



MARKET OPPORTUNITIES FOR A DISTRIBUTED BASE LOAD WIND/HYDROGEN POWER PLANT

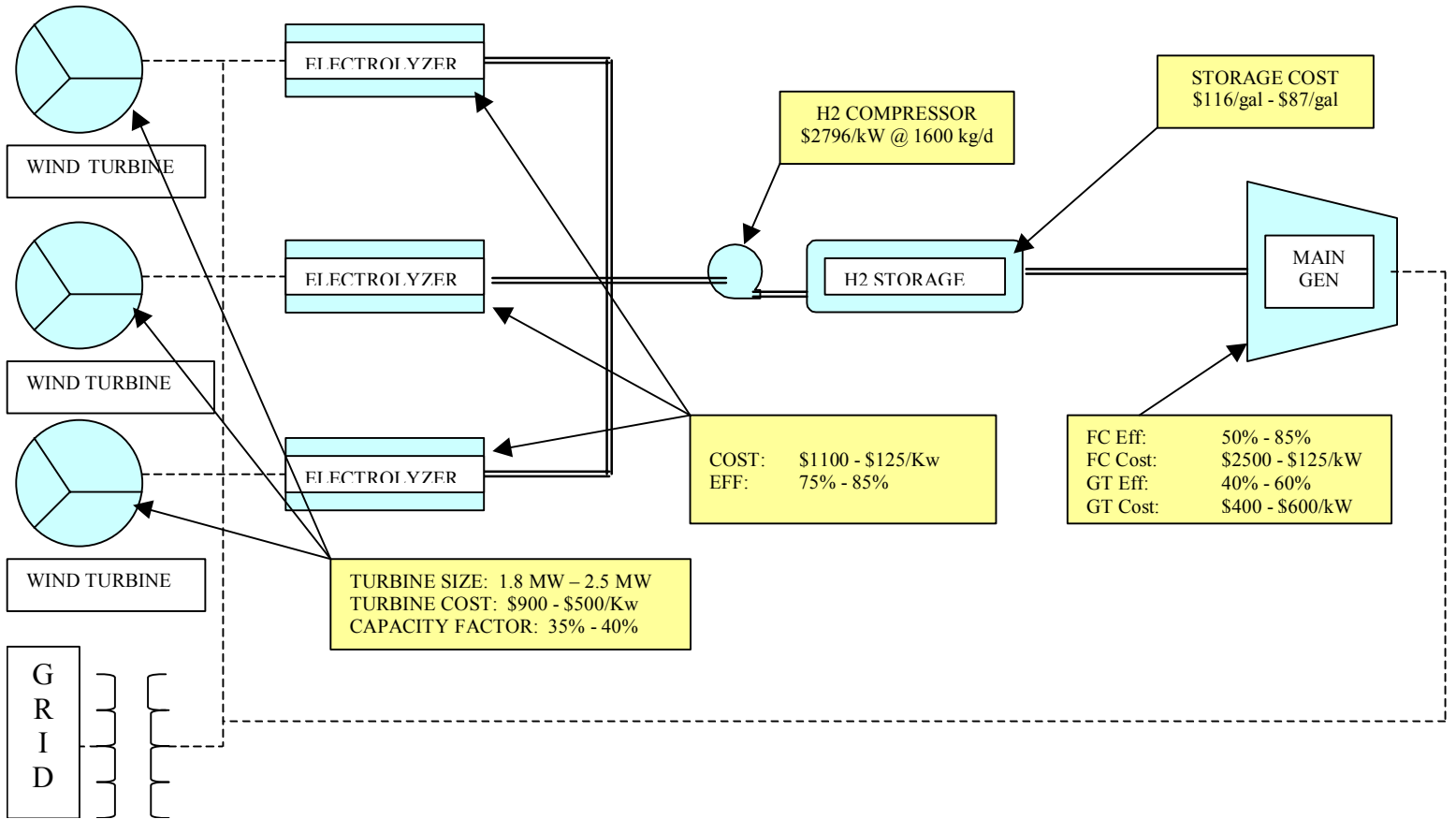
By Mike Michaud

Topics of Presentation

- Wind Hydrogen Power Plant Concept
- Modeling Assumptions & Basis
- Financial Analysis
- Limitations of Analysis
- Base Load Plant Costs
- Transmission system Benefits
- Policy Options

Wind Hydrogen Power Plant Concept

- “Fixes” Wind Intermittency Issue
- Only Input Energy is the Wind
- Wind Electricity Used in An Electrolyzer
- Hydrogen stored as Gas
- Hydrogen Fed to a Fuel Cell or Gas Turbine to produce Firm On-Peak Power



Modeling Assumptions & Basis

- Used National Academy of Engineering Hydrogen Study Data for Component Costs & Conversion Efficiency: “*The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs,*” (2004).
- Examined Both Existing & Future Technologies
- Design for 5 MWe Firm Power, 8 Hours/Day
- Fuel Cell or Gas Turbine for Main 5 MW Generator
- Modeled With & Without Tax Credits

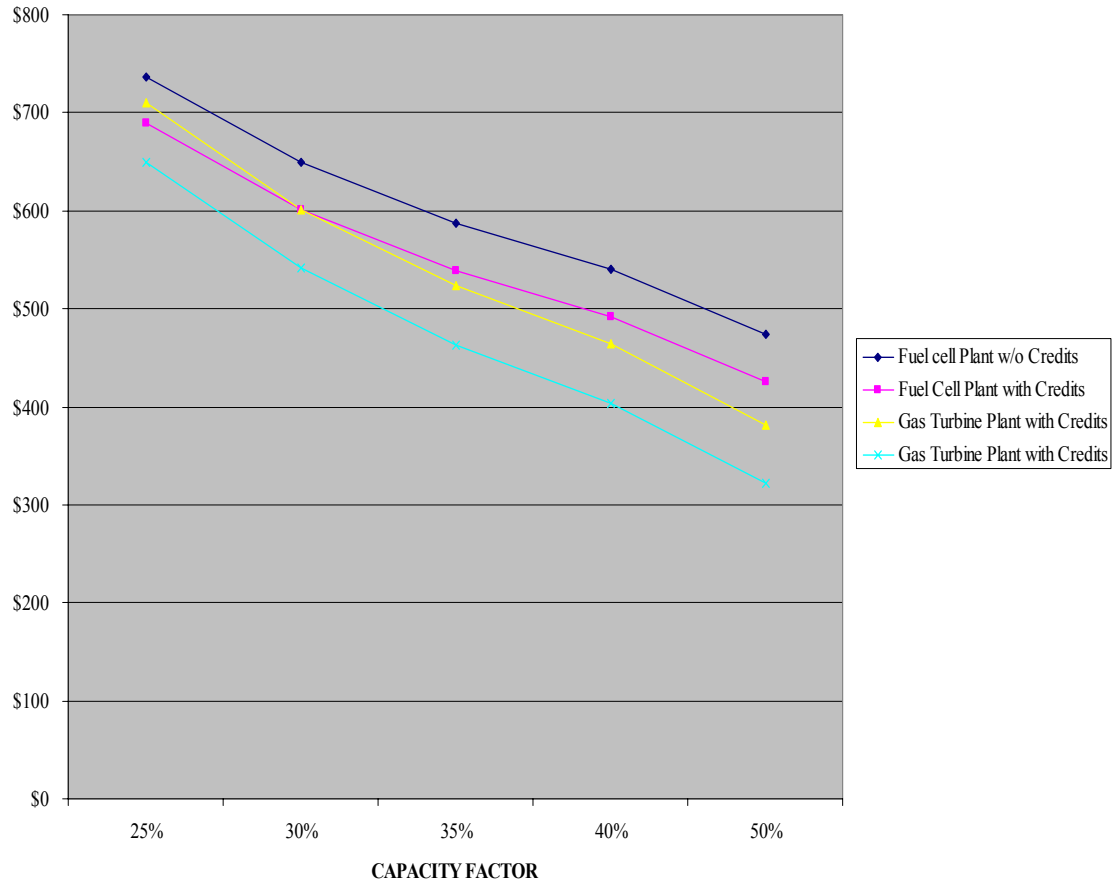
Financial Analysis

- Model Internalized Wind Energy Power Cost
- Finance Period Existing Scenarios: 10%-30 Years
- Finance Period Future Scenarios: 5%-30 Years
- Calculated Annualized Cost of kW-hrs
- Examined Impacts of Production Tax Credits
- Compared Cost of Energy to Midwest Wholesale Power Market Prices

Summary of Model Input Parameters

	PRESENT SCENARIOS	FUTURE SCENARIOS
Wind Turbine Installed cost	\$900/kW	\$500/kW
Wind Turbine Capacity Factor	35 %	40 %
Wind Turbine Size	1.8 MW	2.5 MW
Electrolyzer Cost	\$1,100/kW	\$125/kW
Electrolyzer Efficiency	75 %	85 %
H ₂ Compression	\$2796/kW @ 1600kg/day	\$2796/kW @ 1600kg/day
Gas Storage Cost	\$116/gal phy vol	\$87/gal phy vol
Gas Turbine Cost	\$400/kW	\$600/kW
Gas Turbine Efficiency	40 %	60%
Fuel Cell Cost	\$2,500/kW	\$125/kW
Fuel Cell Efficiency	50%	85%
Power Conditioning	\$100/kW	\$100/kW
Plant Operation Time	8 hours/day	8 hours/day
Nominal Interest Rate	10 %	5 %
Service life	30 years	30 years

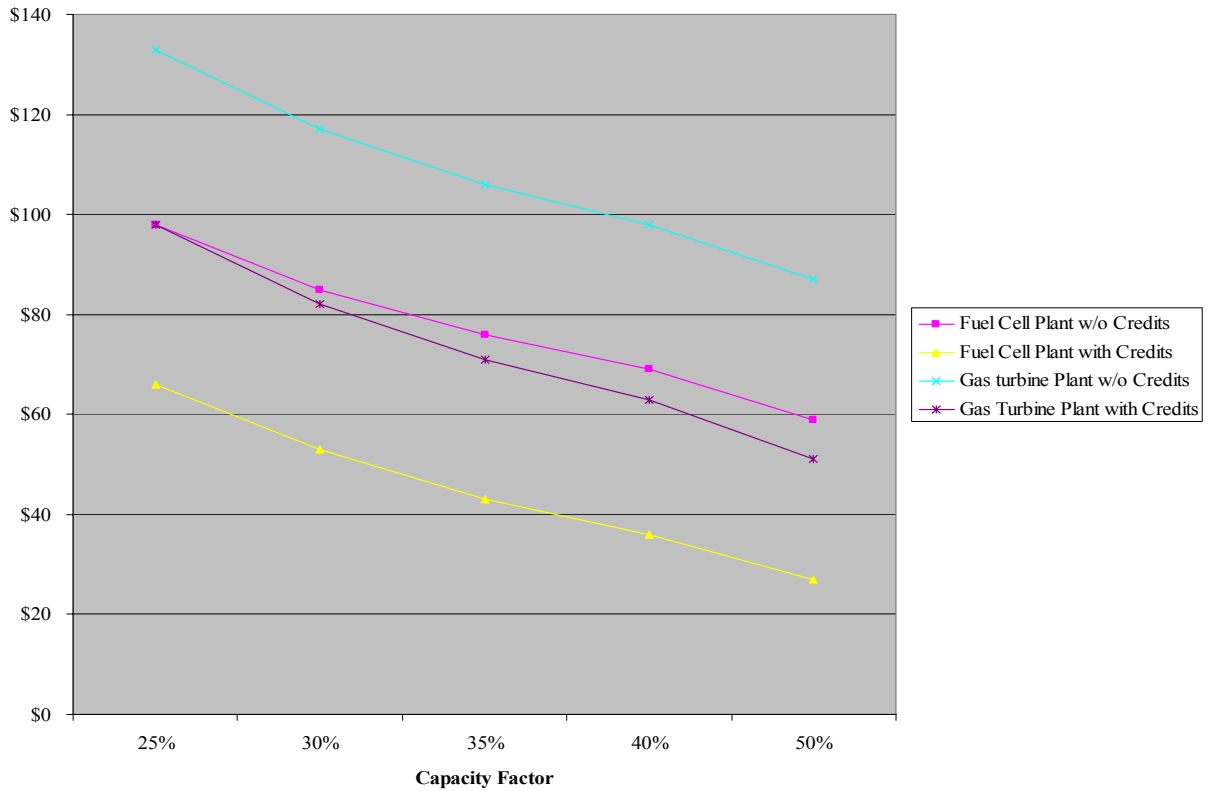
EXISTING ENERGY COST (\$/MW-hr) vs TURBINE CAPACITY FACTOR



Existing Technology Cost Summary

	TOTAL CAPITAL COST	TOTAL COST/KW	ANNUALIZED ENERGY COST/ MW-HR
Fuel cell Plant w/o Credits	\$63,304,068	\$12,660	\$587
Fuel Cell Plant w Credits	\$63,304,068	\$12,660	\$539
Gas Turbine Plant w/o Credits	\$56,395,353	\$11,279	\$523
Gas Turbine Plant w Credits	\$56,395,353	\$11,279	\$463

FUTURE ENERGY COST (\$/MW-hr) vs TURBINE CAPACITY FACTOR

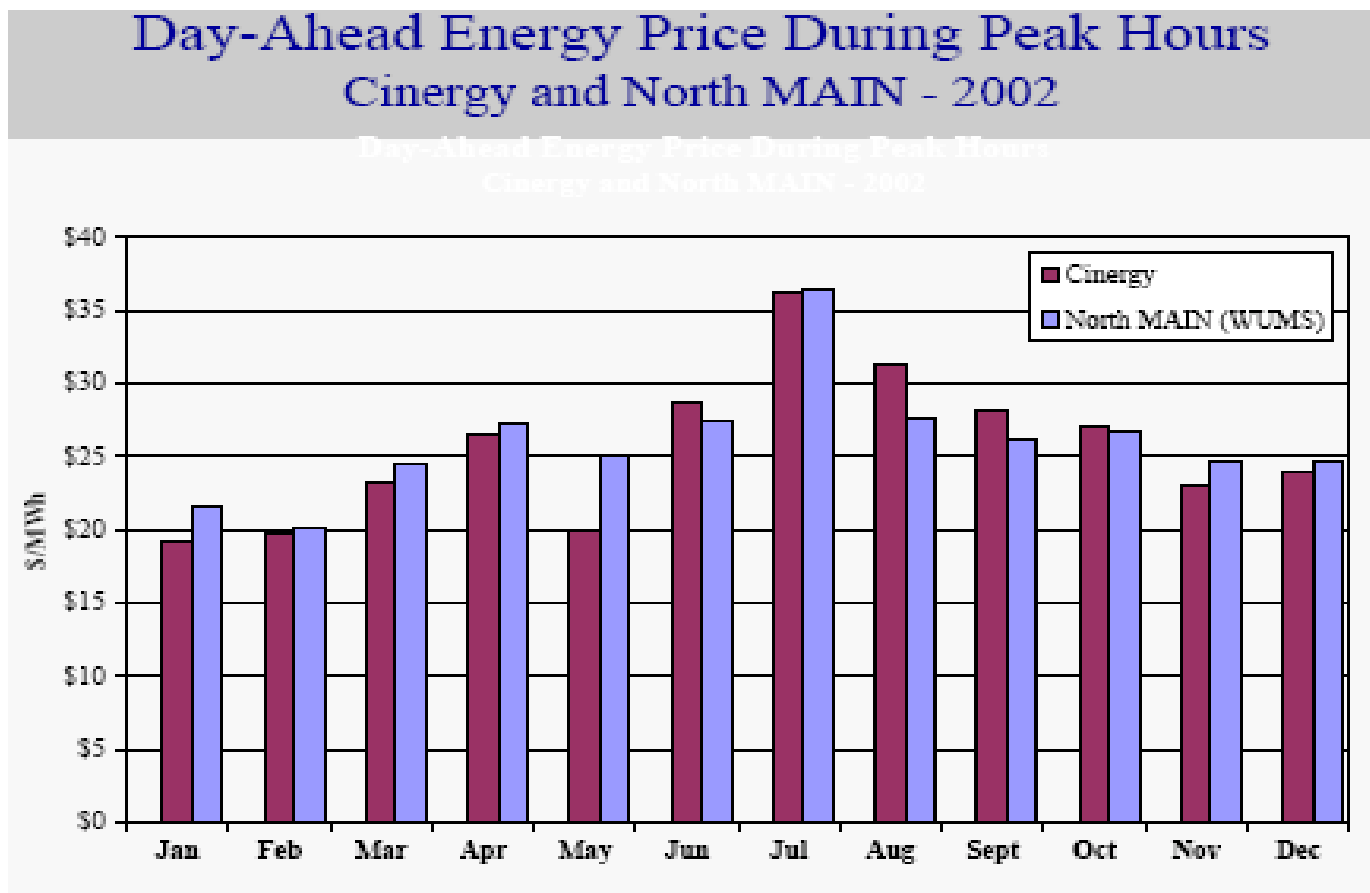


Future Technology Cost Summary

	TOTAL CAPITAL COST	TOTAL COST/KW	ANNUALIZED ENERGY COST/ MW-HR
Fuel cell Plant w/o Credits	\$10,681,434	\$2136	\$69
Fuel cell Plant with Credits	\$10,681,434	\$2136	\$36
Gas Turbine Plant w/o Credits	\$15,192,516	\$3038	\$98
Gas Turbine Plant with Credits	\$15,192,516	\$3038	\$63

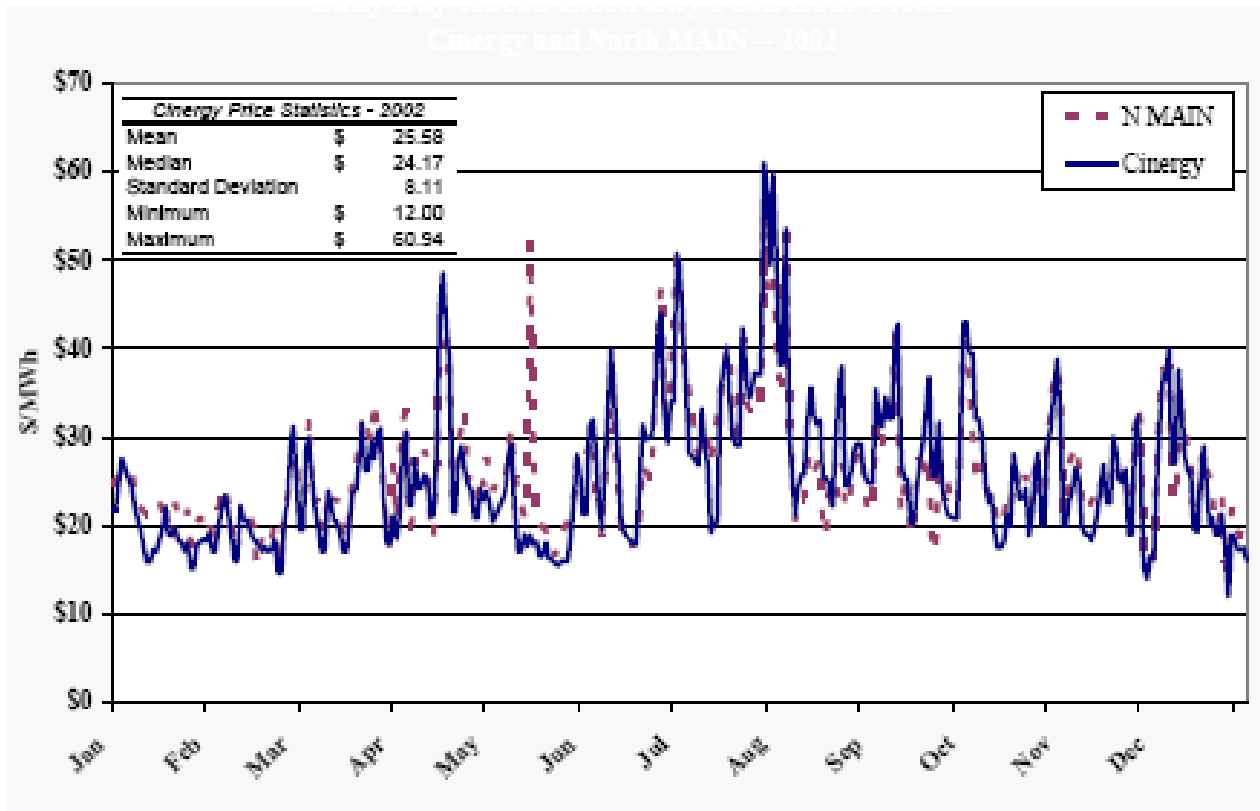
DAY-AHEAD AVERAGE MARKET PRICES 2002

“2002 State of the Market Report”, MISO, April 2003



Day-Ahead Peak Hour Prices, Cinergy and North MAIN

“2002 State of the Market Report”, MISO, April 2003



Financial Analysis Results

- Existing Technologies Cannot Compete in Market
- Both of the Future Models, with Fuel Cell and Gas Turbines are Competitive

Limitations of Analysis

- Optimistic Finance Assumptions Impact Energy Cost
- Thermal Energy Recovery Not Examined
- Water Side Components Not Included
- Storage Volume Not Correlated to Wind Availability
- Technology Innovations Are Not Guaranteed
- Future Variation in Wholesale Market Price?

Implications of Analysis

- The Combination of Low Cost Renewable Wind Energy, Hydrogen Storage, and Fuel Cells is Extremely Promising as a Firm Energy Source
- Policy Shifts To Support This Technology Are Prerequisites to its Widespread Deployment

WHAT ABOUT COMBINING WIND/H₂ PLANTS?

- Staggering Hourly Delivery Schedules Produces Firm Power over More Hours/Day
- Intermediate and Base Load Plants become Possible
- Cost/ MW-hr Does NOT Change
- 5 MW Plants Can Be Sited Near Load At Distribution Substations

New Base Load Technology?

- Increase the Storage Volume Size and the Number of Turbines
- No Change To Main Generator Required, Just Run It 24 Hours
- Improved Cost Efficiencies in Hardware

Future Base Load Plant Costs

	Total 8 Hr CAPITAL COST	Total 24 Hr CAPITAL COST	Total 8 hr COST/kW	Total 24 hr COST/kW	8 hr ANNUAL ENERGY COST/ MW-HR	24 hr ANNUAL ENERGY COST/ MW-HR
FC Plant w/o Credits	\$10.6 M	\$28.4 M	\$2136	\$5681	\$69	\$61
FC Plant with Credits	\$10.6 M	\$28.4 M	\$2136	\$5681	\$36	\$29
GT Plant w/o Credits	\$15.2 M	\$36.0 M	\$3038	\$7192	\$98	\$78
GT Plant with Credits	\$15.2 M	\$36.0 M	\$3038	\$7192	\$63	\$42

Transmission System Benefits

- Constraint Management
- Value Added to “Conditional Firm” Service
- Can Continue to Build Wind Plants in Outlet Capacity restricted Zones
- Increases Efficiency of Line Use by Flattening the Line Loading Duration Curve

Technology Policy Options

- Support Research into Technology Optimization
- Construct Demonstration Facility
- Education & Information Dissemination
- Stakeholder Involvement is a Crucial Element
- Develop Industry Standards & Permitting
- Integrate Technology Into Resource Planning