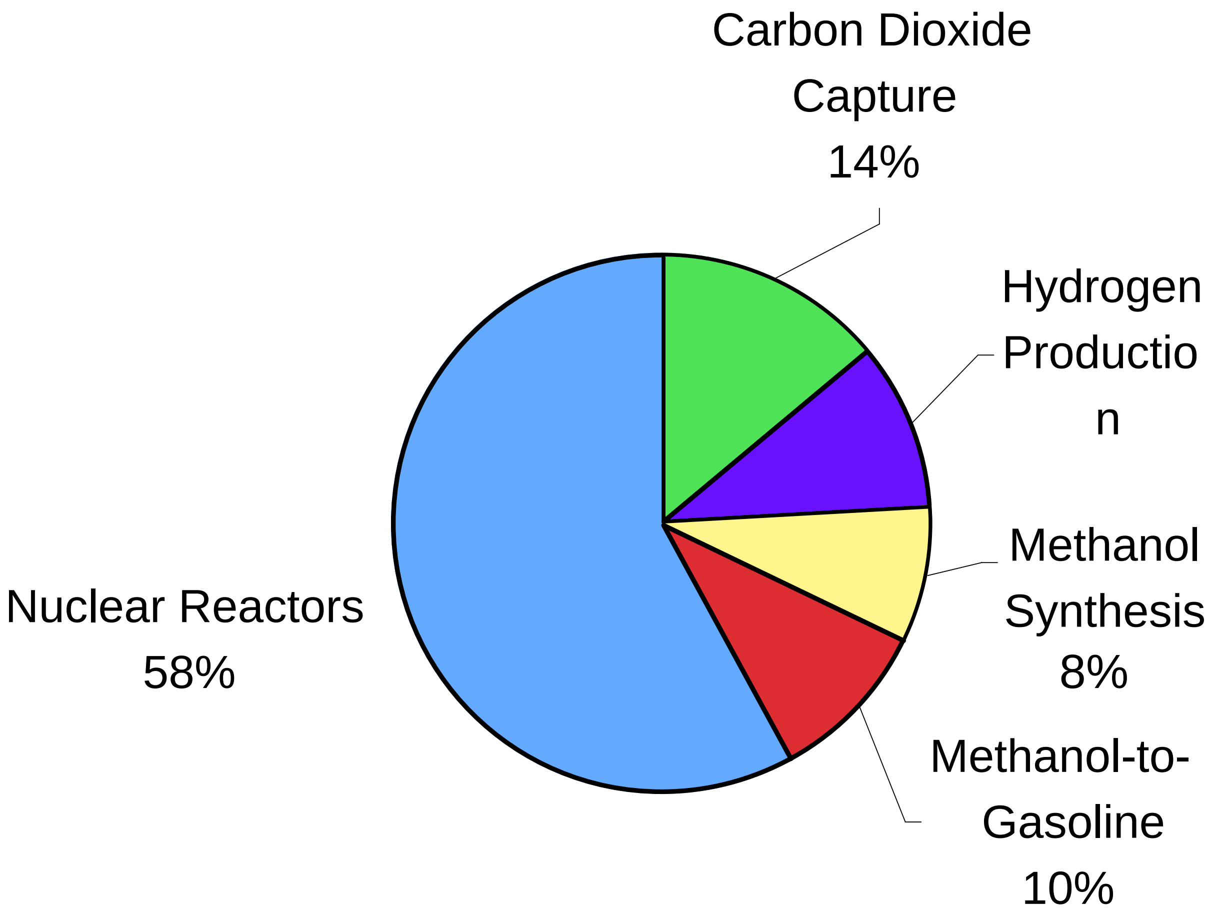
Solid Waste Generation by Plants Producing Equivalent Gasoline



Initial Estimate of Economics

- **Capital Cost (overnight)……………..….. $5.2 billion**
- **Operating Costs**
  - **Variable ……………………………….. $0.42 / gal**
  - **Fixed …………………………………….. $1.12 / gal**
- **Estimated cost to the consumer ……. $5.00 / gal +/- 30%**

Capital Cost Distribution



Implications of Selected Developing Technologies

- **Evaluation Case ………………..………………….. $5.00 per gallon**
- **Process with improved electrolyzer materials ……..……………….... $4.60 per gallon**
- **Process with steam electrolysis for hydrogen production …………………….... $4.30 per gallon**
- **Larger process with steam electrolysis .. $4.10 per gallon**
- **Larger process with steam electrolysis and improved stripping cell materials … $3.90 per gallon**

US Production of Refined Products

- **Current US production levels**
  - **Gasoline ………………………………. 9,010,000 bbl/day**
  - **Distillate Fuel Oil …………………….. 4,130,000 bbl/day**
  - **Jet Fuel**
    - **Civilian …………………………….. 1,290,000 bbl/day**
    - **Military …………………………….. 140,000 bbl/day**

- **Number of baseline Green Freedom™ plants needed to meet current production levels**
  - **Gasoline ………………………………. 530**
  - **Jet Fuel + Distillates ………………. 350**
  - **Military Jet Fuel …………………….. 30**

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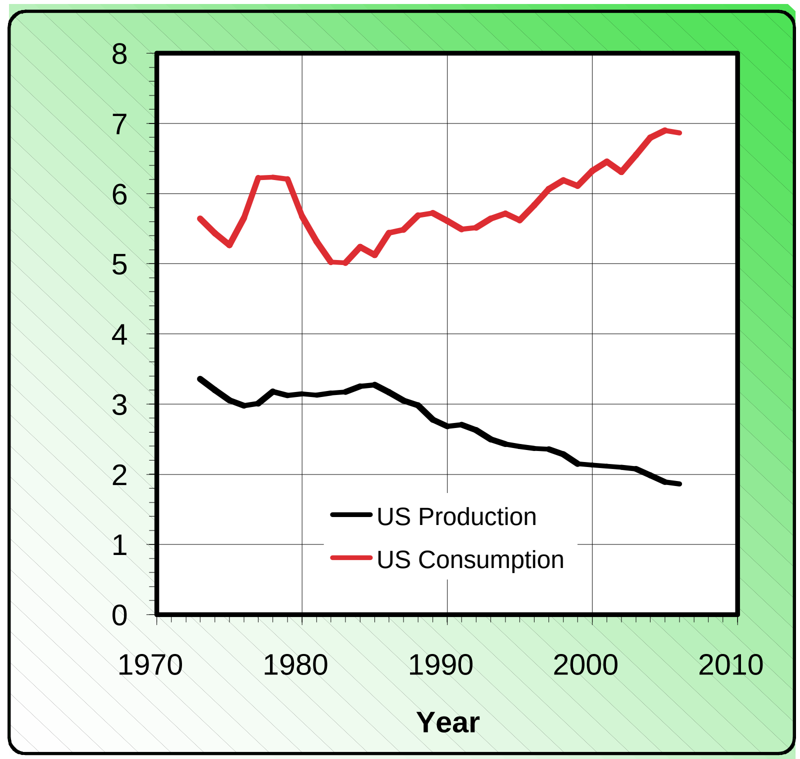
Offset Deployment Goals

- **Since the mid 1980s**
  - **Domestic production has declined at a rate of 62 million bbl/yr**
  - **Domestic consumption has consumption has increased at a rate of 74 million bbl//year**
- **Green Freedom could offset declining production and increasing consumption**
  - **Building 9 plants per year would compensate for decreasing production**
  - **Building an additional 11 plants per year would keep imports at current levels**



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Green Freedom™ is a "Multi-issue" Solution

1. **Replaces dependence on fossil fuel**
2. **Provides fuel and material security**
3. **Has zero or less net carbon emissions**
4. **Fuels are compatible with existing transportation vehicles**
5. **Relies on abundant, free, and non-hazardous feed material**
6. **Is compatible with existing energy-delivery infrastructure**
7. **Ends intrusive exploration for and extraction of fossil fuels**
8. **Limits the environmental impact to the production facility footprint and a small waste stream volume**
9. **Relieves potential pressure on agriculture capacity and forests**
10. **Stabilizes energy prices**
11. **Has predictable costs**

Status

- **Concept Development 2005 - 2007**
- **Integrated system performance and economic evaluations 2006 - 2007**
- **Academic and industrial reviews 2006 - 2007**
- **Planned demonstration of new technology and design optimization studies 2008 - 2009**
- **Prototype development and testing of key subsystems - unscheduled**
- **Consortium**

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Questions?