The Hype About Hydrogen
The Mainstream Analytic View

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Clean Energy Advocate

- Former Acting Assistant Secretary of Energy
  - Led a 10x increase in hydrogen, 3x in fuel cells
  - Oversaw DOE alternative fuels/vehicles effort
  - Led U.S. GHG-mitigation technology strategy
- Principal, Capital E Group, www.cap-e.com
  - We work with companies and VCs on fuel cells, clean energy, distributed generation….
- Exec Dir, Center for Energy & Climate Soltns

The Hype About Hydrogen

- Started as a primer
- Talked to 100 experts, looked at 100 studies
  - Now a steady stream of good analysis
- Strong consensus of independent analysts
  - Continued R&D is valuable.
  - Stationary fuel cells very promising (esp. high-temp)
  - For H2 cars as a climate solution, *think post-2035*.

Mainstream Scientific View

"Fuel-cell cars, in contrast [to hybrids], are expected on about the same schedule as NASA's manned trip to Mars and have about the same level of likelihood."

Scientific American

May 2004

Mainstream Analytic View

- "… promoting alternative fuels would be a costly strategy for reducing emissions."

  Dept. of Transportation, Final Report, 9/03
  Fuel Options for Reducing GHGs

- "Hydrogen is neither the easiest nor the cheapest way to gain large near- and medium-term air pollution, greenhouse gas, or oil reduction benefits." Sperling and Ogden, UC Davis, Spring 04

The Climate Can't Wait for Hydrogen

- Even "in the advanced technology case with a carbon constraint … hydrogen doesn't penetrate the transportation sector in a major way until *after 2035*." Jae Edmonds et al., PNNL, 2/04
- Before then, H2 cars likely to *increase* GHGs.
  - Zero-CO2 H2 cars avoid CO2 at cost of *$700/ton!*

E.C. Joint Research Center & EUCAR, 1/04

The Global Warming Century

10° F

Recent Climate Developments

- New analysis shows satellite data confirms global warming
  - Troposphere is warming faster than the surface
- CO2 concentrations growing rapidly
  - Annual rate of over last three years exceeds annual growth rate over last decade by 64%

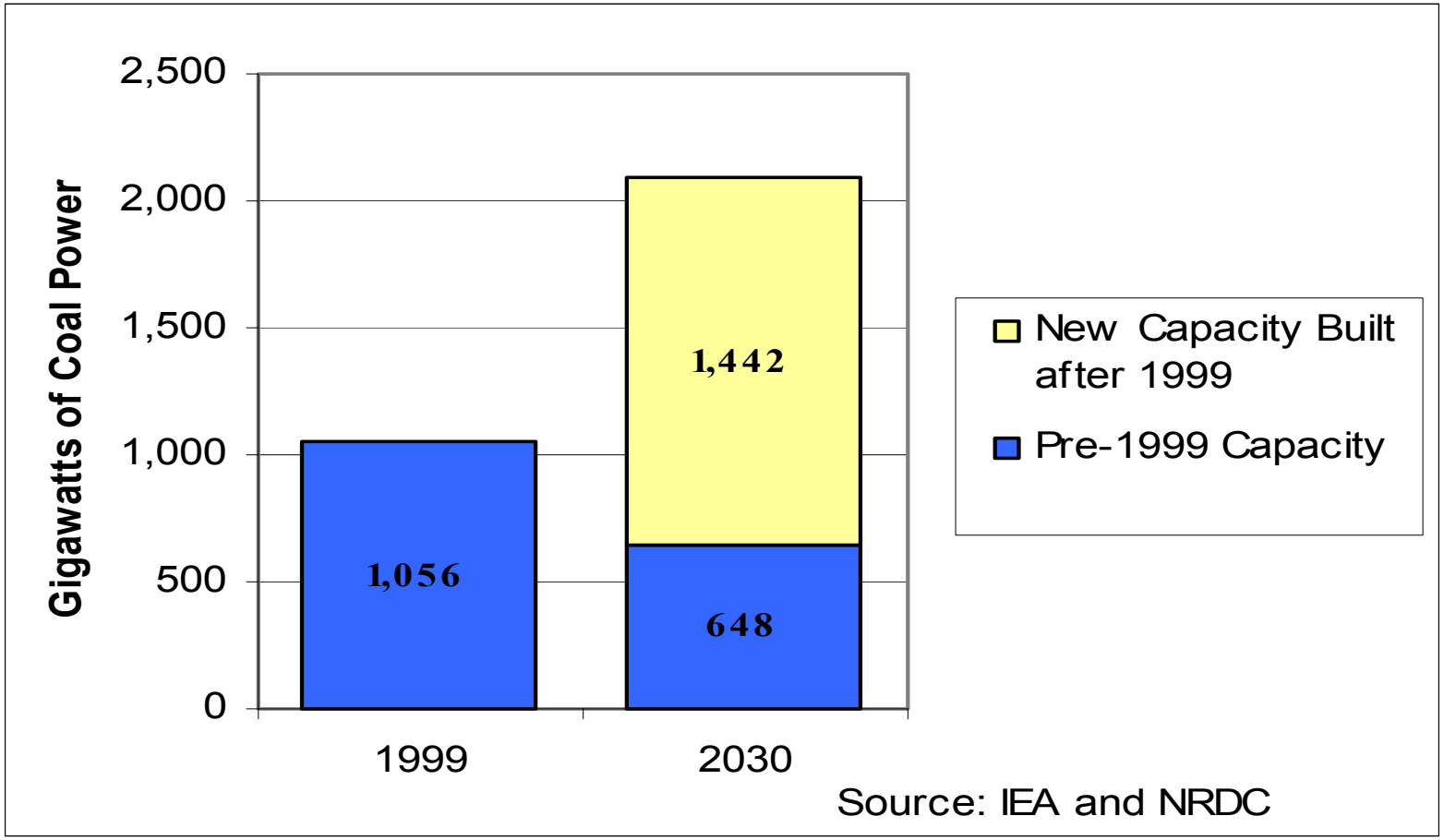
Climate Action is Inevitable

- “It is clear that Kyoto is not radical enough.”

  -- Prime Minister Blair 2/03

- Calls for 60% reductions in CO2 by 2050.

2/3 of 2030 Coal Plants not yet Built



Five Vehicle Strategies to Reduce Pollution and Oil Use

- Efficiency
- Hydrogen
- Electricity
- Biofuels
- Synthetic Diesel Fuels (with sequestration)

Hydrogen is like Electricity

- Both are energy carriers
  - 95% of H2 in U.S. is made from CH4
- Neither are inherently good for environment
  - Promoting H2 use is like promoting electricity use
- Green electricity is, however, much more affordable than green hydrogen

For the Foreseeable Future

- H2 cars will generate more GHG, NOx, PM, and mercury emissions than Prius does *today*.
- Renewable energy (and natural gas) deliver far more emissions reductions, far more cheaply, making electricity than making hydrogen.

Hype Hurts

"Exaggerated claims have damaged the credibility of alternate transportation fuels, and have retarded acceptance, especially by large commercial purchasers."

Energy Policy, 2002

AFV Lessons From 1990s

- 0.5% of all vehicles today after much effort
- Reasons from 2000 GAO Report:

  "*the relatively low price of gasoline, the lack of refueling stations for alternative fuels, and the additional cost to purchase these vehicles.*"

- Will we learn from history?

The 7 Barriers to AFVs

1) High first cost for vehicle
2) Storage (i.e. limited range)
3) Safety and liability
4) High fueling cost (compared to gasoline)
5) Limited fuel stations: Chicken & egg problem
6) Not a cost-effective pollution-reducer
7) Tough competition: Hybrids (e.g. Prius)

Barrier 1: Fuel Cell Cost

- PEM engines cost ~$4000/kw. Need <$50/kw *while* increasing durability 4x, maintaining high efficiency, addressing heat rejection….
- This ~100x drop could take decades
  - PV, wind took 20 years for a 10x drop
- Major technology breakthrough needed

FCs must beat $100/kw to compete

"Even with the most optimistic assumptions, the fuel cell powered vehicle offers only a marginal efficiency improvement over the advanced CI/hybrid and with no anticipation yet of future developments of IC engines. At $100/kW, the fuel cell does not offer a short term advantage even in a European market."

Oppenheim (UCB) and Schock (MSU),
Society of Automotive Engineers, 2004

Barrier 2: The Storage Showstopper?

- "The DOE should halt efforts on high-pressure tanks and cryogenic liquid storage…. They have little promise of long-term practicality for light-duty vehicles." (NRC, 2/04)
- "We're not even close to solving storage technology issues yet." (Toyota, 2/04)
- "*A new material must be discovered*." (APS 3/04)

High-Pressure Storage

- 10,000 psi
- 7x+ gas tank size (4x with FCV efficiency)
- Currently very expensive tanks
- 15% energy penalty
- Costly, unreliable multi-stage compressors
- Safety concerns
- Greatly limits fueling locations

Barrier 3: Safety and Liability

- Hydrogen: Good safety record in industry BECAUSE of onerous codes and standard.
- The typical fueling "station violates all safety regulations for hydrogen and no sensible zoning board would permit it, if made aware of the facts."

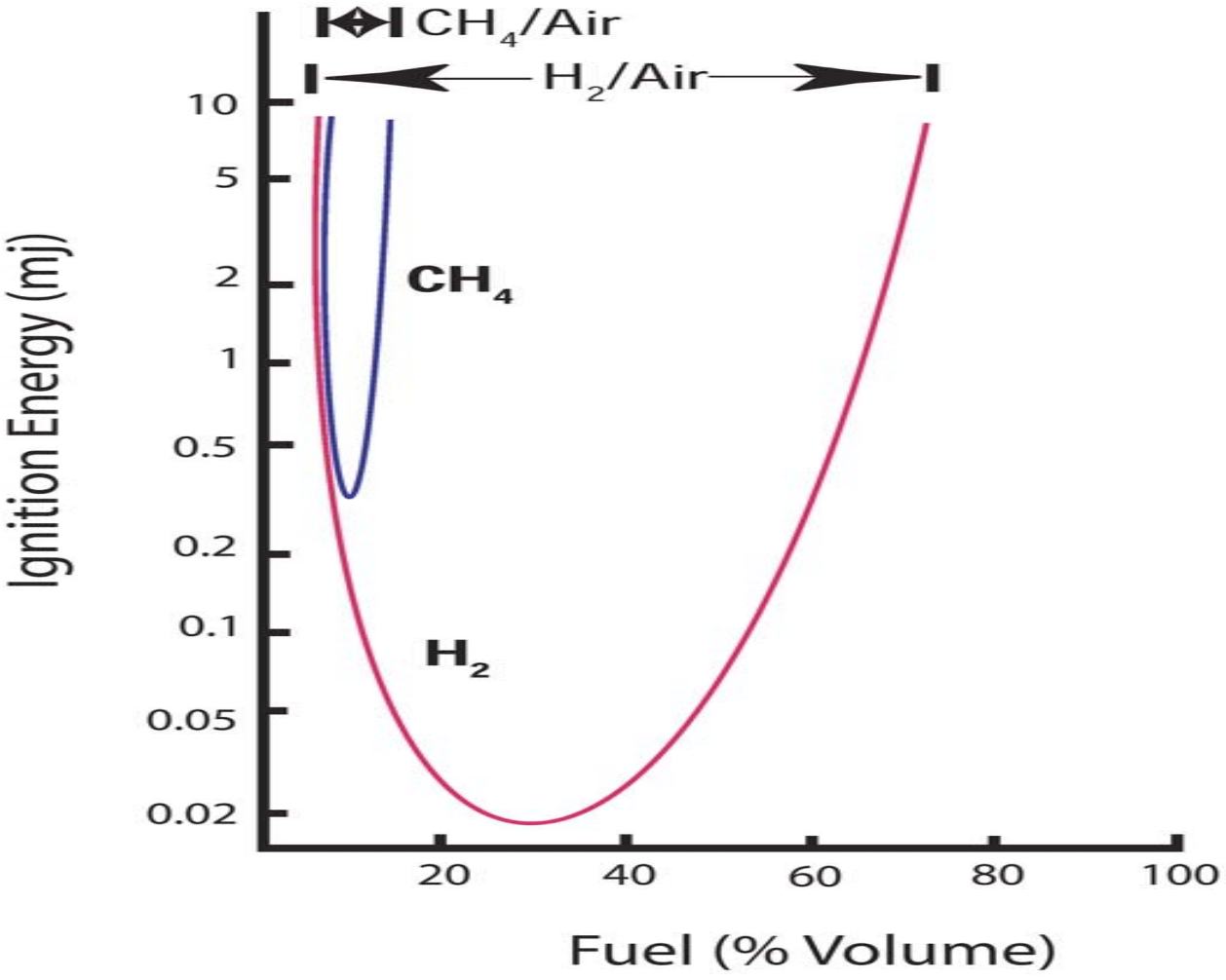
  Reuel Shinnar, Prof. Chem. Engineering

  Technology in Society (2003)
- Need new storage technology

Unusually Dangerous Fuel

- Some benefits (won't splatter, pool), BUT
- Very leaky
- Odorless (probably unfixable)
- Invisible and burns invisibly
  - "A broom has been used for locating small hydrogen fires."
- Highly flammable (cell phone, lightning)
- HENCE: Onerous codes and standards.
- High-pressure hydrogen leaks can self-ignite.

H2 Much More Dangerous than CH4



Liability Issues are Serious

"… it is difficult to imagine how hydrogen risks can be managed acceptably by the general public when wide-scale deployment of the safety precautions would be costly and public compliance impossible to ensure."

Russell Moy, Ford's former group leader for energy storage programs
Energy Law Journal, 11/03

Barrier 4: Most Expensive Alt. Fuel

- "The daily drive to work in a hydrogen fuel cell car will cost four times more than in an electric or hybrid vehicle." (Ulf Bossel, 3/04)
- H2 from CH4, grid: $4 to $8+ gallon equiv.
- "Green" H2: $8+ gallon equiv.
- Will consumers accept the high price of H2?
- Will early adopters accept dirty H2?

H_2 Production with Pipeline Delivery (ND-Chicago)

500 MW
$1000/kW
util. 40%

200 MW

200 MW
$1000/kW
η ~75%

O_2 Gas

3 gal/kg H_2

4500 kg (150 MWh)
$100/kWh

Hydrogen
Buffer Storage

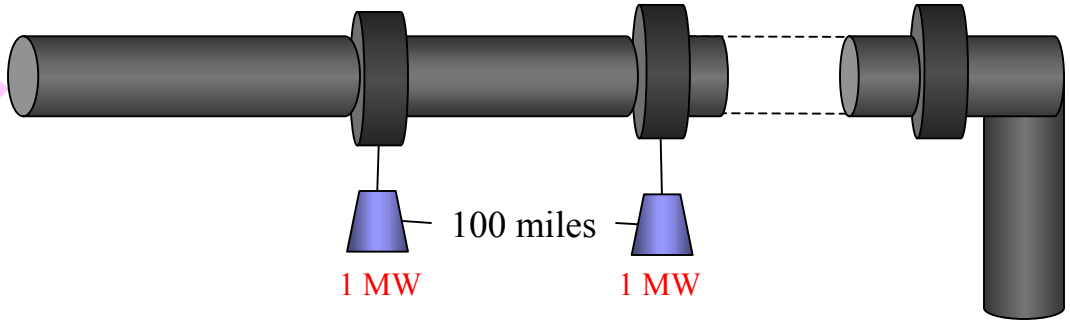
350 bar

6 MW
$1000/kW
η ~80%

4500 kg/hr, 25 bar

North Dakota - Chicago
1000 miles

North Dakota-Chicago: 1000 miles
Hydrogen pipeline
10" Diameter, 25 bar
$1MM /mile
η ~85% (1000 miles)



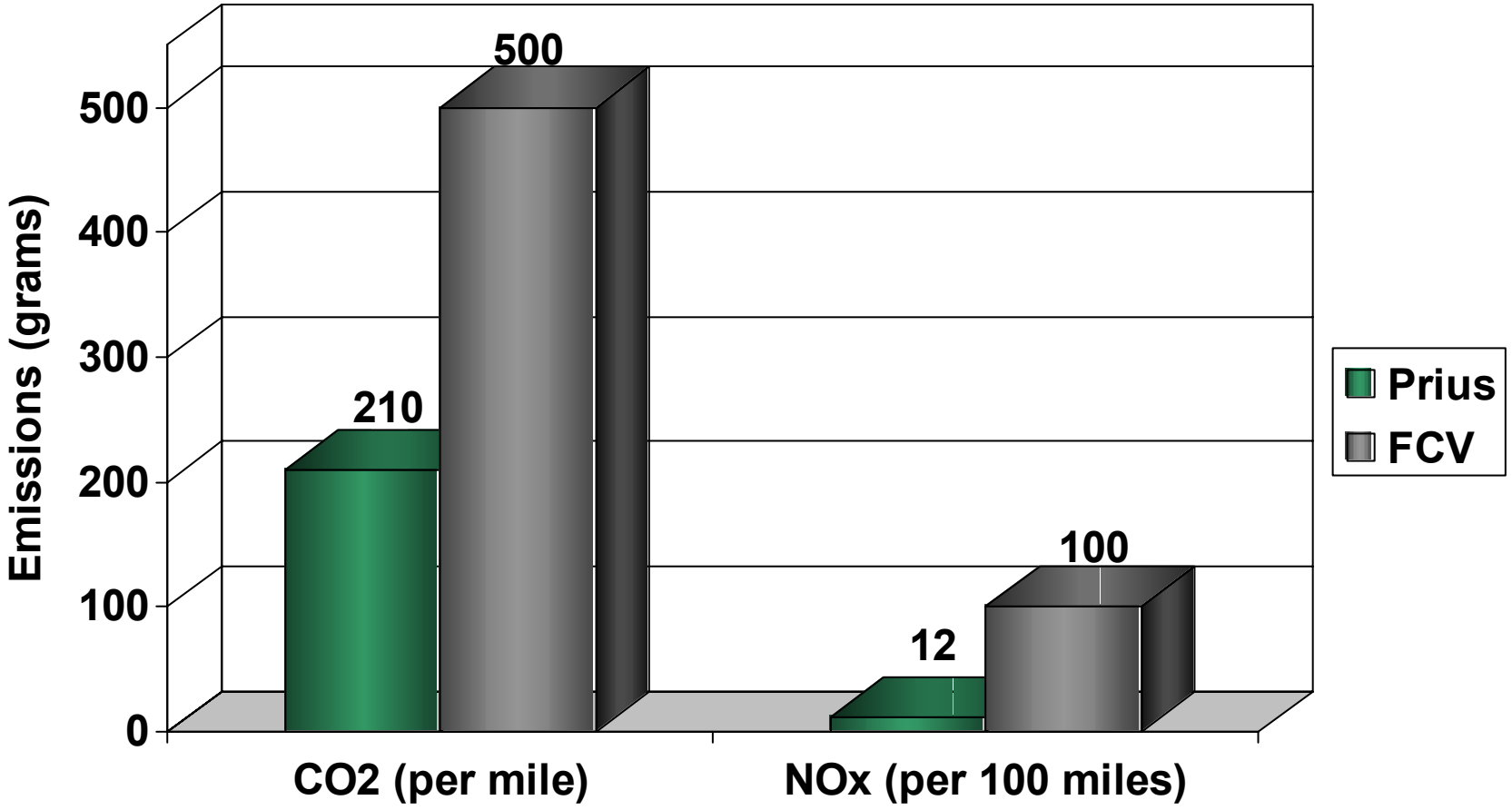
H_2 production:
91,809 kg/day
@ $8.9/kg

Water Consumption
324,000 gal/day

Source: General Electric, 9-03

Gasoline Prius vs H2 FCV Emissions

(H2 from grid electrolysis)



NRC on Hydrogen Transition

"But in no prior case has the government attempted to promote the replacement of an entire, mature, networked energy infrastructure before market forces did the job. The magnitude of change required … exceeds by a wide margin that of previous transitions in which the government has intervened."

Whither Natural Gas Vehicles?

- "The largest problem the NGV industry faced in Canada was *a stalling in investment in public refueling facilities*, which in turn retarded [vehicle] conversion sales. Investment in new refueling facilities stalled because existing stations did not build up sufficient load to make them profitable."

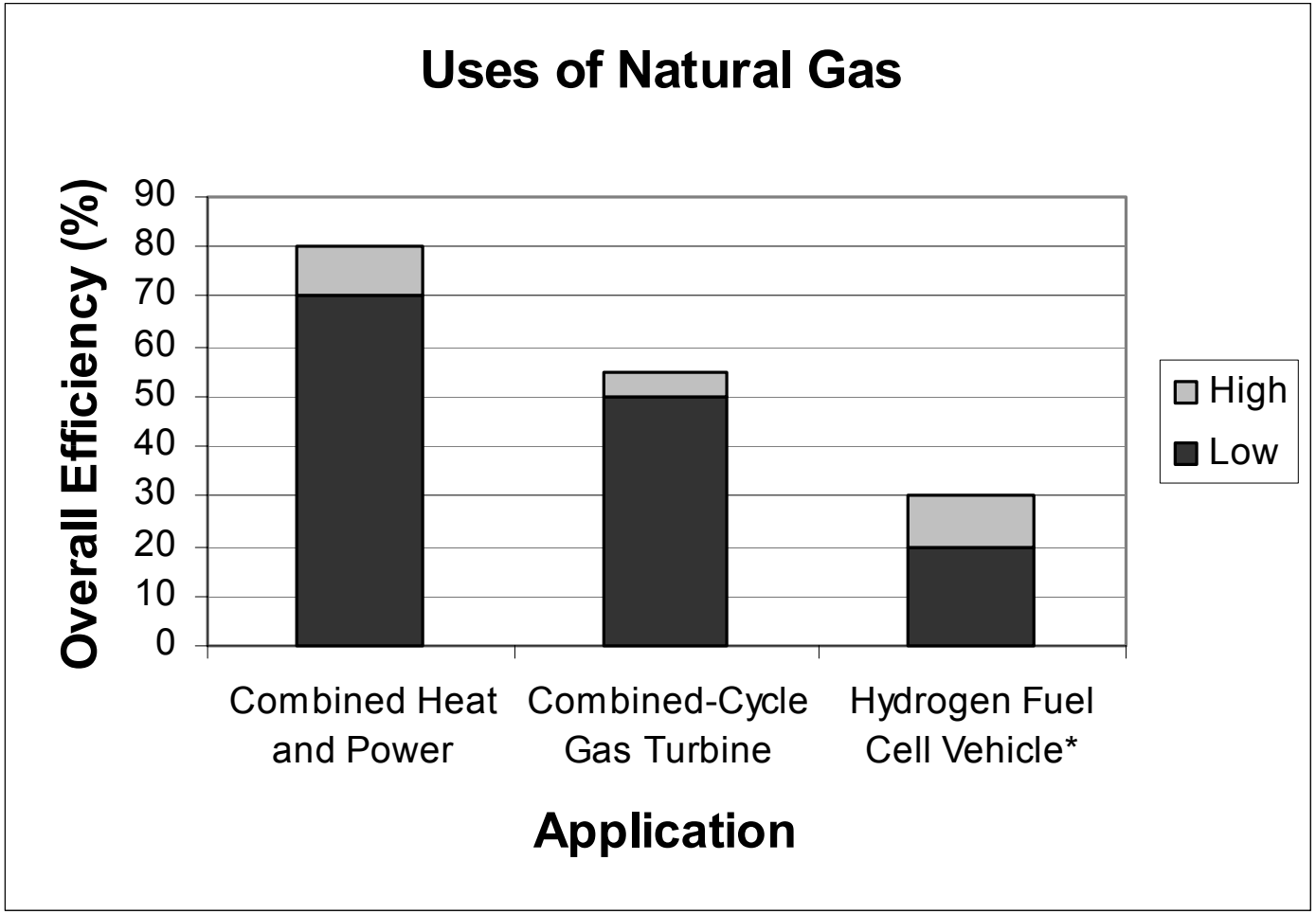
  Energy Policy, 2002

Barrier 5: Chicken-and-Egg Problem

- BP: 30% to 50% fuel station coverage needed from day one
- Argonne: $600 billion infrastructure cost
- Shell: “hundreds of billions of dollars”
- Who’ll build infrastructure without cars on the road *and* vice versa?

Shell Plan for Fuel Stations (11/03)

- $20 billion covers 2% of cars on H2
- $5000+ per car initially
- ¼ Onsite electrolysis
- ¼ Onsite methane reforming
- ¼ Trucked in liquid
- ¼ Trucked in gas
  - 40,000 kg truck delivers 400 kg of H2

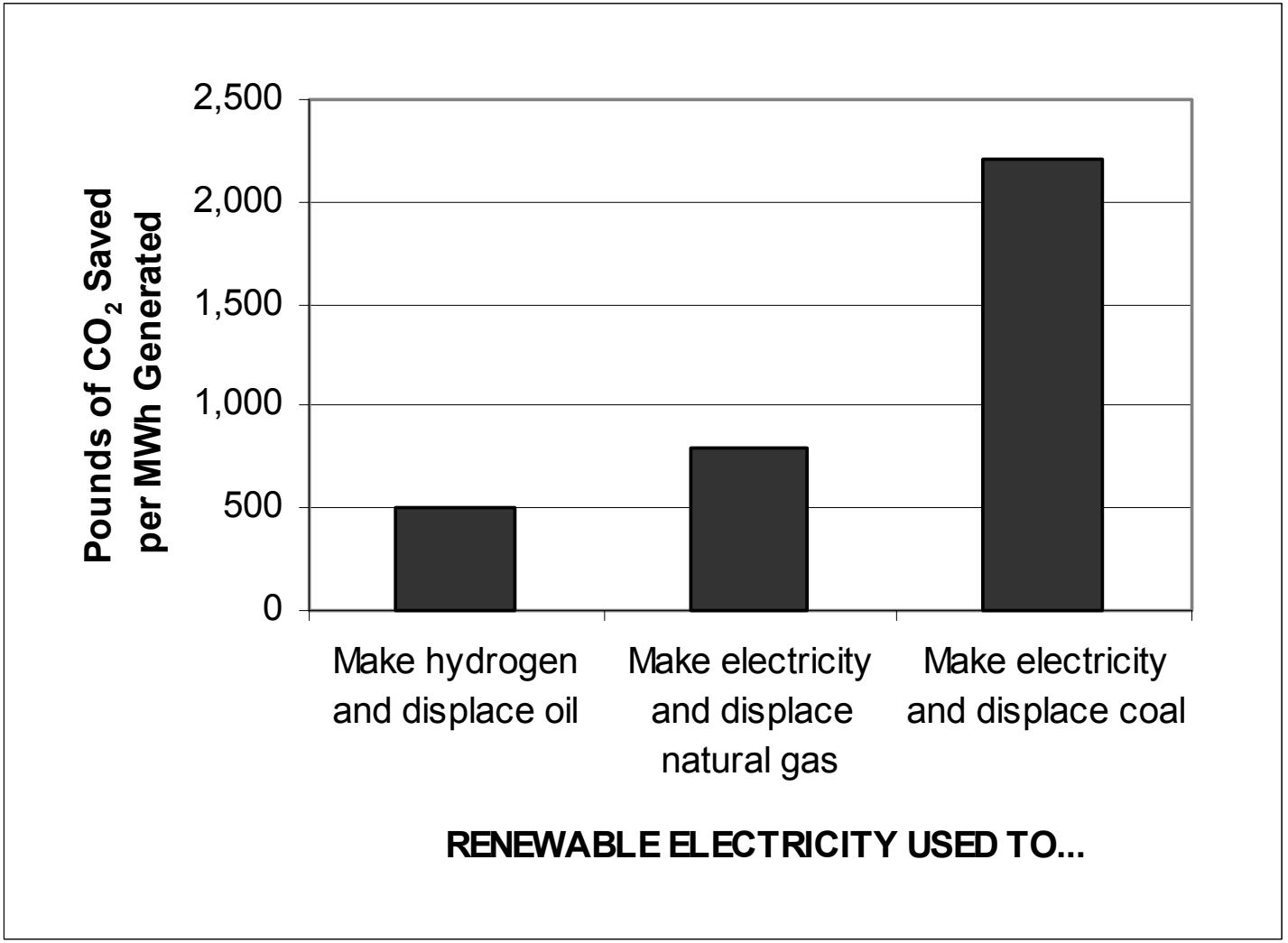

Uses of Natural Gas
Overall Efficiency (%)
90
80
70
60
50
40
30
20
10
0
Combined Heat and Power
Combined-Cycle Gas Turbine
Hydrogen Fuel Cell Vehicle*
Application
High
Low

Will Fuel Cell Cars Power Homes?

- Uneconomical Power
- Environmentally Inefficient
- Major safety issues
- Unlikely carmakers will design such cars
- In sum, probably not

Barrier 6: H2 not a CO2-saver pre-2035

- "It is highly likely that fossil fuels will be the principal sources of hydrogen for several decades." (NRC 2/04)
- H2 cars can't help fight global warming until:
  - After "CO2 emissions from electricity generation are virtually eliminated…." (*Science*, 7/03)
  - After "there is a surplus of renewable electricity." (UK Study, 1/03)

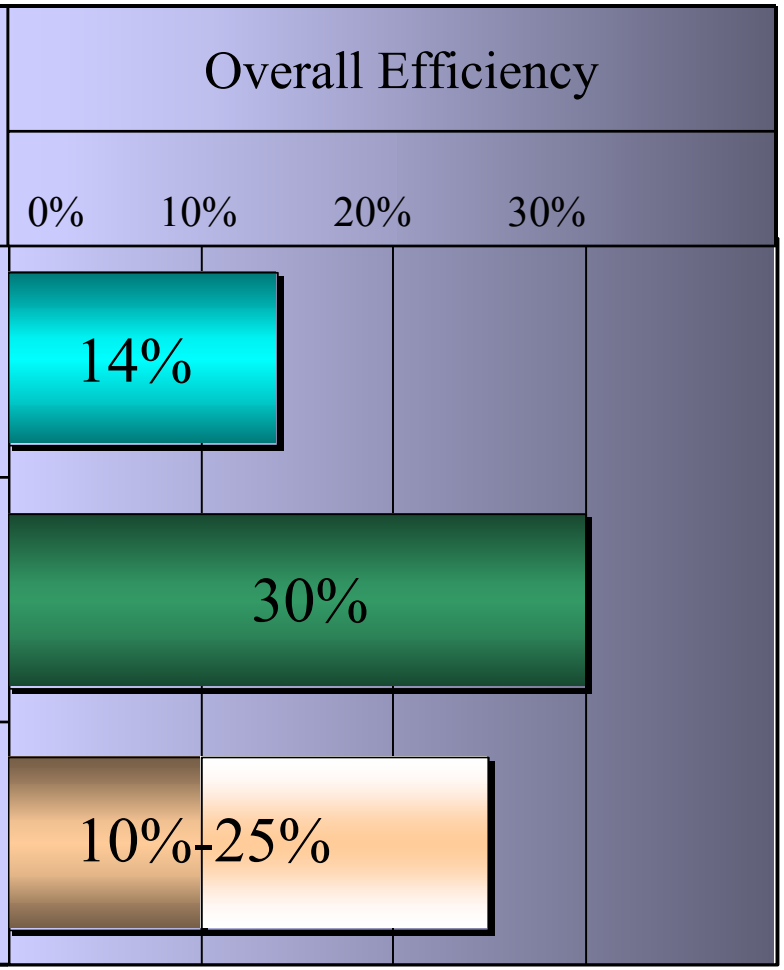

Pounds of CO_2 Saved per MWh Generated
2,500
2,000
1,500
1,000
500
0
Make hydrogen and displace oil
Make electricity and displace natural gas
Make electricity and displace coal
RENEWABLE ELECTRICITY USED TO...

Barrier 7: The Competition (today)

- Compared to hybrid PZEVs like the Prius:
  - FC: Will cost more ($20,000+)
  - FC: 3x+ annual fuel bill (5x+ green H)
  - FC: 1/3 range (and less roomy)
  - FC: Limited fueling options
  - FC: Major safety and liability issues
  - FC: NOT greener
  - Likely through 2025 if not much longer

Prius is Tough to Beat

	Fuel Efficiency	Vehicle Efficiency	Overall Efficiency
Average 2004 Car	80%	18%	14%
2004 Toyota Prius	80%	37%	30%
Fuel Cell Vehicle*	20%-50%	50%	10%-25%



Sources: Toyota, Argonne, CECS

The Future Competition: Efficiency

- Improved gasoline-hybrids
- Carbon-fiber lightweighting
- Diesels
  - 40% of new cars in Europe
- Hybrid diesels
  - 100 km/liter VW city car
- Fleet mix

Business Week 4/17/04

- "We think the importance of fuel economy will only increase. We will push for more hybrids."
  William Clay Ford, Jr.
- "Progress [toward hydrogen] is slower than people realized. We're in favor of the hybrid because it works today." James Press, COO Toyota USA
- "I frankly do not view hybrids as the future transportation solution." GM Vice-Chair Robert Lutz

The Future Competition: Biofuels

- Crop/food waste
- Dedicated non-corn feedstocks
- Why use biomass for H2?
  - More efficient conversion to ethanol
  - Make use of existing infrastructure/engines
- Prius on E85 = 300 mpg car.

The Future Competition: UZEVs

- Urban zero-emission vehicles = Plug-in hybrids
  - Over time, the hybrid battery will be bigger, better
  - More and more gasoline will be displaced
  - Run the car pure-electric in cities
- Why use future clean electricity for H2?
  - UZEV uses electricity 3 to 4 times more efficiently
  - Make use of existing infrastructure/vehicles

EPA 2003 ZEV Certifications:

Fuel Cell Vehicle Electric Vehicle

50 miles/kg H2

60 kWh/kg 30 kWh/100mi

1.2 kWh/mi ⟷ 0.3 kWh/mi

Fuel cell vehicle uses four times as much electricity per mile

2003 Honda FCX	
Miles per kilogram of hydrogen **51** city **48** hwy Annual Fuel Cost: **$1515***	
EPA Air Pollution Score	Best 10 (0 – 10)
Range	170 miles
Fuel	Hydrogen
Fuel Cell	Polymer Electrolyte Membrane
Motor	60 kW DC
Energy Storage Device	Ultracapacitor
*Annual fuel cost is estimated assuming 15000 miles of travel per year (55% city and 45% highway) and a fuel cost of $5.05 per kilogram of gaseous hydrogen.	

2003 Toyota RAV4 EV

Electric Vehicle

Possible Tax Incentives

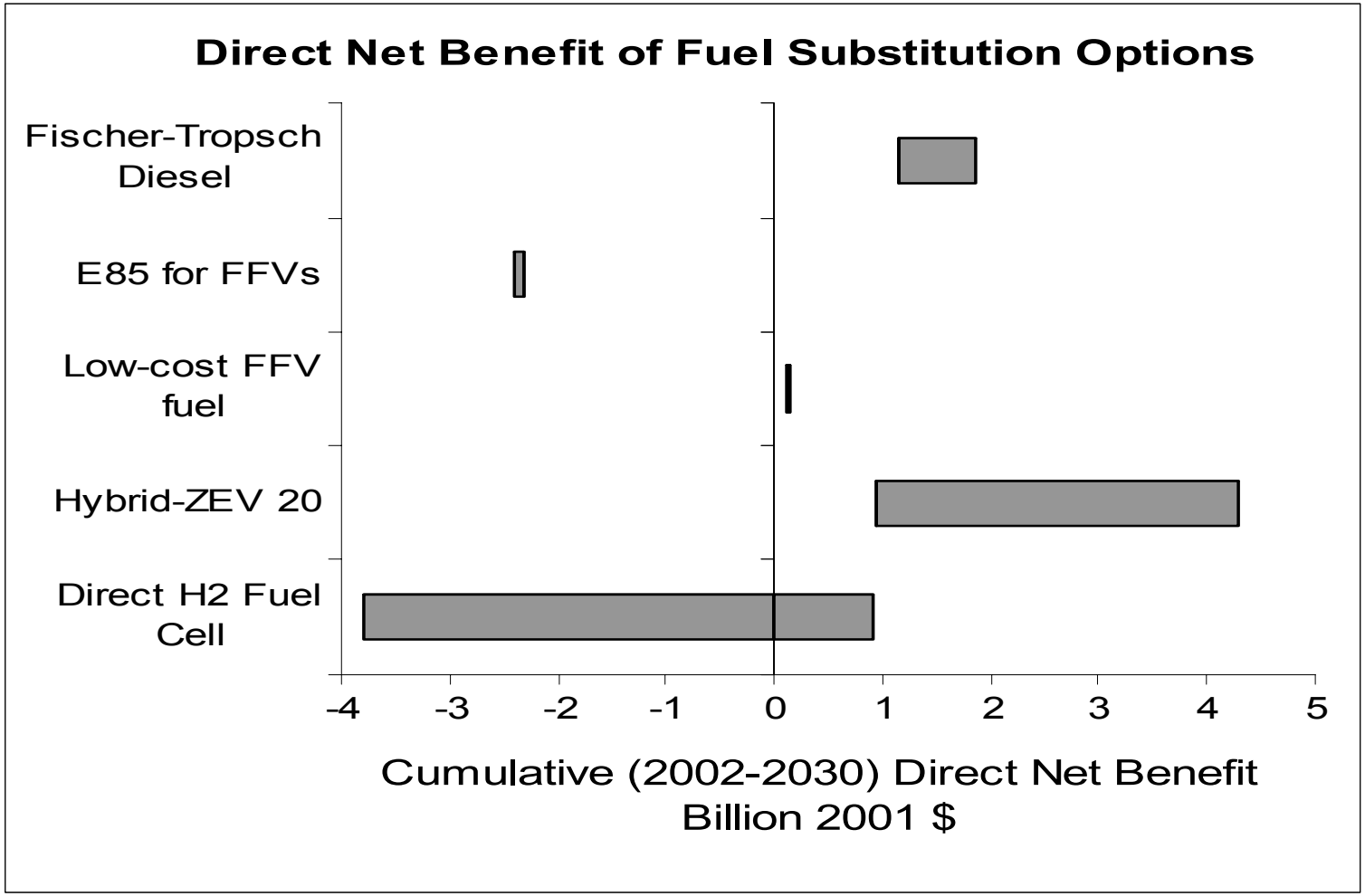
Use your Gas Prices Switch to Metric units

Fuel Economy	
Fuel Type	Electricity
Energy Consumption(city) (kW-hrs/100 miles)	**27**
Energy Consumption(hwy) (kW-hrs/100 miles)	**34**
MPG (city)	**125**
MPG (highway)	**100**
MPG (combined)	**112**
Annual Fuel Cost	**$362**

ZEVs need hybrid technology

- ZEVs need batteries, electric drives….
  - Fuel cell vehicles
  - Battery electric vehicles
  - Plug-in hybrids
- So, if a zero-tailpipe emission ZEV is the goal, the road goes through the hybrid AT PZEV

CA Energy Commission & Air Board 8/03



Bottom Line I

- Continued R&D is important
  - "Revolutionary breakthroughs" needed. (APS 3-04)
  - "Success is not certain." (NRC chair 3-04)
- Understand that FCVs could be a technological dead-end
- Don't base business investment on belief H2 cars will have commercial success by 2025.

Bottom Line II

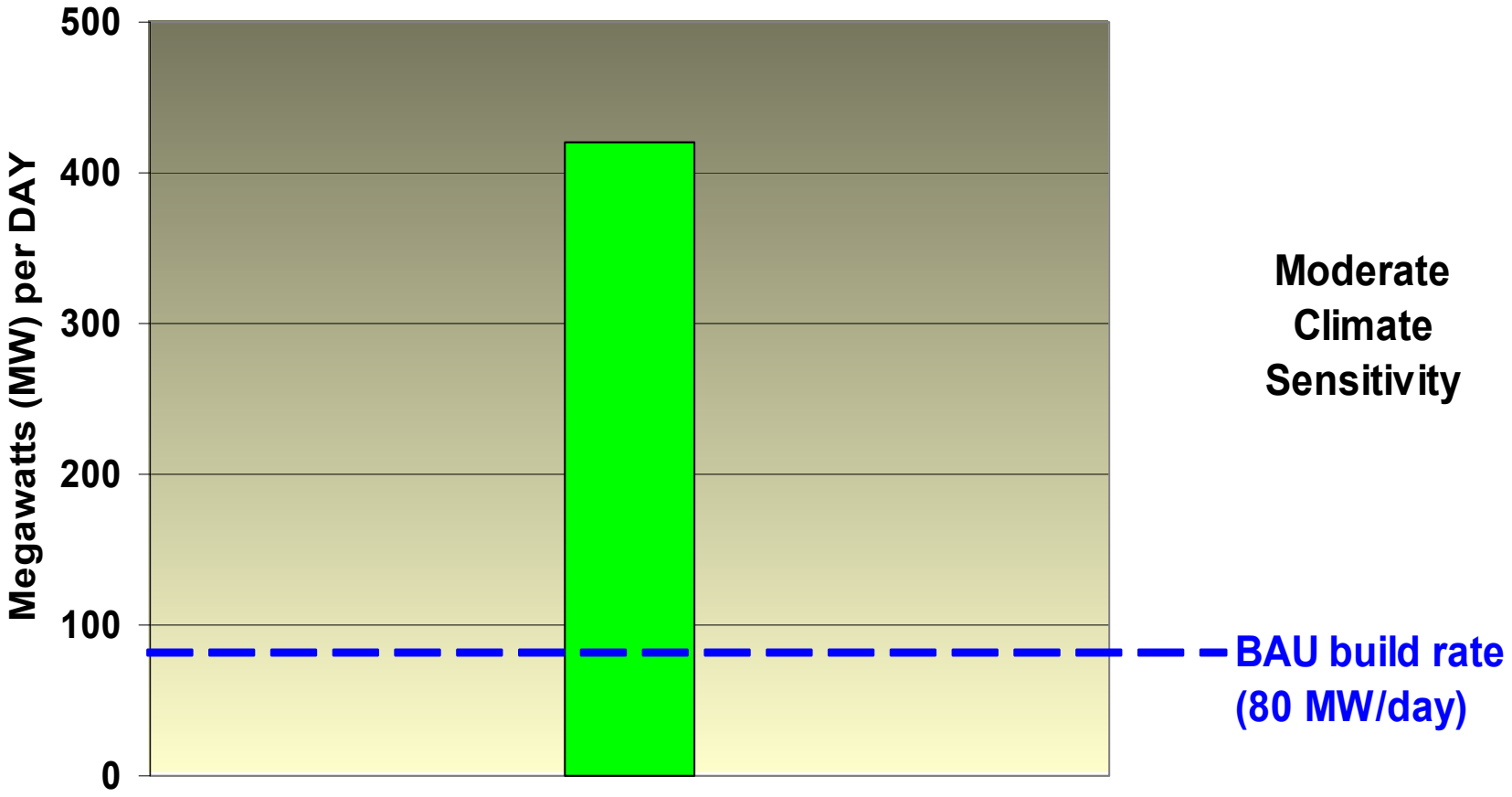
"The forced transition to a hydrogen economy may prevent the establishment of a sustainable energy economy based on intelligent use of precious renewable resources."

Ulf Bossel, 3/04

Bottom Line for Policymakers

- For serious $$$ to H2 cars and infrastructure, think post-2025.
- Hydrogen ICEs are *bad* for the environment
- Hydrogen highway is 20+ years premature.
- FCVs *only* environmental benefit is in cities.
- Don’t put all your ZEV eggs in FCV basket.

Clean Energy Build Rate to Stabilize at *7.2 degrees F* Warming Globally



Sources: *Science* (3/03), IEA, NRDC