Connecticut Fuel Cell Activities: Markets, Programs, & Models

DOE State's Call - December 16, 2009

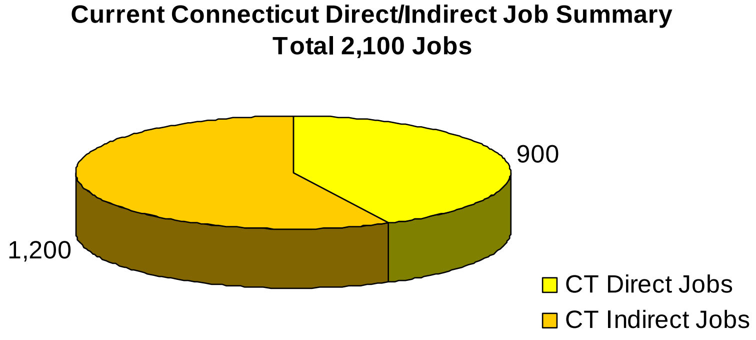
Joel M. Rinebold

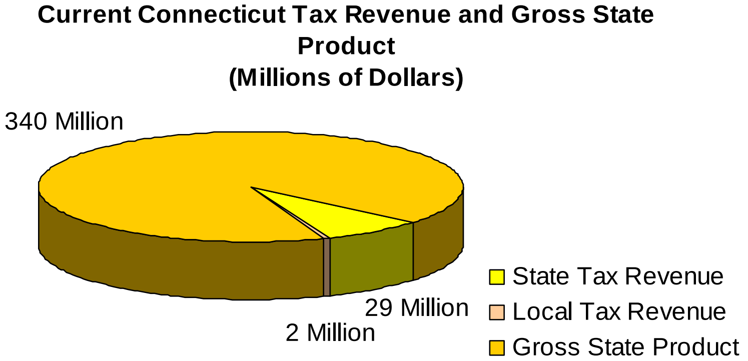
Hydrogen Programs

- Connecticut Hydrogen Roadmap (Fuel Cell Economic Development Plan)
- A National "Green Energy" Economic Stimulus Plan based on Investment in the Hydrogen and Fuel Cell Industry
- Connecticut DOT Plan for Hydrogen Stations and Zero Emission Fuel Cell Vehicles (In Development)
- Renewable Portfolio Standards
- Project 150 and Grant Programs
- Connecticut Hydrogen Fuel Cell Economy
- Connecticut Regional Resource Center

Connecticut Market Growth

- In 2006, there were over 900 jobs associated with research and development and manufacture of equipment (1,156 in 2007).
- Over 1,200 indirect jobs in 2006 (over 1,500 in 2007).
- The industry contributed $29 million in local tax revenue, and over $340 million in gross state product in 2006.





Economic Multipliers

Economic Multipliers			
	Employment	Industry Revenues	Employee Compensation
Multiplier	2.31	1.84	1.72

- For each job the hydrogen and fuel cell industry directly supports, an additional 1.31 jobs are indirectly supported elsewhere in Connecticut.
- For every $1.00 of revenue generated by industry, and additional 84 cents of revenue is received by the state of Connecticut.
- For every $1.00 paid to industry employees, an additional 72 cents is paid by other employers in the supply chain.

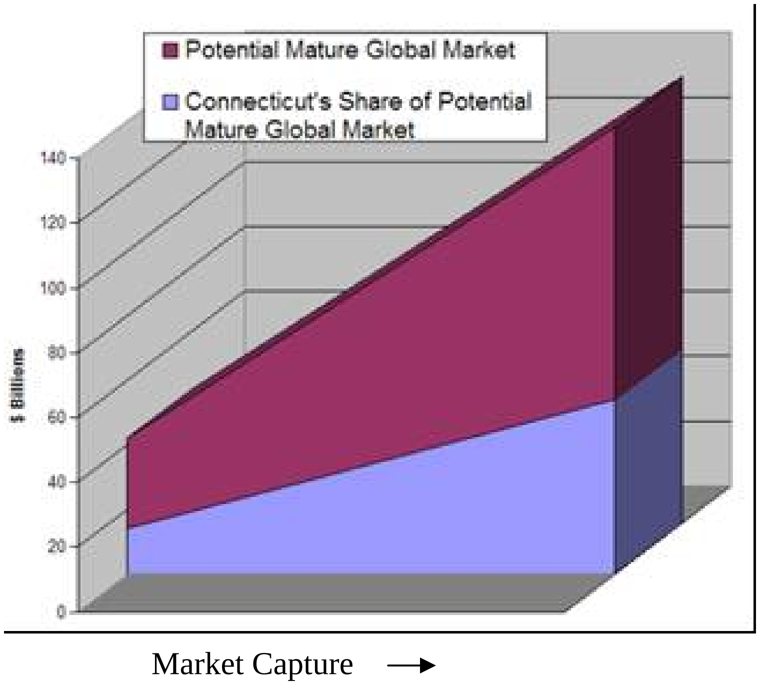
Industry Employment

Industry Employment			
	2006	2007	2010 (Estimated)
Direct Employment	927 Jobs	1,156 Jobs	1,635 Jobs

- Job growth directly associated with the industry is estimated to grow by over 700 jobs between 2006 and 2010, however such growth would be modest compared to potential applications of a mature market.

- Connecticut's hydrogen and fuel cell industry presently employs 1,156 employees, an increase of 229 jobs since early 2006.

Potential Mature Global Market



- A mature global market could generate between $43 and $139 billion annually.
- If Connecticut captures a significant share of the distributed generation and transportation markets, revenues could be between $14 and $54 billion annually.
- A mature market would require a Connecticut employment base of tens of thousands.

Emissions Reductions and Energy Savings

- Fuel cell generation facilities can substantially reduce emissions, greenhouse gases, and energy use.

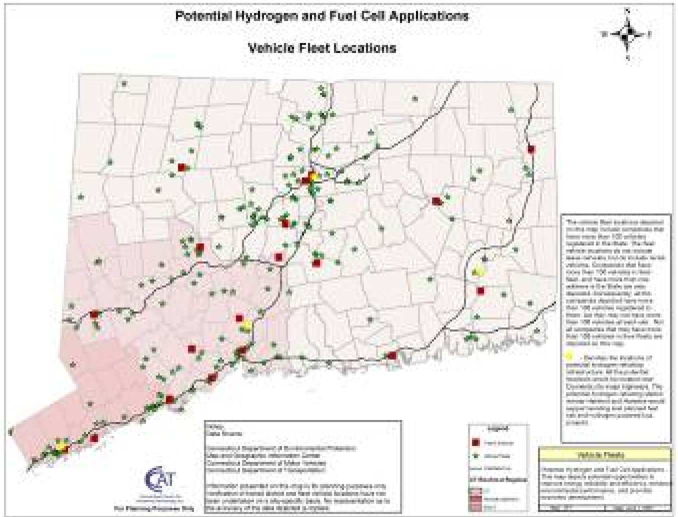
Potential Average Annual Emissions Reduction and Energy Savings Associated with the Displacement of 40 MW of Conventional Fossil Fuel Generation			
Air Emissions		Energy Savings	
NO_X	224 tons	Btu	1.4 – 1.6 Trillion
SO_2	187 tons	No. 2 Oil Equivalent	10 - 12 Million Gallons
CO_2	144,365 tons		

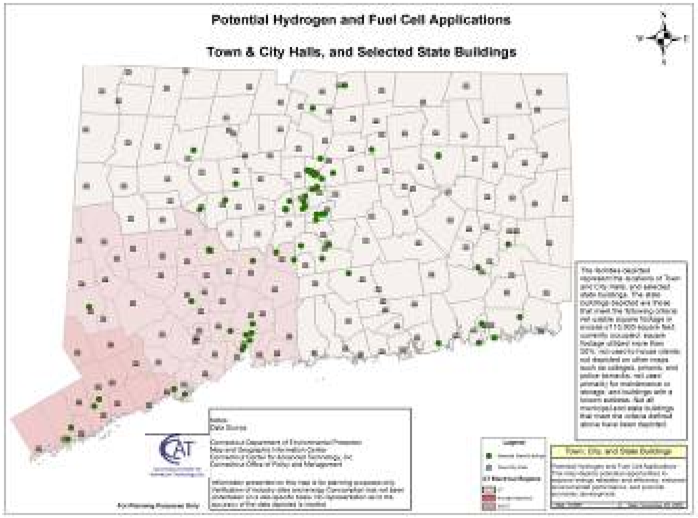
- Fuel cells would increase transportation efficiency by two to three times.

Average Expected Energy Use (mpge)					
Passenger Car		Light Truck		Transit Bus	
Hydrogen Fuel Cell	Gasoline Powered Car	Hydrogen Fuel Cell	Gasoline Powered Light Truck	Hydrogen Fuel Cell	Diesel Powered Transit Bus
81.2	29.3	49.2	21.5	7.04	3.9

Targeted Deployment

- Targeted deployment of hydrogen and fuel cell technology could effectively meet electric power, thermal and transportation needs, reduce emissions, increase energy efficiency, and reduce costs.
- Examples of targets include state public buildings, prisons, universities, hospitals, transit fleets, delivery fleets, major highway fueling stations, etc.



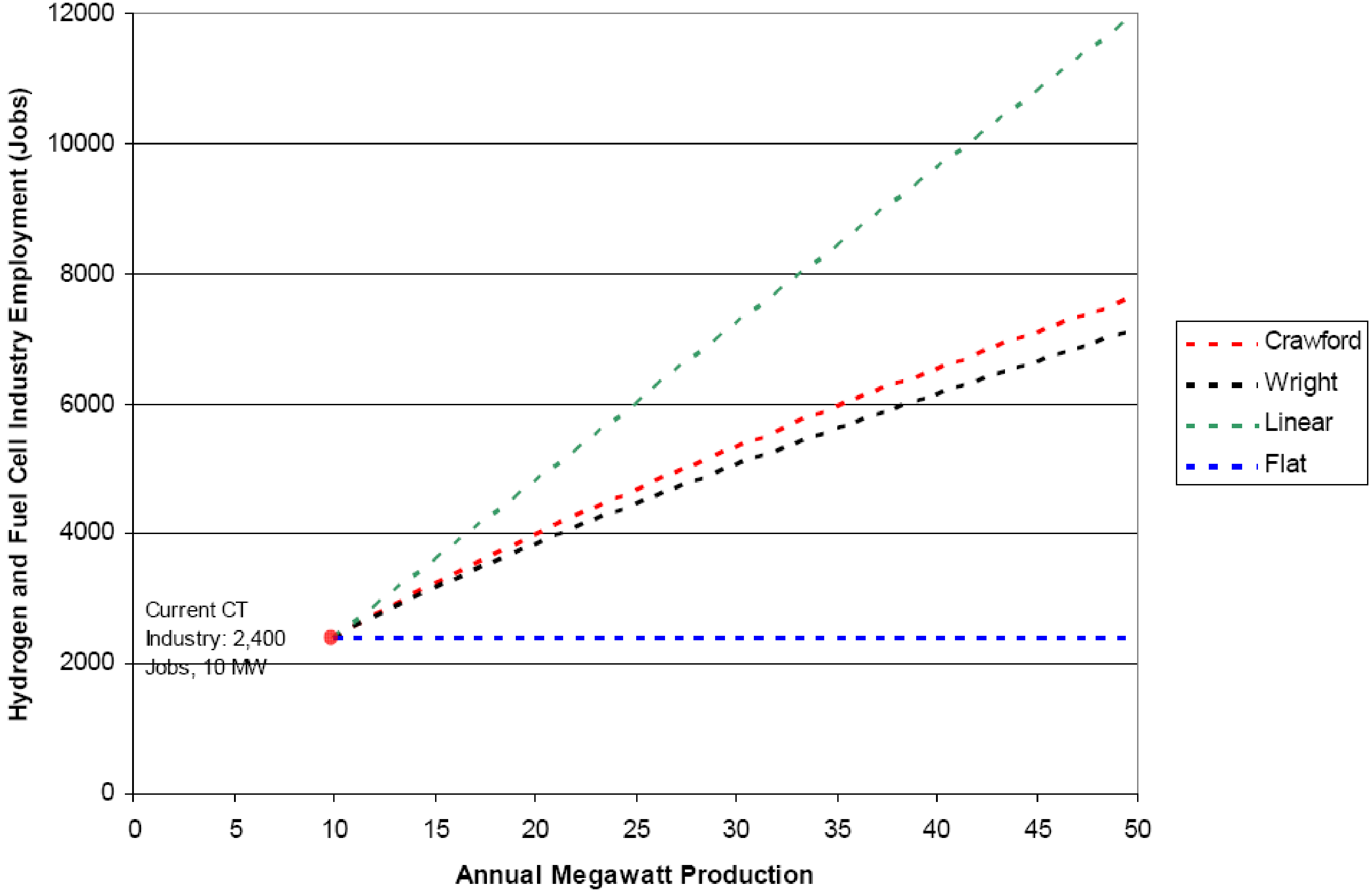


Connecticut Supply Chain

- There are opportunities for further supply chain development for fuel cell manufacturing in Connecticut.
- There are over 150 Connecticut companies that have the capability to be part of the fuel cell supply chain.
- The future state of a Connecticut supply chain can conceivably consist of hundreds of suppliers and tens of thousands of employees.

Connecticut OEM Activities	
What do Connecticut OEMs currently do?	What do Connecticut OEMs currently make?
• Manufacture • Repair • Refurbish • Test • Assemble • Install	• Turn-key fuel cell systems • Fuel cell stacks • Fuel cell plates • BOP equipment • Hydrogen production equipment

Industry Employment

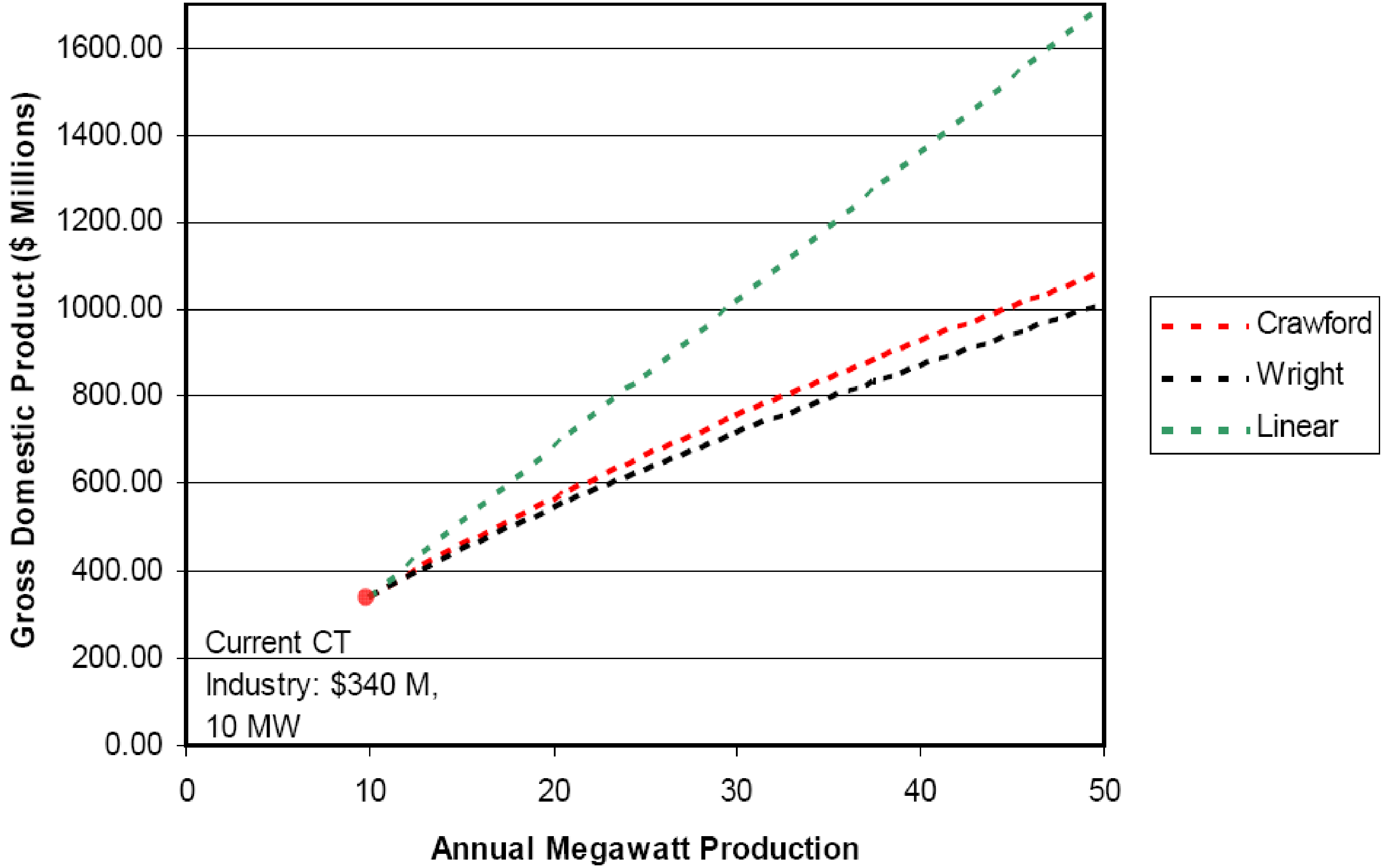


Industry Employment

Results:

- Approximately 7,100 direct, indirect and induced jobs per 50 MW of consistent annual production of hydrogen and fuel cell manufacturing.

Gross Domestic Product

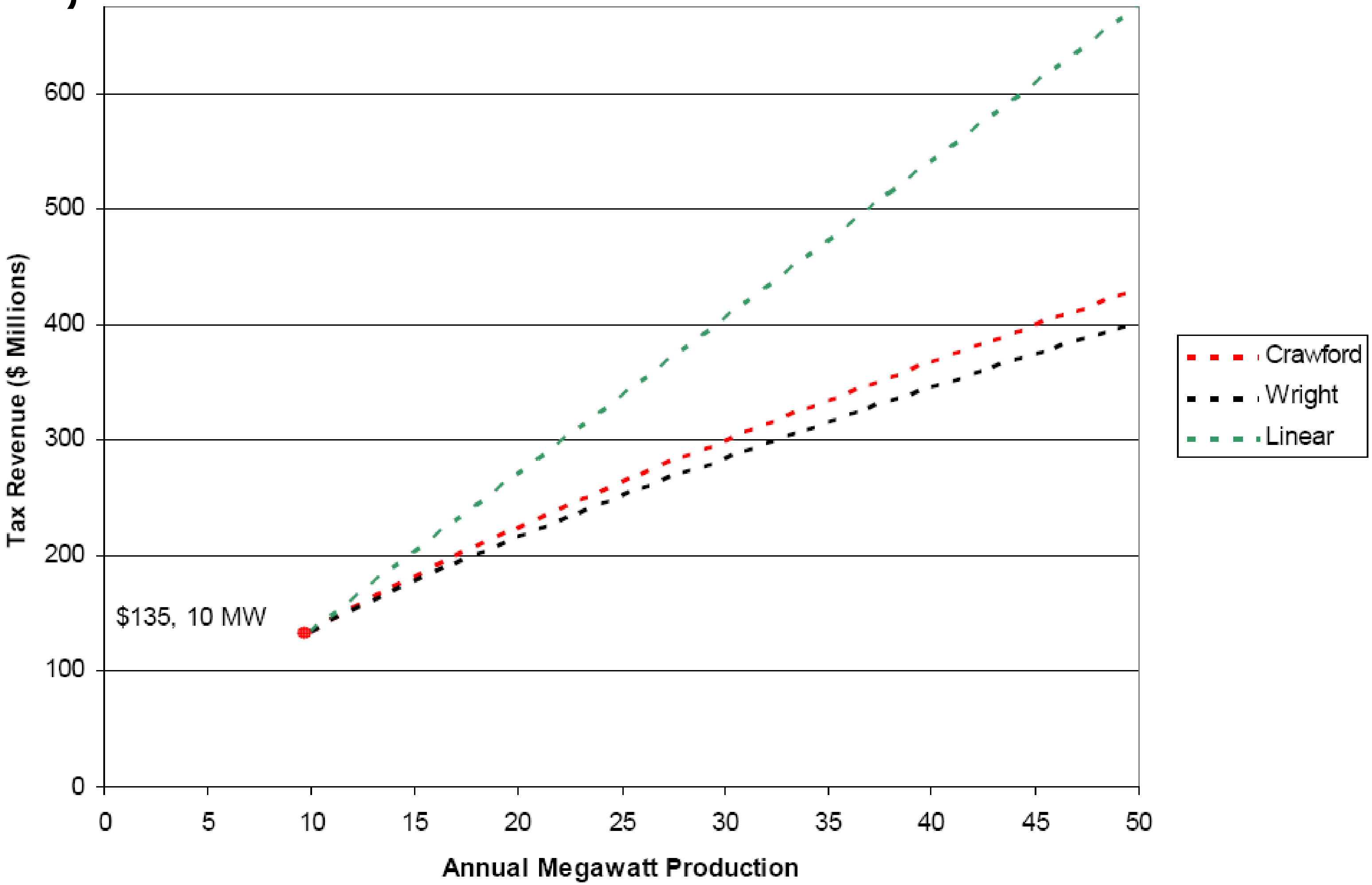


Gross Domestic Product

Results:

- Approximately $1 billion in gross domestic product per the annual production of 50 MW of hydrogen and fuel cell manufacturing.

Local, State and Federal Tax Revenue

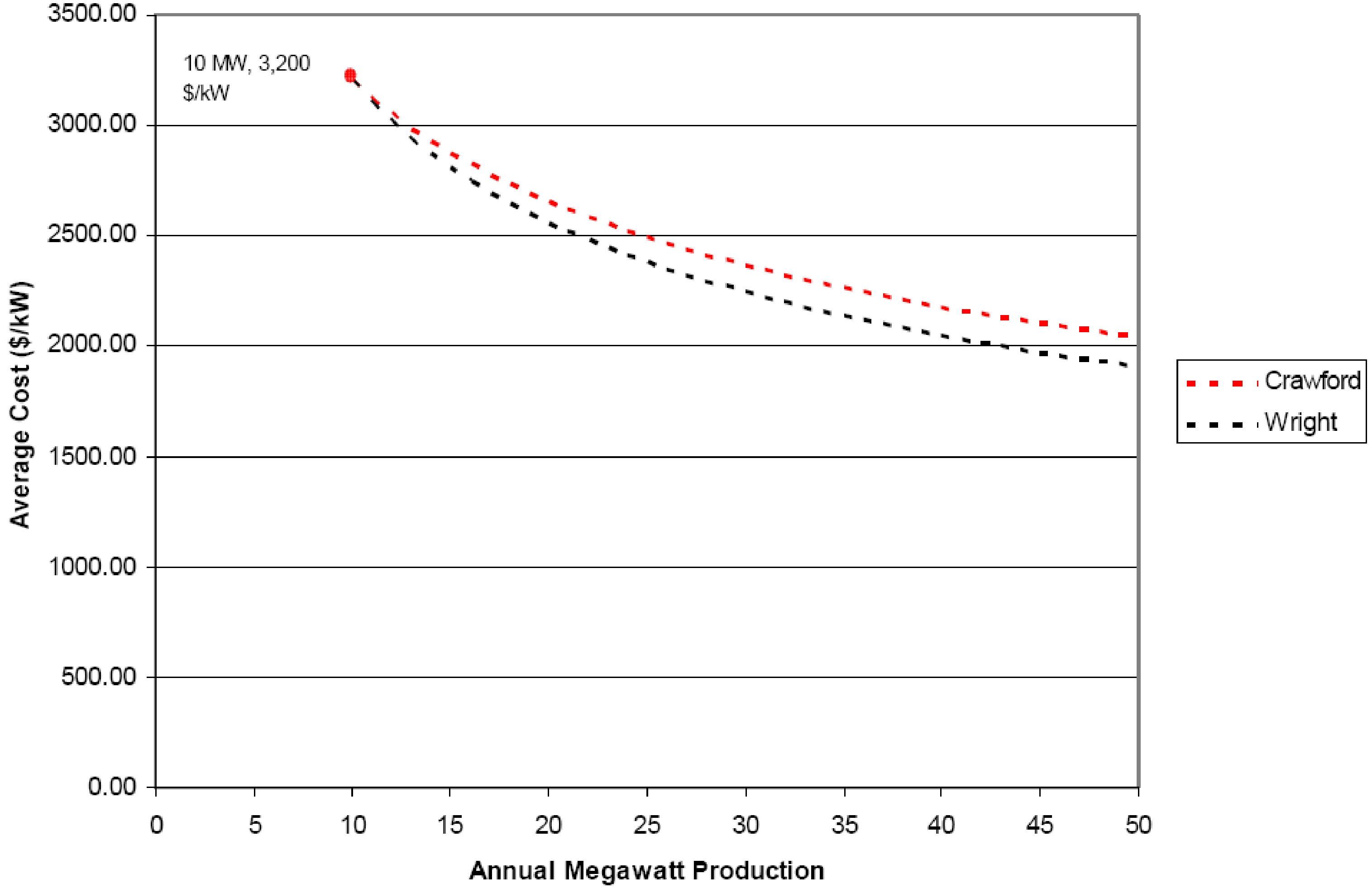


Local, State and Federal Tax Revenue

Results:

- Approximately $400 million in federal, state, and local taxes annually for 50 MW of annual hydrogen and fuel cell production.

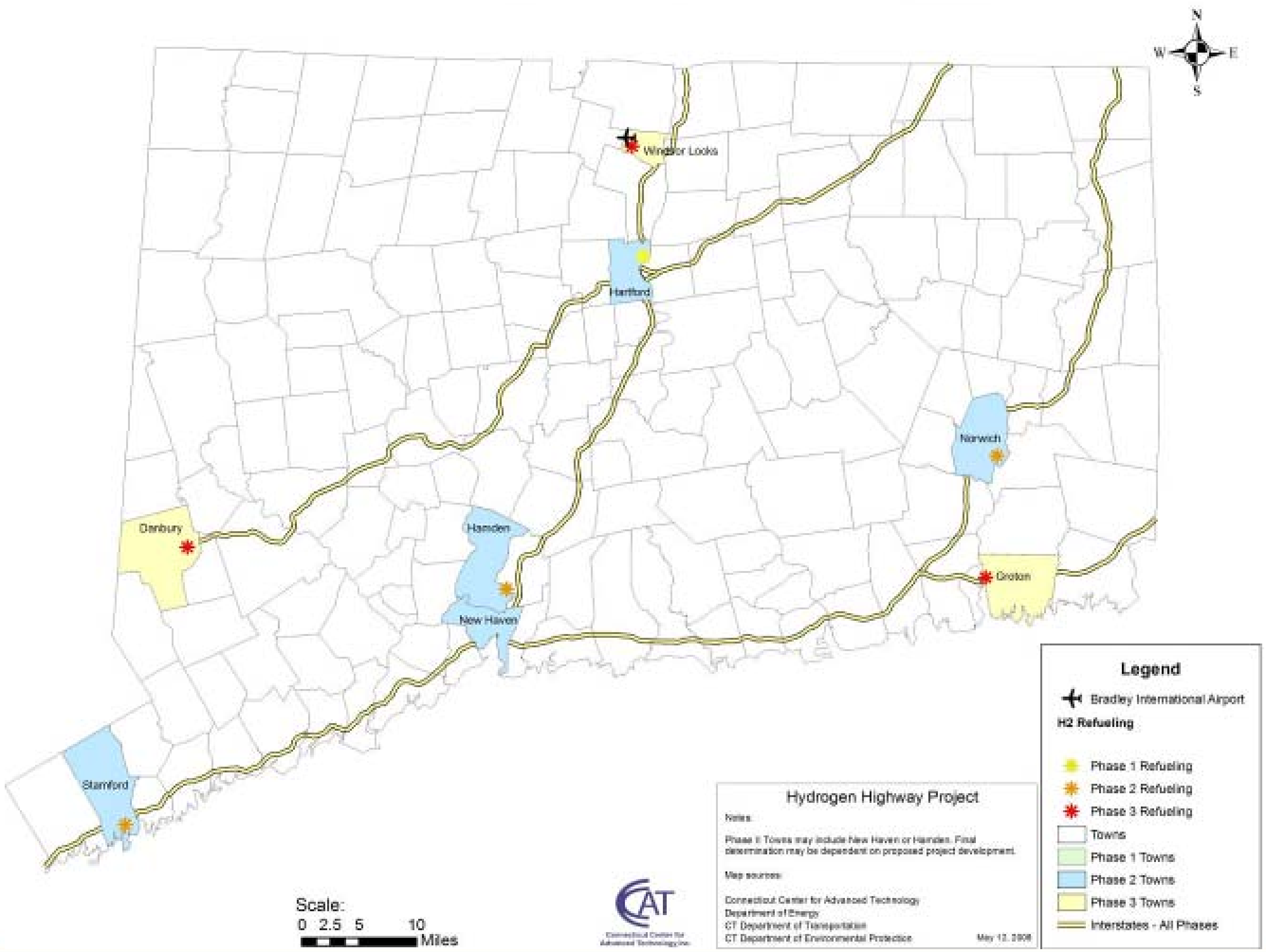
Reducing Production Cost



Plan Outline:

- **I. Introduction**
  - A. Hydrogen and Fuel Cell Vehicles: Value
  - B. Demand for Hydrogen and Vehicles
  - C. Costs and Development
    - i. Hydrogen Generation
    - ii. Refueling Stations
    - iii. Transit Buses
    - iv. Passenger Vehicles
  - D. Technology
    - i. Hydrogen Generation
    - ii. Refueling Stations
    - iii. Transit Buses
    - iv. Passenger Vehicles
- **II. Infrastructure**
  - A. Station/facility characteristics
    - i. Pressure
    - ii. Volume
    - iii. Hydrogen Production, Delivery, Storage
    - iv. Codes & Standards
    - v. Permits & Approvals
    - vi. Connecticut laws and regulations
- **III. Strategies**
  - A. Passenger vehicle strategy
  - B. Transit vehicle strategy
  - C. Expansion and availability
    - i. Clustering
    - ii. Fleets
    - iii. Vehicle manufacturers
    - iv. Station distribution/deployment
      1. Public
      2. Private
  - D. Station locations and fuel demand
  - E. Schedule and costs
  - F. Products and infrastructure principally manufactured in Connecticut
  - G. Program evaluation
- **IV. Funding/Financial**
  - A. Examination of appropriate funding
    - i. Federal
    - ii. State
    - iii. Private
  - B. Federal and private cost sharing
- **V. Conclusion**

Phased Infrastructure Deployment

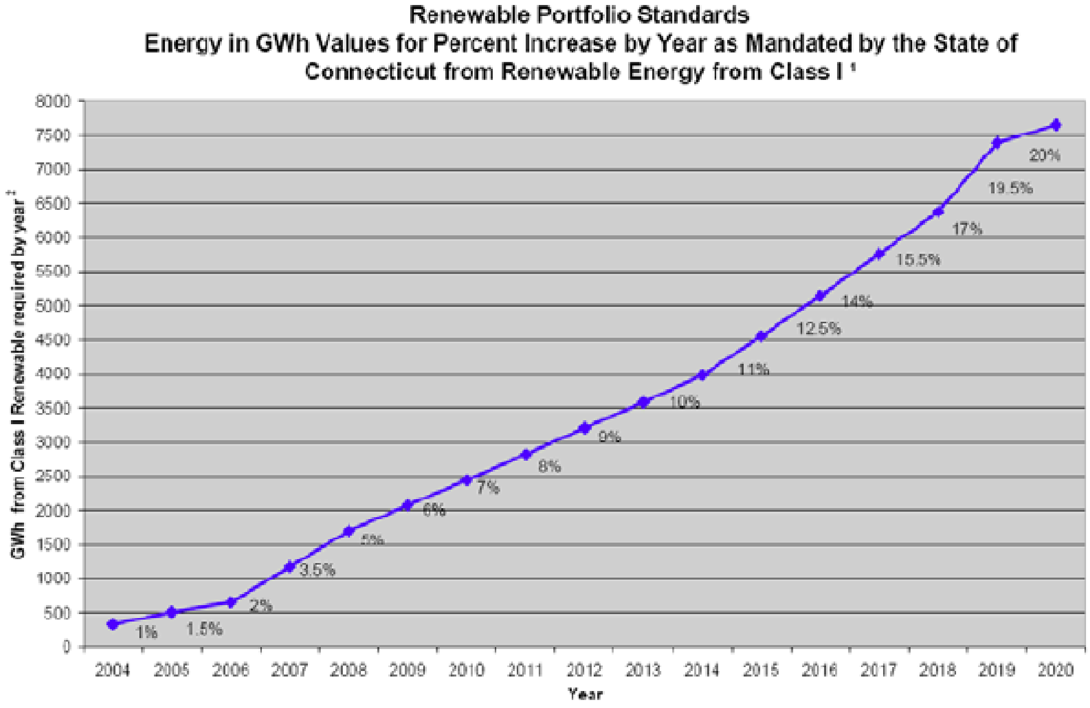


Connecticut Clean Energy Fund

- Grants up to $4M per project
- Incentive cap = $2.50 per Watt
- Pays approx. 25-50% of total system cost
- Limitations:
  - Site must have base load greater than fuel cell output
  - Site must be able to use at least 50% of thermal energy
  - Must have access to natural gas service or other fuel

Source: Connecticut Clean Energy Fund

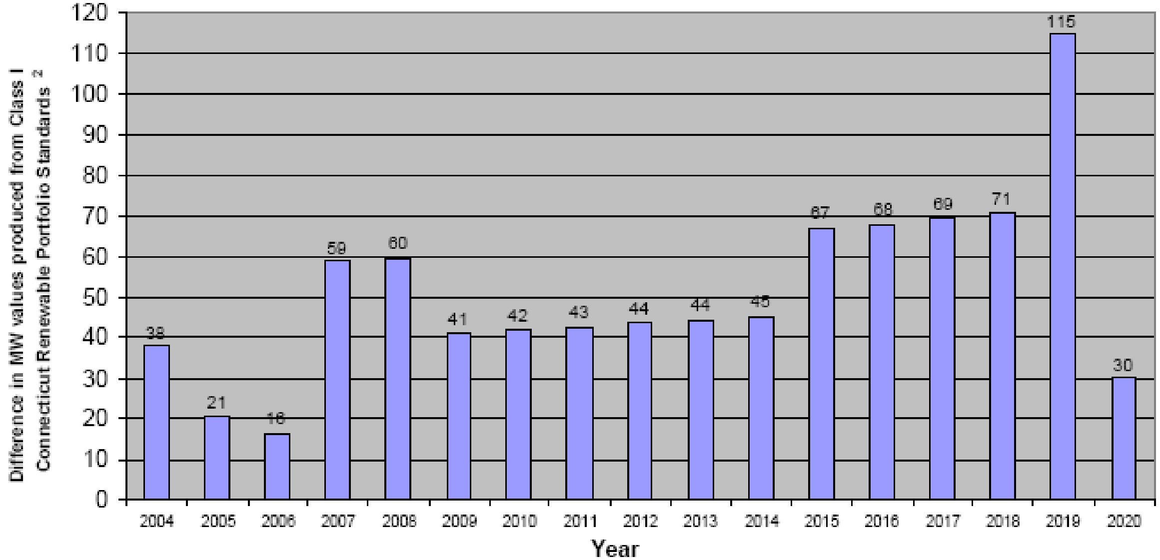
Annual Percentage Increase of Connecticut's RPS



1. Energy Growth Estimates are based on the compound Growth Rate of .88 % as provided by The Connecticut Siting Council.
2. Based on 100% load factor

Projected Average Annual Capacity Increase of Connecticut's RPS

Projected Capacity from Year to Year Based on the Renewable Portfolio Standards Percent Increase as Mandated by the State of Connecticut from Renewable Energy from Class I[1]



1. Energy Growth Estimates are based on the compound Growth Rate of .98% as provided by The Connecticut Siting Council.
2. Based on 100% load factor

Project 150

- Initiative to develop 150 MW of renewable generating capacity in CT
- Long Term EPA by the Department of Public Utility Control

Fuel Cell Projects

Round 2:

- DFC-EPG Milford (Milford) - 9 MW
- Stamford Hospital (Stamford) - 4.8 MW
- Waterbury Hospital (Waterbury) - 2.4 MW

Round 3:

- Bridgeport Fuel Cell Park (Bridgeport) - 14.9 MW
- DFC-ERG Bloomfield (Bloomfield) - 3.6 MW
- DFC-ERG Glastonbury (Glastonbury) - 3.4 MW
- DFC-ERG Trumbull (Trumbull) - 3.4 MW
- EPG Fuel Cell (Danbury) - 3.4 MW

Other Programs

Renewable Energy Credits

- RECs awarded for renewable energy projects including fuel cells

Low Interest Loans for Customer Side DG

- Interest rate 1% below applicable rate or no more prime rate
- DPUC/Banc of America

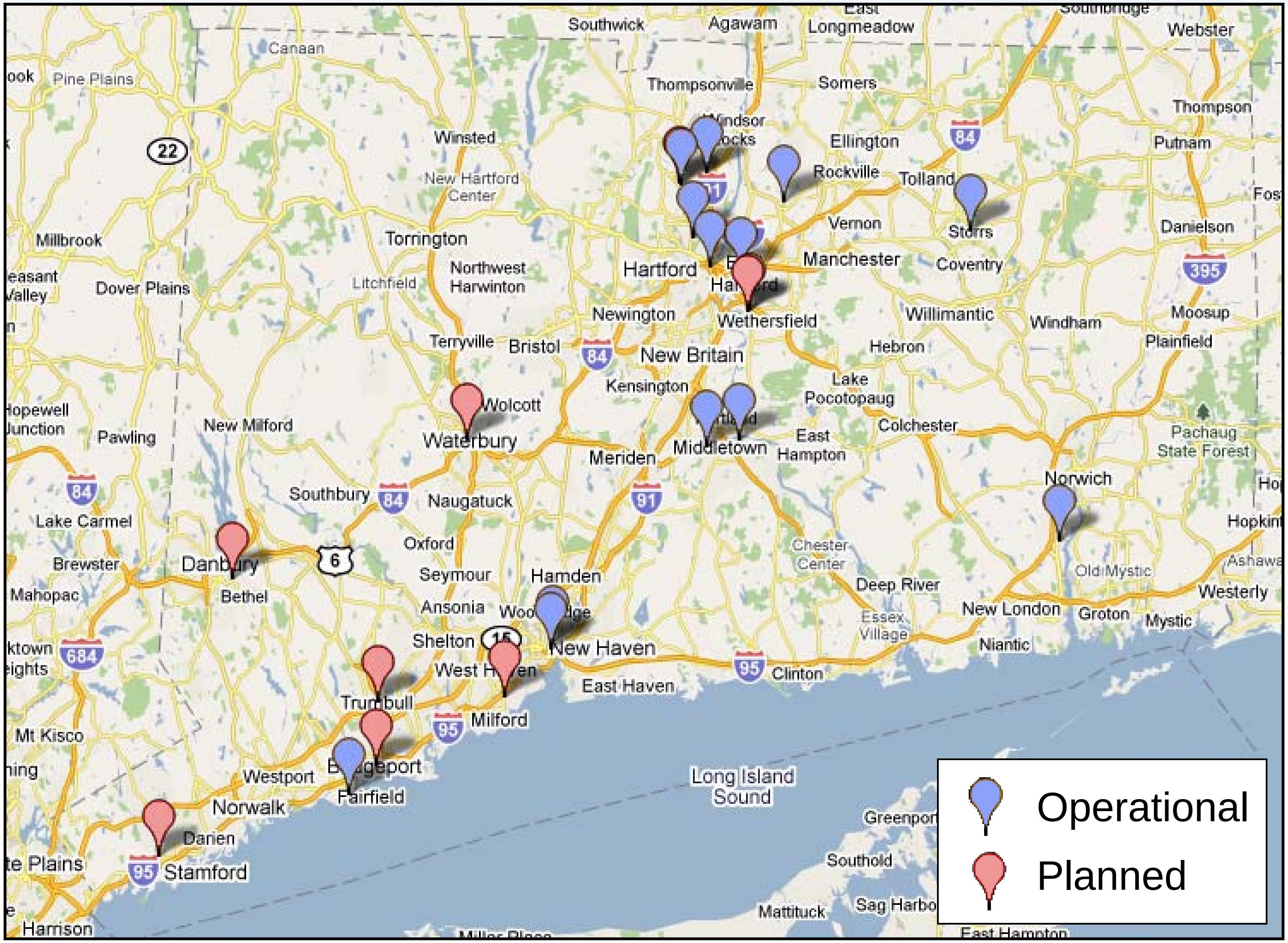
Discounts from Natural Gas

- Distribution charges waived for DG projects

ISO-NE Demand Response Program

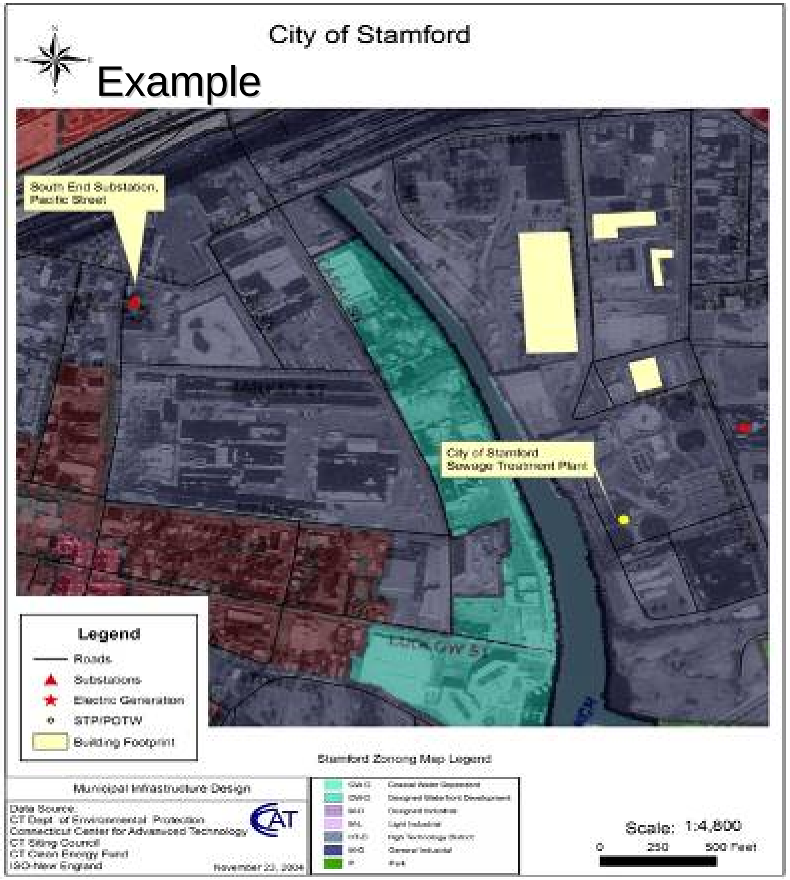
- Backup rates and demand ratchets are eliminated for customers who install projects

Connecticut Fuel Cell Locations



Project Analysis

- Define problem/opportunities
- Identify community solutions
- Collect detailed information
- Identify application for fuel cells
- Initiate economic model



Project Analysis

Dates From	To	# Days	Electric Consumption On-Peak (kwh)	Off-Peak (kwh)	Total (kwh)	30-day avg (kwh)	Demand On-Peak (kw)	Off-Peak (kw)	Hours Use (hrs)	Total Cost $	Unit Cost ($/kwh)
12/8/2005	1/10/2006	33	213,626	141,920	355,546	323,224	869.2	642.8	372	38,648	.109
1/10/2006	2/7/2006	28	198,766	119,078	317,844	340,547	1005.3	748.7	339	43,604	.137
2/7/2006	3/8/2006	29	200,241	121,652	321,893	332,993	911.1	645	365	43,121	.134
3/8/2006	4/6/2006	29	210,470	119,737	330,207	341,593	1054.9	669.6	324	47,723	.145
4/6/2006	5/7/2006	31	231,349	144,819	376,168	364,034	1118	854.5	326	52,132	.139
5/7/2006	6/7/2006	31	264,476	146,459	410,935	397,679	1306.8	1128.8	304	56,937	.139
6/7/2006	7/9/2006	32	291,478	184,120	475,598	445,873	1341.8	1208.7	332	63,753	.134
7/9/2006	8/8/2006	30	321,126	196,720	517,846	517,846	1347.8	1204.4	384	70,413	.136
8/8/2006	9/7/2006	30	279,436	161,991							
9/7/2006	10/5/2006	28	250,136	144,103							
10/5/2006	11/5/2006	31	219,233	147,768							
11/5/2006	12/6/2006	31	249,024	136,473							
12/6/2006	1/8/2007	33	219,404	143,193							
1/8/2007	2/6/2007	29	200,563	126,252							

Billing Dates From	To	# Days	Gas Consumption Total (Ccf)	30-day Avg (Ccf)	Total Cost ($)	Unit Cost ($/Ccf)
12/31/2005	1/31/2006	31	14,653	14,180	23,495.95	1.603
1/31/2006	2/28/2006	28	14,239	15,256	18,757.67	1.317
2/28/2006	3/31/2006	31	12,343	11,945	14,457.48	1.171
3/31/2006	4/30/2006	30	6,893	6,893	8,891.74	1.29
4/30/2006	5/31/2006	31	4,135	4,002	5,976.04	1.445
5/31/2006	6/30/2006	30	1,677	1,677	3,056.33	1.822
6/30/2006	7/31/2006	31	792	766	2,184.01	2.758
7/31/2006	8/31/2006	31	1,206	1,167	2,563.23	2.125
8/31/2006	9/30/2006	30	3,194	3,194	4,691.52	1.469
9/30/2006	10/31/2006	31	9,457	9,152	13,985.00	1.479
10/31/2006	11/30/2006	30	9,430	9,430	11,274.37	1.196
11/30/2006	12/31/2006	31	13,447	13,013	15,508.31	1.153
12/31/2006	1/31/2007	31	17,225	16,669	19,081.11	1.108

Provide one year (12 months) of utility data

CT Hydrogen Fuel Cell Economy

Project Analysis

Utility Inputs

Combined Heat a
Connec

UTC FC	Technology
1,328	KWAC Peak Host Demand Capacity
47%	Host approximate Load Factor
4,728,797	kWhs Host Average Energy Demand
0%	Host Expected Retun on Equity
1,198,139	btu/hr Average Host Heat Demand
400	KWAC Fuel Cell Installation
97.00%	Capacity Factor
8,126	Average Heat Rate
27,620	mmbtu Heat Input Per Year Required
3,398,880	Fuel Cell Gen is 71.9% of Host Requirement
1,560,229	btu/hr Average generated by UTC FC
15.32	Utility Avoided Energy Cost ¢/kWh
3.0%	Utility & Nat Gas & LFG Esc. Rate
3.0%	O&M Esc. Rate
$11.95	Natural Gas $/mmbtu
$0.00	Fuel Oil Cost $/mmbtu
$11.95	Natural Gas and Fuel Oil Cost $/mmbtu
$30.00	Recs Market Value De-Esc @2%
2.00	O&M ¢/kWh
80.0%	Natural Gas or Oil Fired Boiler Efficiency
15	- Number of Years in the Analysis
rate 58	Host CL&P Electric Rate
Third Party Rate	0.00

CL&P ☑
U I ☐
Non Profit ☐

Electric Demand → KWAC Peak Host Demand Capacity

Thermal Demand → btu/hr Average Host Heat Demand

Utility Rates → Host CL&P Electric Rate

Economic Financial Analysis

Payback in year 2

NPV	$1,533,124
IRR	40%

Cost of Capital:

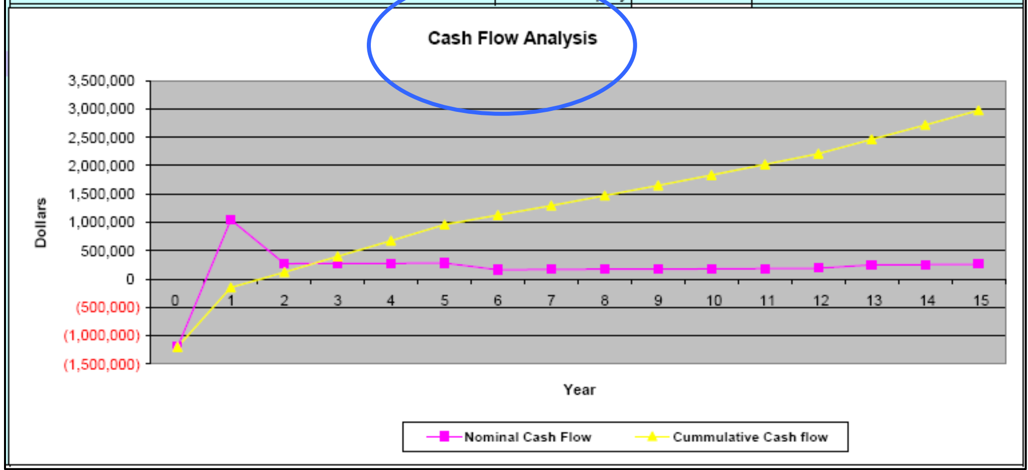
	Percent	Rate	pre-tax
Debt	100.00%	7.00%	7.00%
Equity	0.00%	12.00%	0.00%
Weighted Capital Cost			7.00%

Finance Term - 12 Years

Depreciation - 5 Years

Capital Cost:

UTC FC	$3,000	perKW
Install Cost	$0	perKW
B/E Analysis		perKW
Total Cost	$3,000	perKW
Or	$1,200,000	Dollars
Re-stack	$1,500	per KW
Subsidies&Tax	(780,000)	
Host Equity	$0	



Financial Variables

- Payback term
- Cash flow
- Net present value
- Depreciation
- Internal rate of return
- Financing method
- Capital costs
- Installation and restacking cost
- Investment tax credits

Regional Resource Center
A Connecticut Center for Advanced Technology/US DOE Partnership Initiative

DOE State's Call - December 16, 2009

Tom Drejer

Partnership Initiative

- Promote hydrogen/fuel cell applications
- Target state and local government officials

Goals

- Reduce energy costs
- Improved energy reliability
- Enhance environmental performance

Outreach

- Educate stakeholders on benefits
- Explain Regional Resource Center
- Review assisted modeling capabilities
- Provide examples of modeling and projects
- Review available funding
- Provide additional resources and potential partners

Functions:

- Provides online information, models, tools
- Targets: local and state planners
- Subjects: quantified costs and benefits
- Identification of potential sites
- Ensures planners have the right information
- Ensures appropriate application of technology
- Information sharing and case studies

U.S. DOE Partnership Online Models

-Economic/Cost Model

- Heating and Electricity Cost Savings

-Energy Management Model

- Efficiency Benefits

-Distributed Technology Comparison

- Compares Fuel Cells to Other Technologies

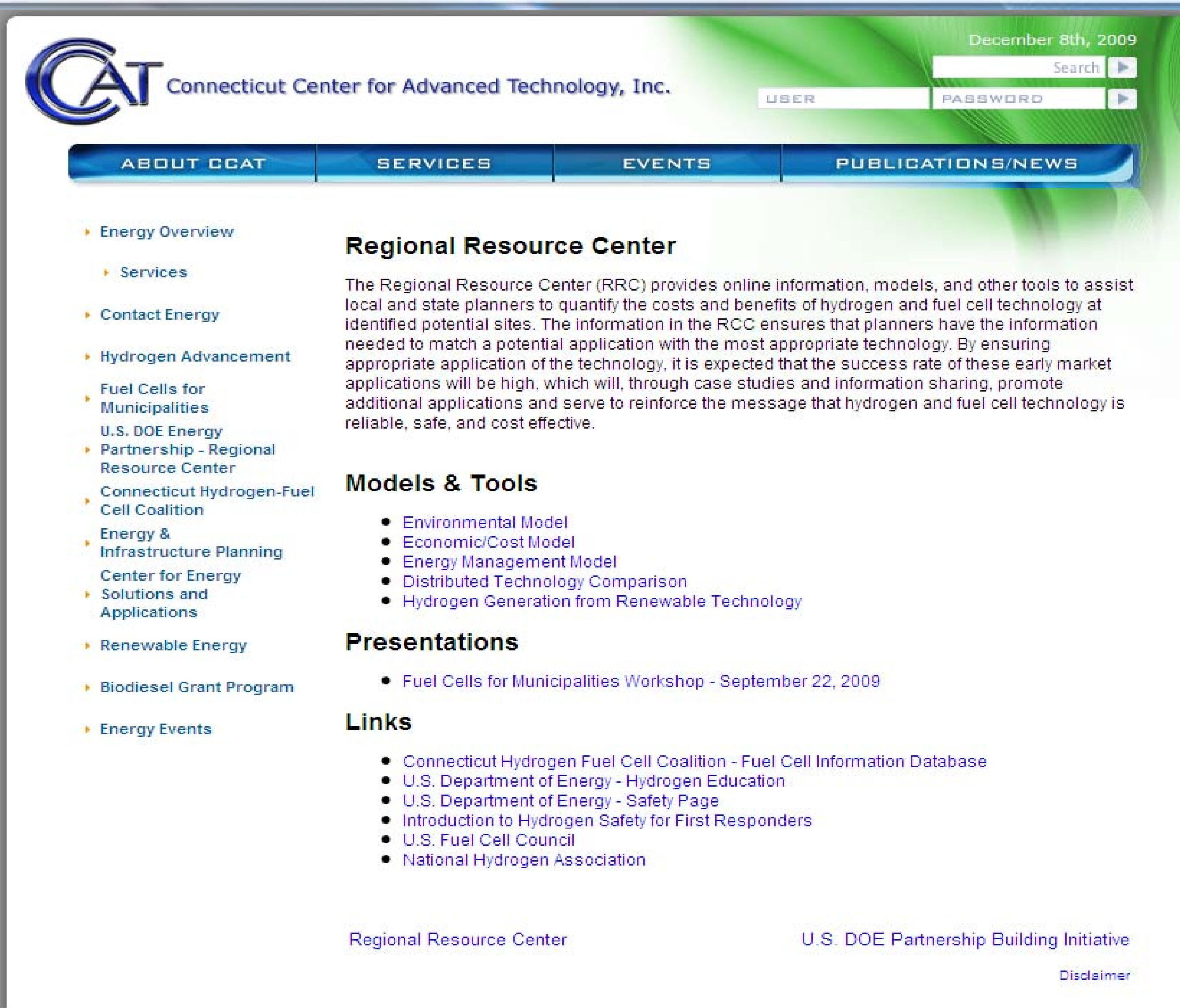
-Hydrogen Generation from Renewable Technology

- Cost of Hydrogen from Renewable Resources

-Environmental Model

- Stationary and Transportation Emissions

Regional Resource Center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- Connecticut Hydrogen-Fuel Cell Coalition
- Energy & Infrastructure Planning
- Center for Energy Solutions and Applications
- Renewable Energy
- Biodiesel Grant Program
- Energy Events

Regional Resource Center

The Regional Resource Center (RRC) provides online information, models, and other tools to assist local and state planners to quantify the costs and benefits of hydrogen and fuel cell technology at identified potential sites. The information in the RCC ensures that planners have the information needed to match a potential application with the most appropriate technology. By ensuring appropriate application of the technology, it is expected that the success rate of these early market applications will be high, which will, through case studies and information sharing, promote additional applications and serve to reinforce the message that hydrogen and fuel cell technology is reliable, safe, and cost effective.

Models & Tools

- Environmental Model
- Economic/Cost Model
- Energy Management Model
- Distributed Technology Comparison
- Hydrogen Generation from Renewable Technology

Presentations

- Fuel Cells for Municipalities Workshop - September 22, 2009

Links

- Connecticut Hydrogen Fuel Cell Coalition - Fuel Cell Information Database
- U.S. Department of Energy - Hydrogen Education
- U.S. Department of Energy - Safety Page
- Introduction to Hydrogen Safety for First Responders
- U.S. Fuel Cell Council
- National Hydrogen Association

Regional Resource Center   U.S. DOE Partnership Building Initiative

Disclaimer

Economic/Cost Model

Microsoft Excel - Fuel_Cell_Economic_Model_06-05-09.xls [Read-Only]

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Reply with Changes... End Review...

A11

U.S. Department of Energy and the Connecticut Center for Advanced Technology Inc. State and Local Government Partnership Building

The economic/cost model assesses potential yearly heating and electricity cost savings when using a fuel cell for baseload power. The model is based upon commercial available baseload fuel cell technologies. Fuel cells used for baseload power should typically not exceed 85% of a facilities load in order to utilize 100% of the fuel cells heat and energy, potential to realiz intended to be a costs of conventi economic analisy Advanced Techno

The model assum facilities electric

To use the model enter the specifie output will display and a combined also displayed to convential and fue

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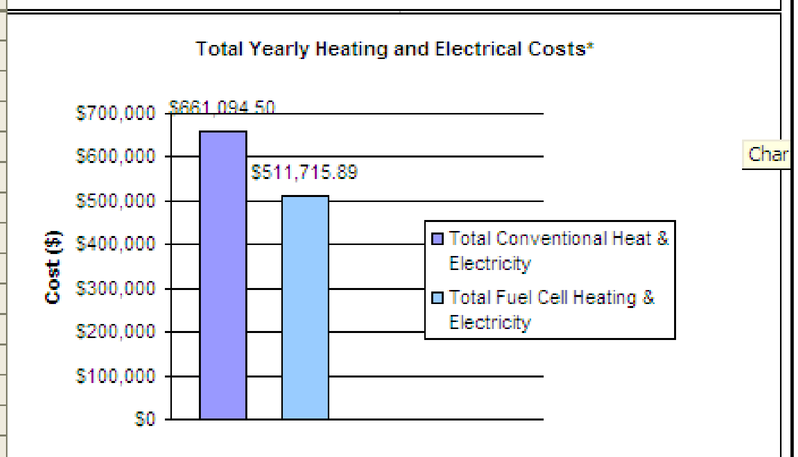

* This analysis assumes 100% use of heat and electricity

	A	B
1	U.S. Department of Energy and the Connecticut Center for Advanced Technology Inc. State and Local Government Partnership Building	
2	**Energy User Profile**	
3	Please Enter Electricity Cost Here (Cents / kWh)	$ 13.00
4	Please Select Heating Fuel Type Here	Natural Gas
5	Enter Your Current Heating Fuel Price Per CCF	$ 1.36
6	Enter Fuel Cell Fuel Price Per CCF (1 ccf = 100 cubic feet of gas)	$ 1.00
7		
8	**Fuel Cell Profile***	
9	**Select Fuel Cell Technology**	400 kW Phosphoric Acid
10	Number of fuel cells	1
11	System Size (kW)	400
12	Capacity Factor (%)	97%
14	Electricity Production (kWh/year)	3,398,880
15	Thermal Output (Btu/hr)	1,560,229
16	*Assumes 100% of the fuel cells heat and electricity is being used.	
17		
18	**Financing and Ancillary Revenues**	
19	Enter Yearly Interest Rate	7%
20	Enter Finance Period (Years)	12
21	Enter State Rebate (Enter Between $0 and $4700/kW)	$ -
22	Federal Tax Credit	$ 360,000.00
23	Yearly Renewable Energy Credits (1 REC = 1MWh of Energy)	$ 101,966.40
24		
25	**Yearly Costs**	

Energy Management Model

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Regional Resource Center - Energy Management Model

The energy management model assesses the efficiency benefits of stationary fuel cell applications. Use the interface below to select the stationary fuel cell output and then select the fuel type to see the fossil fuel equivalent for the potential energy savings using a fuel cell to replace conventional electricity generating technologies.

Choose Fuel Cell Power Output: 300 kW

- (selected) Oil Equivalent Savings (Gal/Year)
- Coal Equivalent Savings (Short Tons)
- Natural Gas Equivalent Savings (CF)

	Btu/kWhr	Oil Equivalent Savings (Gal/Year)	Potential Fuel Cell Specific Savings (MMBtu/Year)
Potential Energy Savings from Replacement of Oil-Fired Generation	4,609	87,219	12,112
Potential Energy Savings from Replacement of Coal-Fired Generation	4,288	81,144	11,269
Potential Energy Savings from Replacement of Natural Gas-Fired Generation	3,976	75,240	10,449
Potential Average Energy Savings from Replacement of Conventional Fossil Fuel Generation	4,171	78,930	10,961

** This is not a life cycle analysis

Sources:
Fuel Cell Economic Development Plan: Hydrogen Roadmap, Connecticut Center for Advanced Technology, Inc, 2008

Regional Resource Center   U.S. DOE Partnership Building Initiative

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Distributed Technology Comparison

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Regional Resource Center - Distributed Technology Comparison

The distributed technology comparison allows a user to compare fuel cells to other distributed technologies including microturbines, combustion turbines, reciprocating engines, photovoltaic systems, and wind turbines. Fuel cells feature the highest efficiency, exceptional heat rates, flexible fuel sources, and low to no emissions. Fuel cells using hydrogen generated from renewable resources are emission free and offer superior efficiency when used in combined heat and power applications.

- (•) Microturbines
- ( ) Combustion Turbines
- ( ) Reciprocating Engines
- ( ) Photovoltaic Systems
- ( ) Wind Turbines

Capstone MicroTurbine

Distributed Technology Comparative Analysis

	Fuel Cells	Microturbines
Size Range (kW)	100 - 2,400	25 - 500
Fuel	Natural gas, hydrogen, landfill gas, digester gas	Natural gas, hydrogen, propane, diesel
Average Efficiency (%)	45	39
Combined Heat and Power Efficiency	✓	✓
Average Installed Cost ($/kW)	5,500	1,000
Average Heat Rate (Btu/kWh)	7,693	12,200
Average O&M Cost ($/kWh)	0.03	0.014
Average Nox Emissions (lb/kWh) (1)	0.000015	0.00049
Average CO2 Emissions (lb/kWh) (1)	0.85	1.19

Hydrogen Generation

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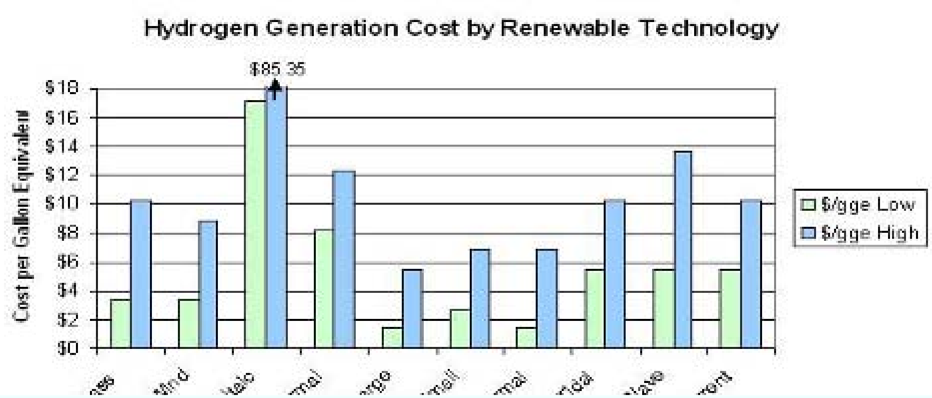
Regional Resource Center - Hydrogen Generation from Renewable Technology*

The table below contains information on the cost of electricity from these renewable technologies and their potential cost to produce hydrogen. The costs are ranged from lowest cost to highest cost available across the globe for each specific electricity generation technology.

Hydrogen Generation from Renewable Technology*

	Price of Electricity		Price per Kilogram		Price per Gallon Equivalent	
	¢/kWh Low	¢/kWh High	$/kg Low	$/kg High	$/gge Low	$/gge High
Biomass	$0.05	$0.15	$3.25	$9.75	$3.41	$10.24
Wind	$0.05	$0.13	$3.25	$8.45	$3.41	$8.88
Solar Photovoltaic	$0.25	$1.25	$16.25	$81.25	$17.07	$85.35
Solar Thermal	$0.12	$0.18	$7.80	$11.70	$8.19	$12.29
Hydroelectricity Large	$0.02	$0.08	$1.30	$5.20	$1.37	$5.46
Hydroelectricity Small	$0.04	$0.10	$2.60	$6.50	$2.73	$6.83
Geothermal	$0.02	$0.10	$1.30	$6.50	$1.37	$6.83
Marine Tidal	$0.08	$0.15	$5.20	$9.75	$5.46	$10.24
Marine Wave	$0.08	$0.20	$5.20	$13.00	$5.46	$13.66
Marine Current	$0.08	$0.15	$5.20	$9.75	$5.46	$10.24
Approximate Cost of Natural Gas Reformation			$2.19	$3.51	$2.30	$3.69

Currently, hydrogen is most commonly produced by steam reformation of natural gas and has proven to be the most cost effective source of hydrogen generation. This is a process in which steam is used to produce hydrogen from natural gas. Learn more here.



Hydrogen Generation

U.S. Department of Energy and the Connecticut Center for Advanced Technology Inc. State and Local Government Partnership Building

Enter Data into the yellow cells then click the link below for results

Wind turbine power will be compared equally among the three renewable technologies (e.g. a 1500kW wind turbine will automatically select 1500kW of photovoltaics and hydroelectric turbines.

Wind Turbine	
Select a Wind Turbine	100 kW (NWD 100)
Unit Rated Capacity (kW)	100
Please select wind class at 50 m (164 ft)	1
No Entry Needed, Value is Disregarded	19.7
Enter Number of Turbines	1
Installed Cost ($/kW)	$1,800
Yearly Maintenance & Miscellaneous Costs (cents/kWh)	$0.01
Enter Capacity Factor (%)	30%
Coefficient of Performance (35% maximum)	25%
Rho (air density lb/f^3)	0.076
Generator Efficiency	80%
Gearbox Bearings Efficiency	95%

Max rated capcity only met at wind speeds greater than ~34 mph

Photovoltaics	
Panel Rated Capacity (kW)	100
Enter Capacity Factor (%)	14%
Yearly Maintenance Cost ($/kWh)	$0.008
Installed Cost ($/kW)	$7,400

Hydroelectric	
Enter the estimated **average** flow rate of water based on peak flows	70
Enter Pressure Head Height (Feet)	50
System efficiency (%)	54%
Capacity Factor (%)	50%
Yearly Maintenance Cost ($/kW)	$100
Installed Cost ($/kW)	$2,500
Turbine Power (Horsepower)	103.95
Turbine Power (kW)	77.52
Number of Turbines Needed	2
kWh/Year	679,036

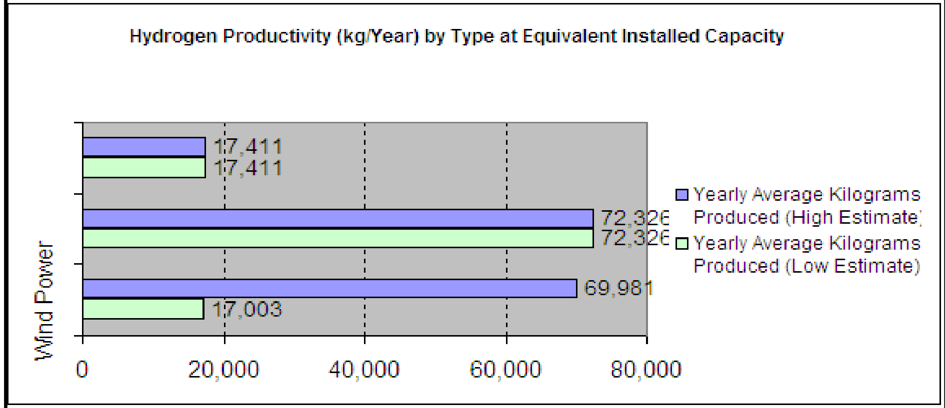
Cubic

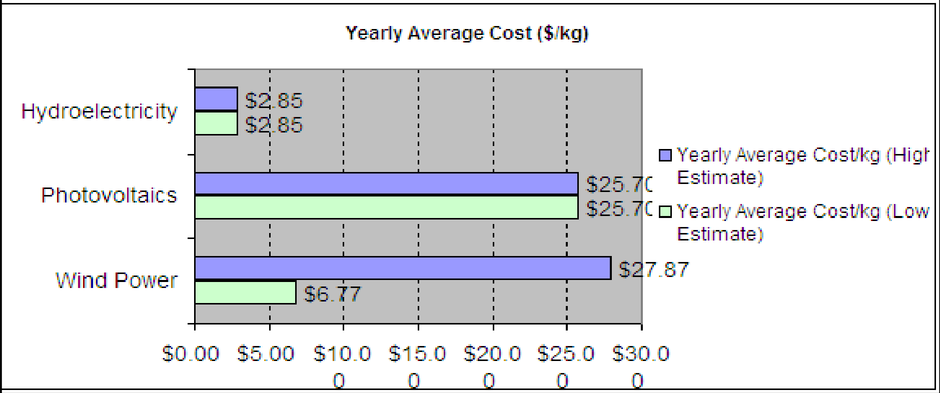
Financial Assumptions	Wind Turbine	Photovoltaics	Hydroelectric
Interest Rate	7%	7%	7%
% Debt	100%	100%	100%
Finance Term (Years)	15	15	15

Energy Production Costs	Wind Turbine	Photovoltaics	Hydroelectric
Yearly Debt Payment	$446,537.88	$1,835,766.86	$41,820.70
Yearly			

U.S. Department of Energy and the Connecticut Center for Advanced Technology Inc. State and Local Government Partnership Building

	Yearly Average Kilograms Produced (Low Estimate)	Yearly Average Kilograms Produced (High Estimate)
Wind Power	17,003	69,981
Photovoltaics	72,326	72,326
Hydroelectricity	17,411	17,411
	Yearly Average Cost/kg (Low Estimate)	**Yearly Average Cost/kg (High Estimate)**
Wind Power	$6.77	$27.87
Photovoltaics	$25.70	$25.70
Hydroelectricity	$2.85	$2.85





Environmental Model

December 8th, 2009

Connecticut Center for Advanced Technology, Inc.

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Regional Resource Center - Environmental Model

The environmental model assesses the environmental benefits of hydrogen and fuel cell applications compared with other conventional technologies. Use the interface below to select either the stationary or transportation application, then choose the power output or vehicle type to find out the potential emissions reductions using hydrogen and fuel cell technology.

Choose Application: Stationary

Choose Power Output: 400 kW

Click here for results

Stationary power is the most mature application for fuel cells. Stationary fuel cell units are used for backup power, power for remote locations, stand-alone power plants for towns and cities, distributed generation for buildings, and co-generation (in which excess thermal energy from electricity generation is used for heat).

STATIONARY OUTPUT *

Potential Average Annual Emissions Reductions Using Fuel Cell Technology Compared to Existing New England Fossil Fuel Electric Generation

NOx (lbs)	3,523.20
SO2 (lbs)	12,938.78
CO2 (lbs)	2,814,966.43
Oil Equivalent Energy Savings (gal)	105,240.49

* Based on the use of natural gas

Environmental Model

- Energy Overview
  - Services
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Choose Application: Transportation

Choose Vehicle Comparison: Transit Bus

Enter Expected Number of Miles Driven: 30000

Click here for results

Fuel cells can be used to provide propulsion or auxiliary power for many transportation applications. Aside from spacecraft, which typically use alkaline fuel cells for onboard power, polymer electrolyte membrane (PEM) fuel cells are the primary type used in transportation.

TRANSPORTATION OUTPUT *

Potential Emissions Reductions Using Hydrogen Fuel Cell Propulsion Systems When Compared To A Transit Bus

NOx (lbs)	826.734
SO2 (lbs)	1.416
CO2 (lbs)	148,329.216
Gallon Equivalent Savings	3,510

* Model assumes availability of hydrogen from renewable resources

Comparison of Conventional Technology to Fuel Cell Technology

Conventional Transit Bus mile per gallon	3.86
Fuel Cell Transit Bus mile per gallon equivalent	7.04

Potential Partners

- Connecticut Center for Advanced Technology
- Connecticut Clean Energy Fund
- Connecticut Siting Council
- Northeast Utilities
- United Illuminating
- FuelCell Energy
- UTC Power
- U.S. Department of Energy

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