Hydrogen Program Goals and Outcomes

Presented at:

2000 Hydrogen Program Annual Review Meeting

Presented by:

Sig Gronich, *Hydrogen Team Leader*

Legislative Mandates

Pursuant to Hydrogen Futures Act of 1996 and the Matsunaga Hydrogen RD&D Act of 1990:

- **DOE shall conduct a research, development, and demonstration program leading to the production, storage, transport, and use of hydrogen for industrial, residential, transportation, and utility applications.**
- **DOE shall conduct a program to accelerate wider application of hydrogen technologies available in the near term as a result of aerospace experience and other research progress.**

Hydrogen Program Vision

In the next twenty years, concerns about global climate change and energy security will create the platform for the penetration of hydrogen into several niche markets. Ultimately, hydrogen and electricity will come from sustainable renewable energy resources, but fossil fuels will be a significant transitional resource during this period. The growth of fuel cell technology will provide a basis for the establishment of the hydrogen option into both transportation and electricity supply markets.

Strategic Goals

Mid-Term

Support technologies that enable early introduction of distributed electric-generation fuel cell systems, and hydrogen fuel-cell vehicles for transportation applications.

Long-Term

Support development of hydrogen technologies that enhance intermittent renewable systems and offer society the promise of clean, abundant fuels.

Current Forces

- **SIGNIFICANT FUEL CELL DEVELOPMENTS AND PARTNERSHIPS**
  - **Daimler-Chrysler, Ford and Ballard have formed partnerships, and pledged $1.5 Billion for commercialization of automotive Fuel Cells**
  - **Edison Development Company, G.E., SoCal Gas, Plug Power have agreement to commercialize residential fuel cells (other companies are also pursuing residential systems)**
  - **I.F.C. has developed high performance fuel cell for automotive and electrical generation systems**
- **CALIFORNIA ZERO EMISSIONS VEHICLE REQUIREMENTS FAVOR EARLY INTRODUCTION OF EITHER ELECTRIC OR HYDROGEN VEHICLES**
- **CALIFORNIA FUEL CELL PARTNERSHIP WAS FORMED**
  - **Demonstrate 50 Hydrogen Fuel Cell cars and 20 Buses by 2003**
- **SIGNIFICANT INDUSTRY INTEREST IN PARTNERSHIP TO BRING FUEL CELLS INTO MINES**

Strategic Approach

- √ **Hydrogen Industry: → Smaller reformers and electrolyzer systems**
  - Improve efficiency, lower emissions, and lower the cost of H_2 production
- √ **Fuel Cell/Hydrogen Integration: → Industry deployment of fuel cells**
  - Enhance the introduction and production of distributed systems that enhance refueling and generation system missions
- √ **Fuel Choice/Infrastructure: → Zero Emission Vehicles**
  - Demonstrate safe and cost-effective systems for hydrogen vehicles in urban non-attainment areas, and to provide on-board hydrogen storage systems
- √ **Long-term Research and Development:**
  - Lower the cost of technologies that produce hydrogen directly from sunlight and water

Hydrogen Program Funding

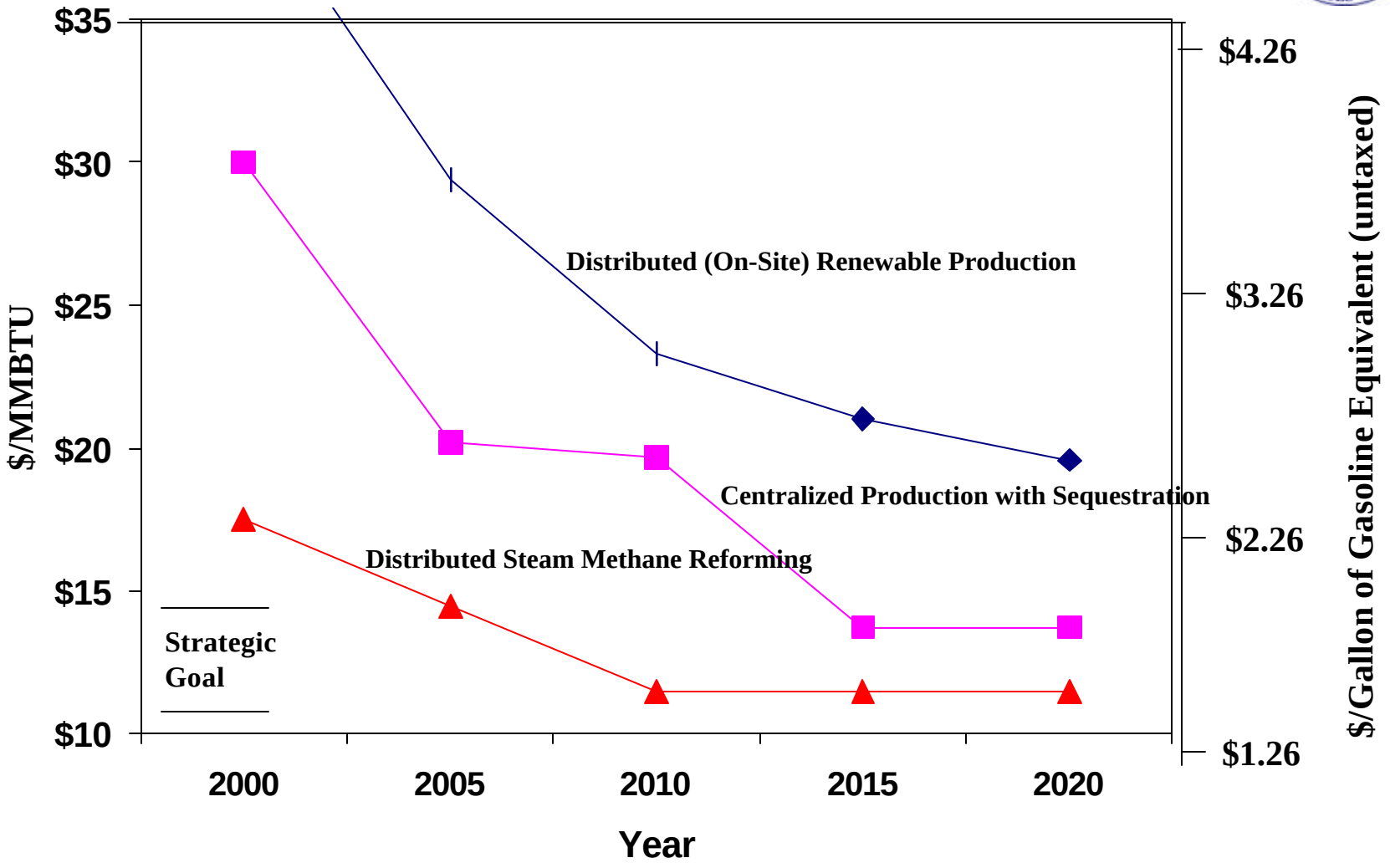
FY 1999-FY 2001 Budgets:

Hydrogen Program Funding Summary	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Core Research and Development • Production • Storage • Utilization	8,951	13,353	13,020
Technology Validation • Renewable/ H_2 Systems • H_2 Infrastructure • Distributed/ Remote Power Systems	10,856	8,754	7,500
Analysis and Outreach	2,169	2,480	2,480
Total	21,976	24,587	23,000

Production Goals

- Improve the efficiency and lower the cost of fossil-based and biomass-based hydrogen production processes to achieve $12 - $15/MMBtu for pressurized hydrogen when reformers are mass produced
- Advance emission-free and renewable-based hydrogen production technologies towards commercial viability, with a target cost of $10 - $15/MMBtu

Cost of Delivered Hydrogen

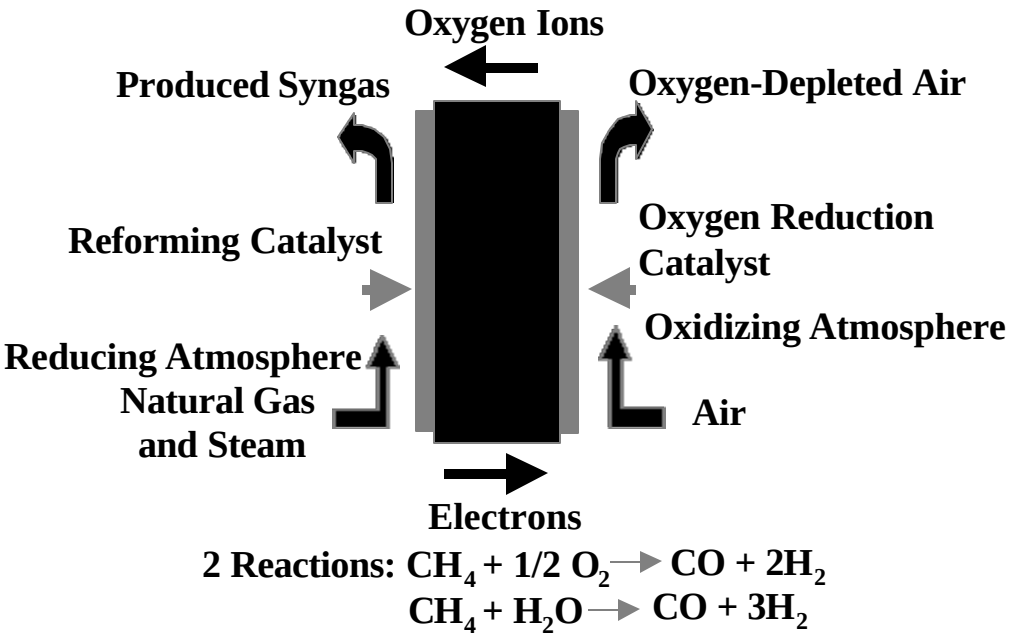


Fossil-based Production

Fossil-based Hydrogen Production		
	ITM Syngas Process	Air Products
	Sorption Enhanced Reaction Process for Production of H2	Air Products
	Liquid Fuel-Reformer Development	Argonne National Laboratory
NEW	Integrated Ceramic Membrane System for H2 Production	Praxair
NEW	Novel Catalytic Fuel Reforming	InnovaTek
NEW	Production of H2 by Superadiabatic Decomposition of Hydrogen Sulfide	Institute of Gas Techonogy
NEW	Thermo-catalytic CO2-Free Production of Hydrogen using Hydrocarbon Fuels	Florida Solar Energy Center
NEW	Thermal Dissociation of Methane using a Solar Coupled Aerosol Flow Reactor	University of Colorado/NREL
NEW	Hydrogen Membrane Separation	Sandia National Laboratories
	Separation Membrane Development	Savannah River Technology Center

ITM Syngas and SER Processes

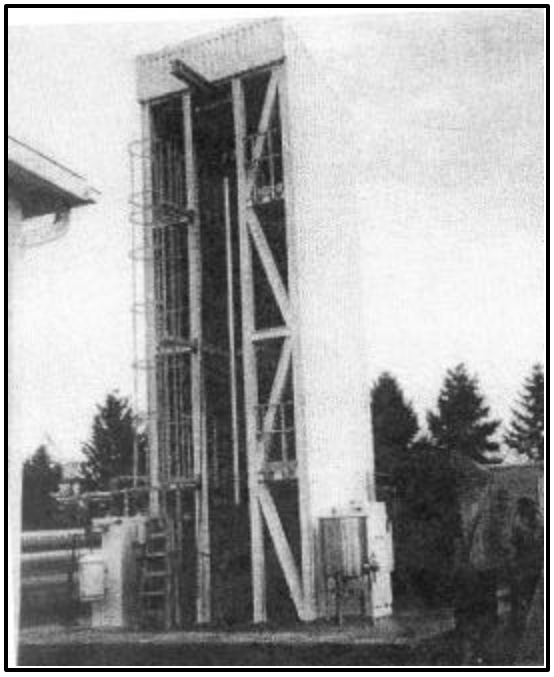
ITM Syngas Process



2 Reactions: $CH_4 + 1/2\ O_2 \rightarrow CO + 2H_2$

$CH_4 + H_2O \rightarrow CO + 3H_2$

SER Process



- **Advance reformer technology that can reduce the cost of hydrogen production by > 25%**

Biomass-based Production

Biomass-based Production		
	Biomass to Hydrogen via Fast Pyrolysis and Catalytic Steam Reforming	National Renewable Energy Laboratory
	Biomass Pyrolysis for Hydrogen Production	Jet Propulsion
NEW	Integrated H2 Production for Agricultural Residues for Urban Transportation	Clark Atlanta University
NEW	Supercritical Water; Partial Oxidation	General Atomics
NEW	Biohydrogen Production from Renewable Organic Wastes	Iowa State University

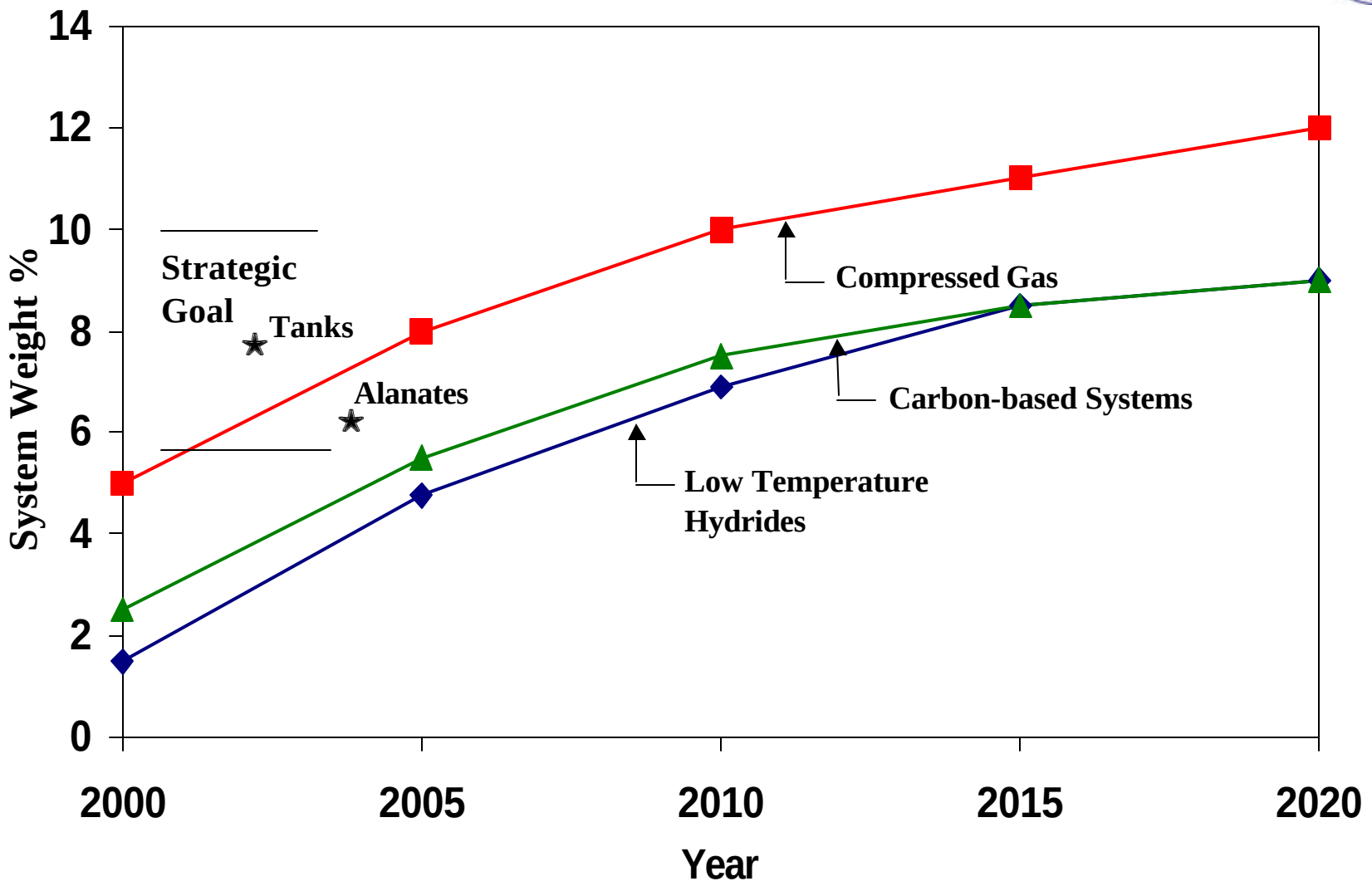
Photoelectrochemical/Biological Production

Photoelectrochemical /Biological Hydrogen Production		
NEW	Photoelctrochemical Hydrogen Production	University of Hawaii
	Photoelectrochemical based Direct Conversion Systems for Hydrogen Production	National Renewable Energy Laboratory
NEW	Solar Photocatalytic H2 Production from Water using a Dual bed Photosystem	Florida Solar Energy Center
	Development of an Efficient Algal H2 Producing System	National Renewable Energy Laboratory
	Two Phase Photobiological Algal H2 Production System	National Renewable Energy Laboratory
	Hydrogen Production by Photosynthetic Water Splitting	Oak Ridge National Laboratory
NEW	Maximizing Photosynthetic efficiencies and Hydrogen Production by Microalgal Cultures	University of California, Berkeley
	Photoproduction of Hydrogen from Glucose	Oak Ridge National Laboratory
	Biological H2 from Fuel Gases and Water	National Renewable Energy Laboratory
	Bioreactor Development for Biological H2 Production	National Renewable Energy Laboratory

Storage and Utilization Goals

- **Demonstrate safe and cost-effective storage systems for use in on-board and stationary distributed electricity generation applications**
- **Demonstrate safe and cost-effective storage systems for on-board applications in urban nonattainment areas**
  - **> 5.5% by weight at low temperature 100^{O}C**
  - **> 20 kg/m^3 for pressurized hydrogen; > 50kg/m^3 for hydrides and carbon-based systems**
- **Develop fuel cell and reversible fuel cell technologies as an efficient low-cost means of converting hydrogen into electric power**

Lightweight and Safe Storage Systems



Car Drop Test

ZDD

Conformable Tank

Storage

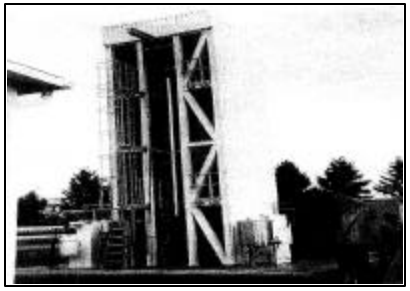
Hydrogen Storage		
	Vehicular Hydrogen Storage using Cryogenic Hydrogen	Lawrence Livermore National Laboratory
NEW	Composite Tank Testing	Sandia National Laboratories
	Hydride Development for Hydrogen Storage	Sandia National Laboratories
NEW	Catalytically Enhanced Hydrogen Storage Systems	University of Hawaii
NEW	Alanate Hydrides	University of Hawaii
	Carbon Nanotube Materials for H2 Storage	National Renewable Energy Laboratory
NEW	Feasibility of Fullerene Hydride as High Capacity H2 Storage System	MER Corporation
NEW	Hydrogen Storage in Polymer Dispersed Metal Hydrides	United Technologies
	Advanced Chemical Hydride/H2 for PEMFC Vehicles	Thermo Power

Stuart Electrolyser

Utilization

Utilization		
	Corrosion of Metallic Components in Fuel Cells	National Renewable Energy Laboratory
	Small Battery-Fuel Cell Alternative Technology Development	Los Alamos National Laboratory
	PEMFC Stacks for Power Generation	Los Alamos National Laboratory
NEW	Low Cost Reversible Fuel Cell System	Technology Management, Inc.
NEW	Hydrogen Delivery Systems to PEMFC	New Jersey Dept. of Transportation
NEW	Gallium Nitride Integrated Gas/ Temperature Sensors for FC System Monitoring H2 and CO	Fluence
	Thick Film Hydrogen Sensor Detector	Oak Ridge National Laboratory
	Interfacial Stability of Thin Film Hydrogen Sensors	National Renewable Energy Laboratory
	High Efficiency Steam Electrolyzer	Lawrence Livermore National Laboratory

Technology Summary



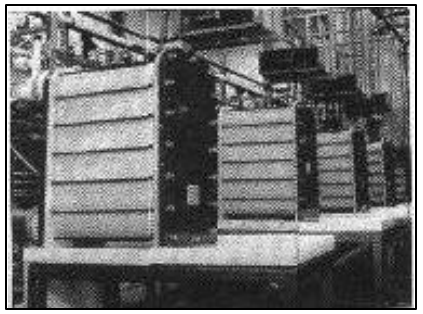
Production

Storage

Electrolyzer

The Hydrogen R&D Program is concentrating on a set of "hydrogen appliances" that can be used at any point along the electric transmission or natural gas pipeline systems for distributed electric generation and transportation applications.

Distributed Generation



Reversible Fuel Cell

Technology Validation Criteria

- √ **Demonstrate Mid-Term Economically Viable Options**

- √ **Demonstration of Integrated Systems to Verify Market Performance and Systems Economics, and Codes and Standards Development**

Technology Validation Programmatic Factors and Lessons Learned

- √ **Renewable/ Hydrogen Systems**
  - √ Electrolyzers and reversible fuel cells are being developed
  - √ Solar economics and development lag
  - √ Wind Powering America and Bioenergy are significant DOE initiatives
- √ **Hydrogen Infrastructure**
  - √ Zero Emission Vehicles
  - √ California Fuel Cell Partnership
  - √ Production and Storage Systems Demonstrations
- √ **Distributed/ Remote Power Systems**
  - √ Collaborate Fuel Cell Strategy with Buildings and Transportation Sectors
  - √ Understand Diesel Reformation Better

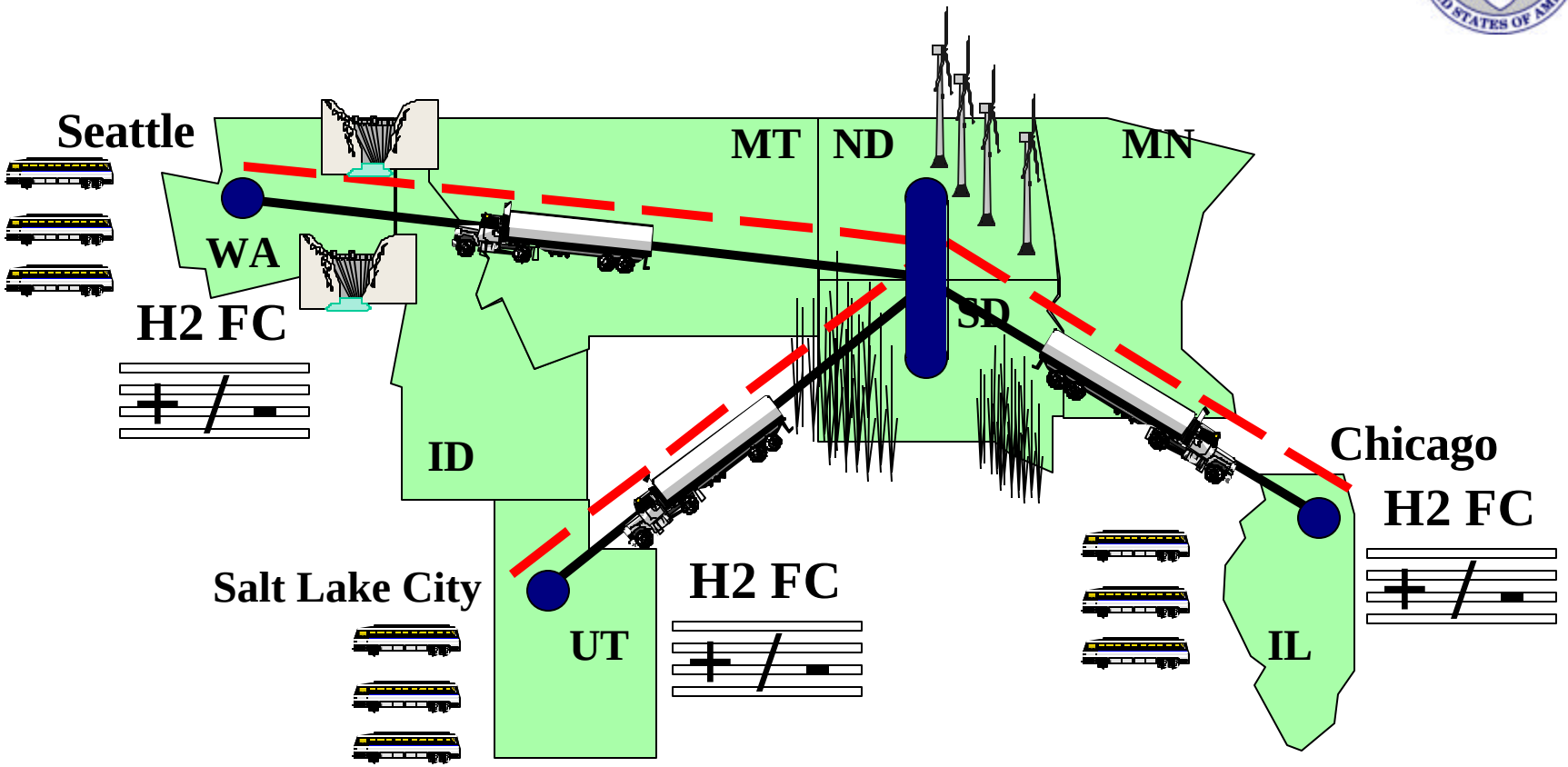
Technology Validation Projects

	Core Research and Development "Hydrogen Appliances"	Distributed Generation OBT/OPT	H_2 Infrastructure OTT	Renewable H_2 Systems OPT
Natural Gas Initiative	Advanced Reformers/ Purification Systems Storage	Collaborate on 50-75 kWe Fuel Cell	Reformers at 50-150 kWe size Co-production with 50-75kWe Fuel Cells Storage Systems	
Renewable Initiative	Biomass Electrolyzers Reversible Fuel Cells Water to Hydrogen			Cogeneration of Hydrogen and Electricity Wind Powering America Bioenergy

Technology Validation

Technology Validation		
Renewable/Hydrogen		
	Production of Hydrogen through Electrolysis	Proton Energy Systems
	Integrated PV Electrolysis Metal Hydride Storage System Assessment	Energy Conversion Devices
	Hydrogen Based Utility Energy Storage	Solar Reactor Technology Group; National Power
Hydrogen Infrastructure		
	Hydrogen Reformer Fuel Cell Power Generator and Vehicle	Air Products and Chemicals
NEW	Hydrogen Generation Field Valadaation System	TBD
	Hybrid Hydrogen Electric Bus Development	University of Nevada Las Vegas
	Hydrogen Enriched Natural Gas Heavy Duty Engine Development	NRG Technologies
	Filling up with Hydrogen-2000	Stuart Energy Systems
	High Pressure Conformable Hydrogen Storage of FC Vehicles	Thiokol Propulsion Company
	Vehicular Hydrogen Storage using Lightweight Tanks	Lawrence Livermore National Laboratory
NEW	High-Pressure Lightweight Tanks	TBD
	Fabrication of Hydride Bed for Technology Validation Project	Sandia National Laboratories
	Fuel Cell Mine Vehicle Development and Testing	Fuel Cell Propulsion Institute
	Industrial Fuel Cell Vehicle	Southeastern Technoogy Center
Remote Power Fuel Cells		
	PEM Fuel Cell Alaskan RAPP	Northwest Power
NEW	Fuel Cell Technology Phase III Alaska	Dias Analytical Power
	Remote Power Fuel Cells Development	University of Alaska
	Big Sky-Analysis of State Resources for Fuel Cell Potential	Montana Trade Authority

Hydrogen Technology Can Carry Farm Power to the Cities



Bio-crude and electricity are delivered to market centers for thermal and electrolytic conversion to H2 (respectively)

Direct hydrogen delivery via pipelines to market centers

Reversible Fuel Cell for Wind Integration

- Time-of-day tariff for Chicago (ComEd)
  - Peak (9 a.m. - 10 p.m.) energy charge ¢5.5/kWh, off-peak is ¢2.3/kWh
  - Summer (June - September) demand charge of $14.24/kW, winter is $11.13
- Wind power is assumed to substitute for off-peak energy at ¢4/kWh
- Reversible Fuel Cell (RFC) assumed at $1000/kW
- Annual savings of $130/kW, RFC pays for itself in 7.72 years
- Time-of-day tariff for New York (ConEd), “supplementary service”
  - Peak (8 a.m. - 10 p.m.) composite energy charge of ¢4/kWh, off-peak composite of ¢3/kWh (rate is adjusted during summer)
  - Year-round demand charge of $2.70/kW, summer-only, add $43.58
- Same wind & RFC assumptions as Chicago
- Annual savings of $205/kW, RFC pays for itself in 4.87 years

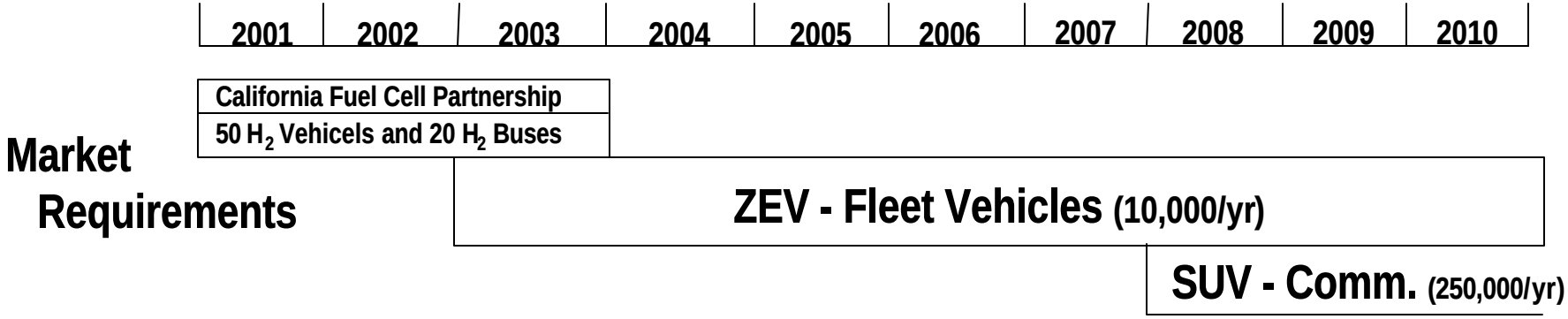
Title II–*Transition to a Hydrogen Based Economy*

- **Reauthorization of Hydrogen Future Act in 2002**
- **Title II Opportunities**
  - **Demonstration of Low-cost Hydrogen Production Systems in the Market Place**
  - **Development of Hydrogen Infrastructure to Support Zero Emission Vehicles**
  - **Demonstration and Cost Reduction of Distributed Power Generation Fuel-Cell Systems**
  - **Increasing Field Experience with these Integrated Systems**

Filling ZEV Vehicle Requirements

Vehicle Type (Must meet all PZEV requirements)	Primary Energy Source	Secondary Energy Source	Zero Emission Range (miles)	PZEV Baseline Allowance	Zero-Emission VMT Allowance	Low Fuel Cycle Emissions Allowance	Total ZEV Allowance
Pure ZEV							
Battery EV	Grid Electricity		Any				ZEV
Stored Hydrogen FCV	Hydrogen		Any				ZEV
Direct Methanol FCV	Methanol	Electricity	Any				ZEV
Fully Meets ZEV Allowance							
LFCE ICE HEV, 73 mile ZE range	Grid Electricity	CNG, Methanol, etc.	73	.2	.5+.1 (max off-vehicle charging)	.2	1.0
Gasoline HEV, 100 mile ZE range	Grid Electricity	Gasoline	100	.2	.6	.2	1.0
Hydrogen ICE HEV, 20 mile ZE range	Grid Electricity or H2 with FC APU	Hydrogen	20	.2	.3+.3 (0 NMOG)	.2	1.0

Technology Pathways



- √ **Continued R & D on Fuel Cells to Improve Performance and Lower Cost of High Volume Fabrication of Components**
- √ **Early Utilization of Fuel Cells in Federal Buildings and Vehicles**
- √ **Provide Low-cost H_2 Production Infrastructure**
  - **Off-board Reforming of Natural Gas (100-300 Vehicles)**
  - **Electrolysers (10-30 Vehicles)**
  - **Small Multi-Residential Fuel Appliances (3-5 Vehicles)**
- √ **Introduction of Hybrid Electric Vehicles**

Safety, Analysis, and Outreach

Safety, Analysis, and Outreach		
Hydrogen Safety		
	Dispersion of Hydrogen Clouds	University of Miami
	Integrated Micromachined H2 Gas Sensors	Advanced Technology Materials
Analysis		
	Analysis of Hydrogen Vehicle Pathways	Directed Technologies
	Process Analysis of Hydrogen Research Activities	NREL
	Hydrogen Energy System Studies	Princeton University
	Integrated Hydrogen Fuel Infrastructure Research and Technology Development	NREL
	Technical and Systems Assessments and IEA Support	Energetics
NEW	Analysis of Hydrogen Production using Biofarming for Microturbine Power	University of North Dakota
NEW	Analysis of Fuel Cells for Maritime Applications	DCH Technologies
Outreach		
	Outreach: Education, Information Exchange, Joint International Working Groups	NHA
	Education Outreach	MRS Enterprises
NEW	H2000 Project Safety Film	H2000

Slide 1

Carbon Displacement (MMTCE/Year)

	2010	2020
Wind	10.8	22.2
Biomass	11.7	17.4
Hydrogen	1.9	13.5
High Temperature Super Conductivity	1.6	6.2
Transmission Reliability	2.8	5.5
Geothermal	1.7	5.5
Solar Buildings	0.9	2.5
Photovoltaics	0.4	1.8
Concentrating Solar Power	0.1	0.2

Prepared GPRA Report of the Office of Power Technologies