Rumning the World on Renewables:
Alternatives to Electricity for
Transmission, Firming Storage, and
Supply Integration of Large-scale
Stranded, Renewable Energy

World Renewable Energy Forum, Denver
Forum 0835, Session 20659
14 May 12, 1030 – 1145
Energy Generation, Distribution, & Transportation

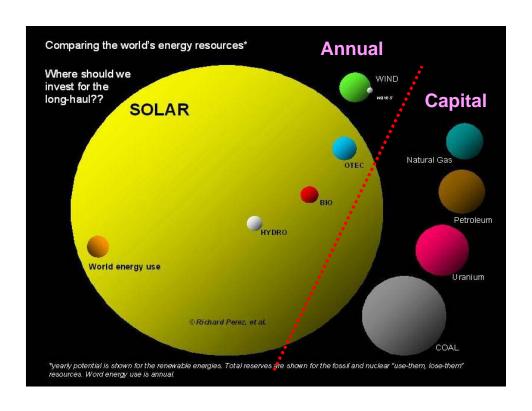
Chair: Bill Leighty, Director
The Leighty Foundation, Juneau, Alaska
wleighty @earthlink.net
907-586-1426 206-719-5554 cell

Panelists

(see Bio handout sheet)

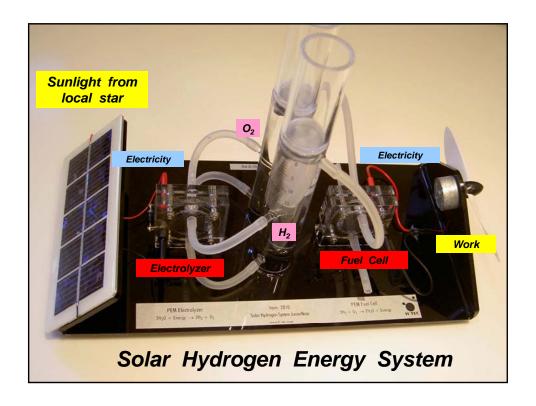
- Prof Mark Z. Jacobson, Stanford University
- Stephen Crolius, Clinton Climate Initiative, RI
- Eddie Sturman, Sturman Industries, Colorado
- Robin McIntosh, Smart Pipe, Houston
- Denis Hayes, Bullitt Foundation, Seattle





Beyond "Smart Grid"

- Primarily DSM
- More vulnerable to cyberattack?
- Adds no physical:
 - Transmission, gathering, distribution
 - Storage
- Next big thing; panacea
- Enable run the world on renewables?
- Must think:
 - Beyond electricity
 - Complete energy systems

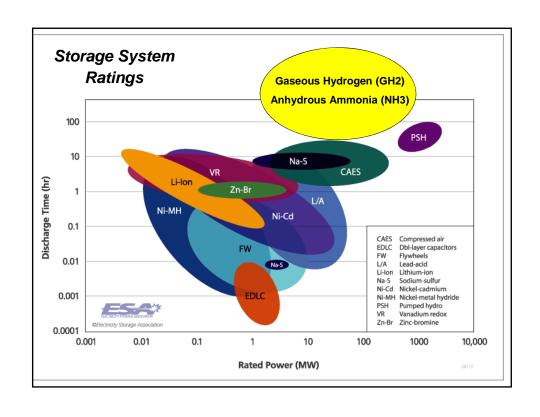


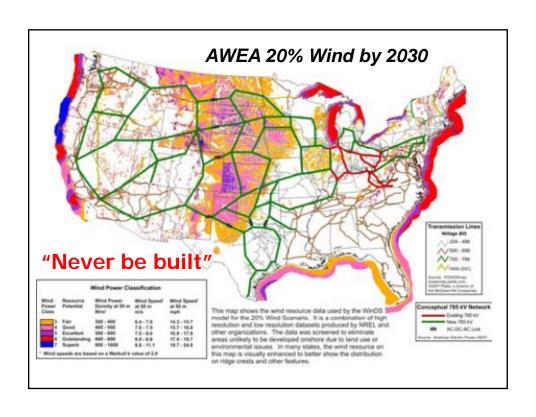
Hydrogen and Ammonia Systems and Fuels

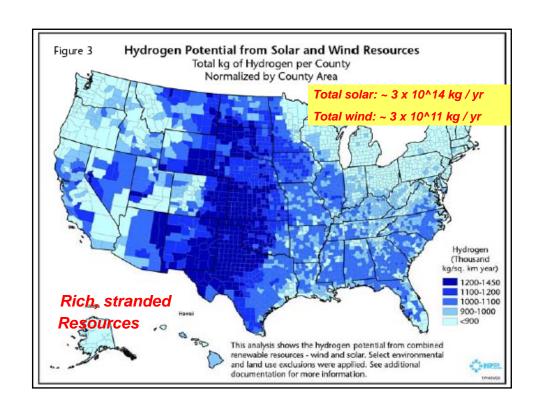
- Solve electricity's RE problems:
 - Transmission
 - Firming storage
 - Grid integration: time-varying output
- Carbon-free fuels
- Underground pipelines
- Low-cost storage: < \$ 1.00 / kWh capital
 - Firm; dispatchable supply
 - Pipelines
 - GH2 in salt caverns
 - NH3 in tanks

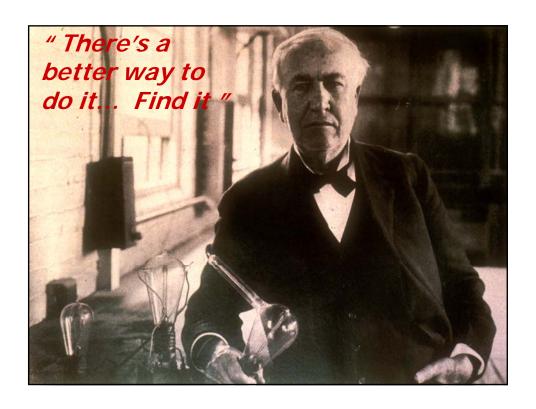
Hydrogen and Ammonia Systems and Fuels

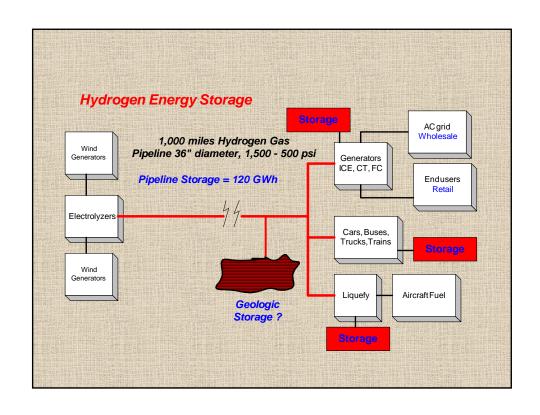
- Delivering fuels: distribution
- ICE, CT, Fuel cell
- CHP on-site
- Utility substation wholesale
- Transportation
 - Rail
 - Truck
 - Personal
- Emissions: H₂O, N₂

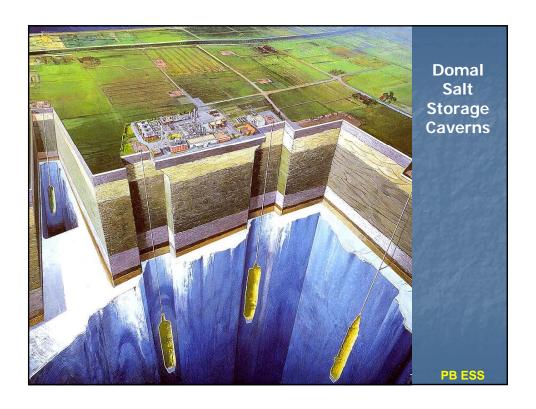


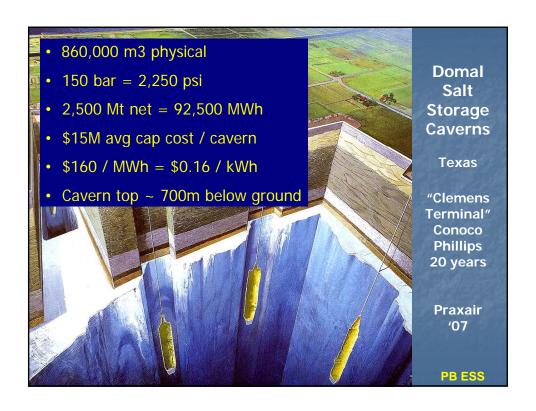


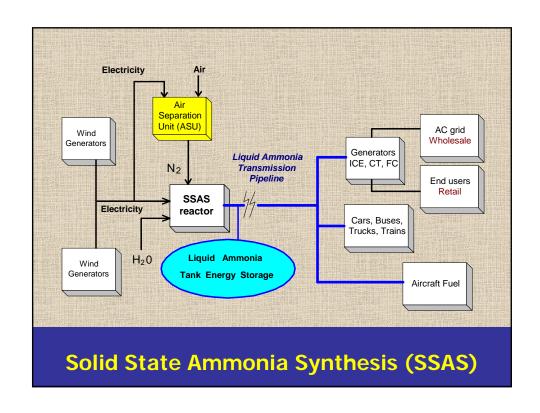




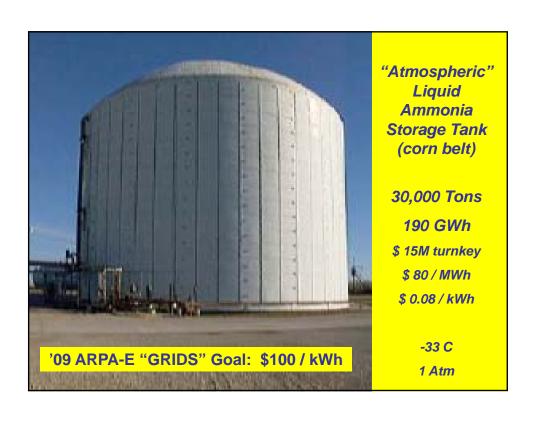


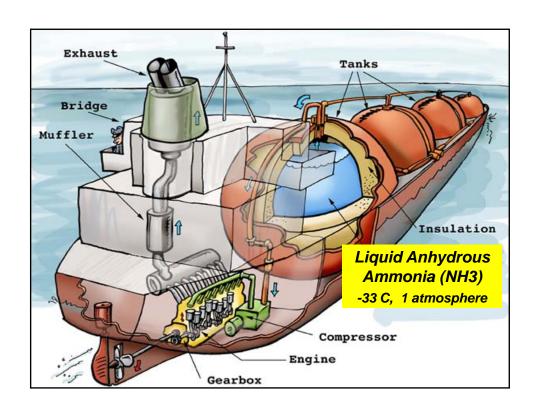


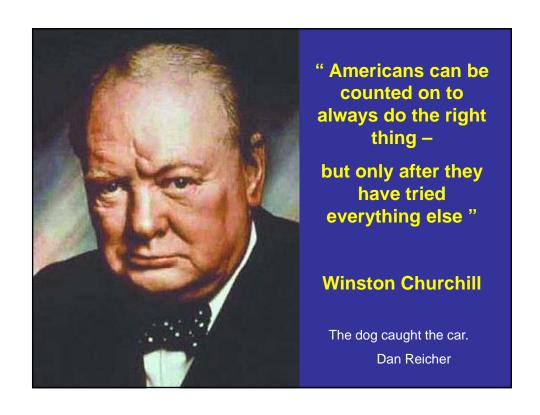


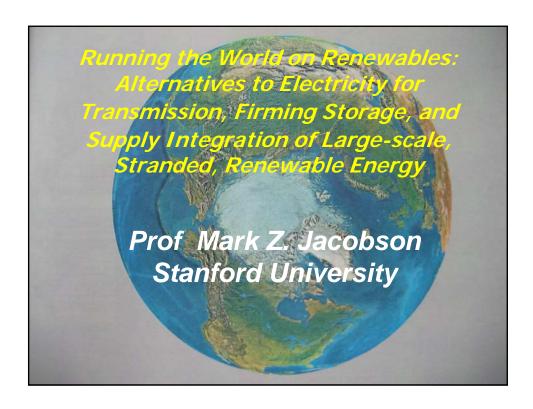












World saturation wind potential and its implications for a sustainable future relying on wind, water, and sunlight producing electricity and electrolytic hydrogen

Mark Z. Jacobson

Atmosphere/Energy Program

Dept. of Civil & Environmental Engineering

Stanford University

Cristina Archer (coauthor)

WREC World Renewable Energy Forum Denver, Colorado, May 14, 2012



Why Study Saturation Wind Power Potential?

A recent study concluded, using a one-line equation, that the world wind potential over land accounting for energy extraction is 1 TW

Another concluded that extractable jet stream power is 7.5 TW

This study uses a physical model to examine the maximum power potential and how power output changes with different installed wind power densities.

It then addresses whether the world can supply its power from wind.

End Use Power Demand For All Purposes

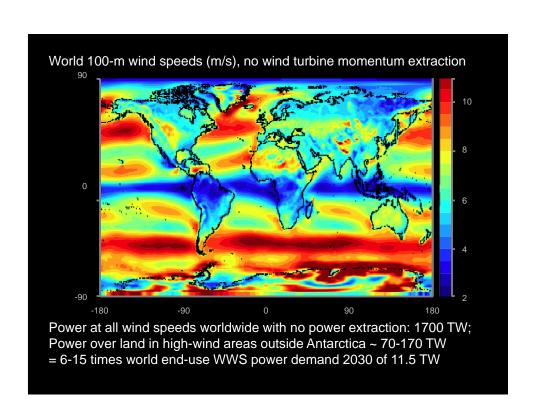
World U.S.

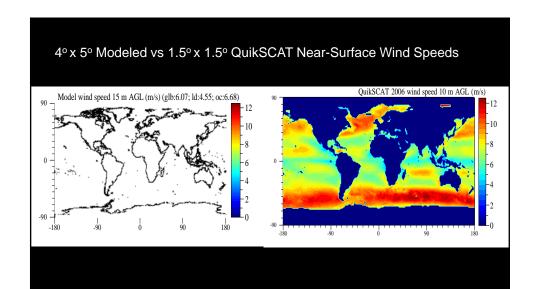
2010 12.5 TW 2.50 TW

2030 with current fuels 16.9 TW 2.83 TW

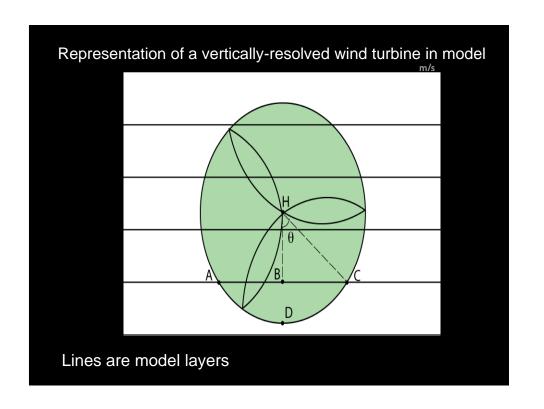
2030 converting all energy to wind-water-sun (WWS) and electricty/H₂ 11.5 TW 1.78 TW (32% reduction) (37% reduction)

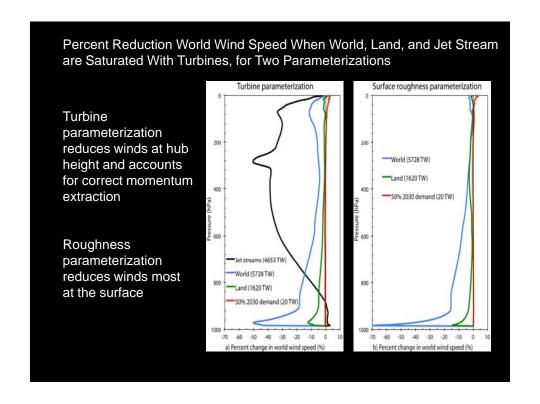
Number of Plant World	ts or De	vices to	Power
Technology	Percent Sup	ply 2030	Number
5-MW wind turbines 0.75-MW wave devices 100-MW geothermal plants 1300-MW hydro plants 1-MW tidal turbines 3-kW Roof PV systems 300-MW Solar PV plants 300-MW CSP plants	50% 1 4 4 1 6 14 20	3.8 mill. (0 720,000 5350 (1.7% 900 (70% i 490,000 1.7 billion 40,000 49,000	
	100%		

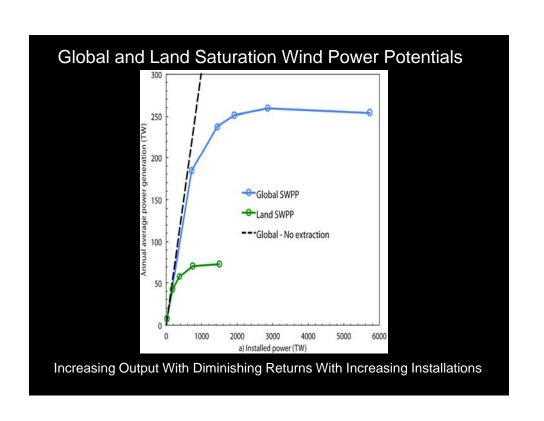


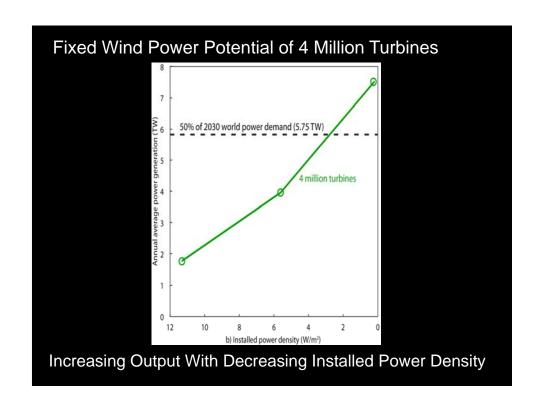


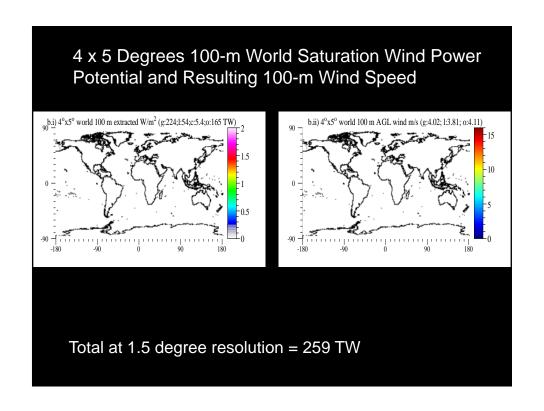
Data from NASA, processed by Dan Whitt and Mike Dvorak



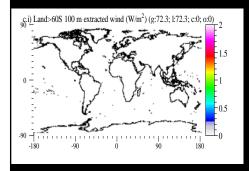


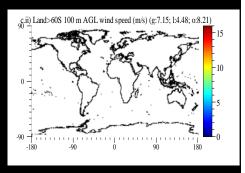






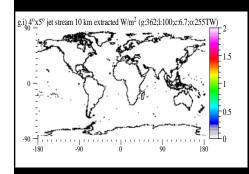


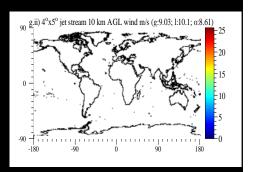




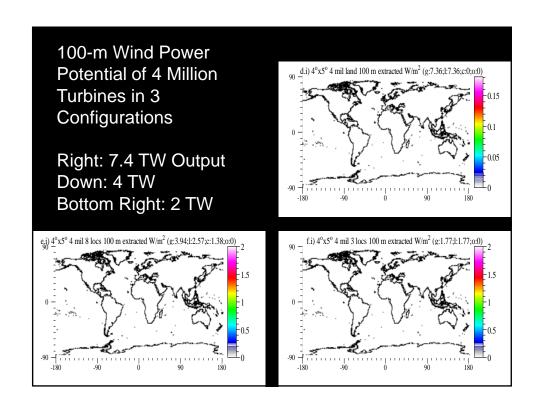
Total at 1.5 degree resolution = 74 TW + 6 TW coastal = 80 TW

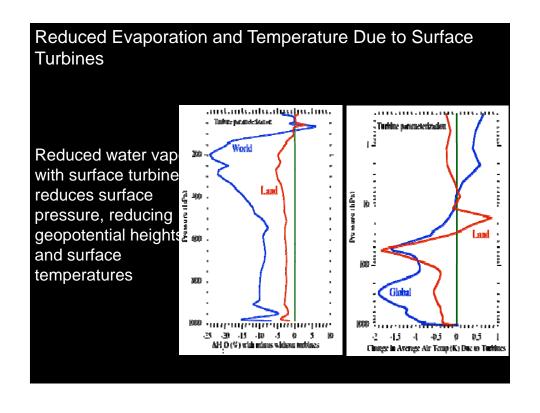
4x5 Degrees 10-km Jet Streams Saturation Wind Power Potential and Resulting 10-km Wind Speed





Total at 1.5 degree resolution = 376 TW





Summary

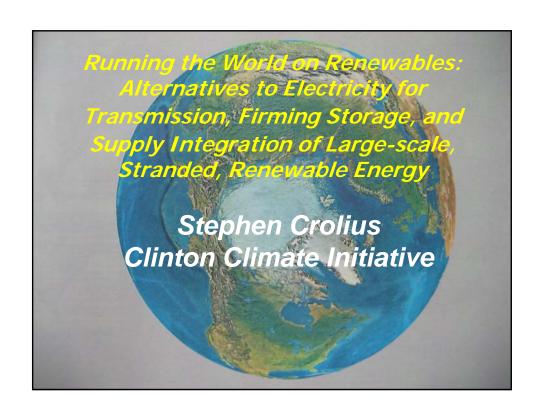
As number of wind turbines increase over large geographic regions, power extraction first increases linearly then converges to a saturation wind power potential:

100 m globally ~ 260 TW 100 m over land plus coastal ocean outside Antarctica ~ 80 TW 10 km in jet streams ~ 375 TW

Thus, no fundamental barrier to obtaining half (5.75 TW) or many times more of world's all-purpose 2030 power demand from wind

Papers:

www.stanford.edu/group/efmh/jacobson/Articles/I/windfarms.html



TRANSPORTATION: BRIDGE MARKET TO THE ULTIMATE H2/NH3 ENERGY ECONOMY



World Renewable Energy Forum

MAY 14, 2012

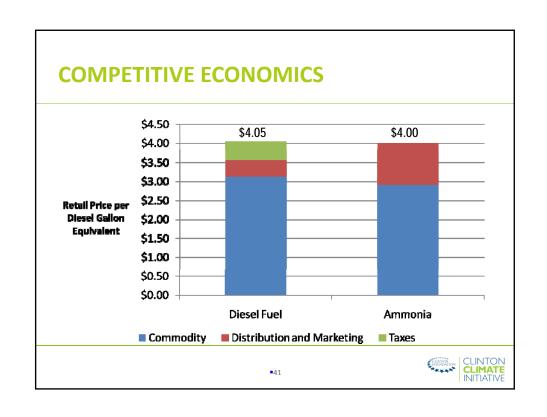


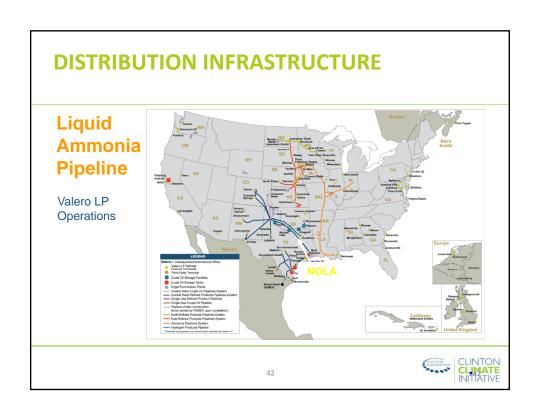
CLINTON CLIMATE INITIATIVE

SUMMARY

- H2 and NH3 may be THE energy carriers of the climate-stable future, but we need to know how we're going to get there from here
- We are working to make transportation the bridge market to the future state
- Essential preconditions are within reach for NH3 to gain a foothold and build momentum in transportation applications
 - Competitive economics
 - Distribution infrastructure
 - Vehicles
 - Mechanism to distinguish green from brown commodity

CLINTON CLIMATE





DISTRIBUTION INFRASTRUCTURE



43



VEHICLES



University of Michigan 2007

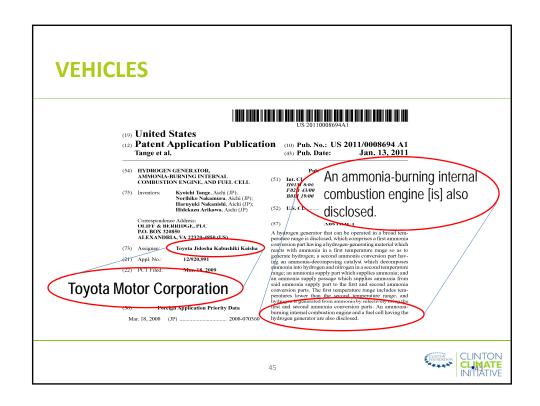
Co-fueled with gasoline and NH3

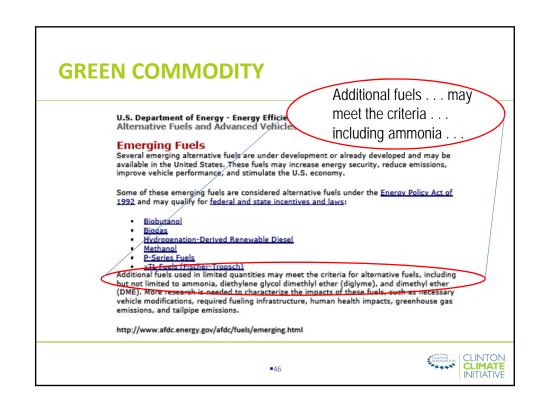
- Idle: gasoline
- Full power: 80% NH3

Successfully driven from Detroit to San Francisco

CLINTOI CLIMAT INITIATIV

•44





GREEN COMMODITY

Guidance on the Petition Process for Evaluation of New Renewable Fuels and Pathways under 40 CFR 80.1416

Background

For the final Renewable Fuel Standard (RFS2) greenhouse gas (GHG) emissions for multiplifecycle GHG emissions is necessary to dete sufficient GHG reductions to qualify under R category or categories. Classification of the fuel

The final rule includes . . . a process for parties to request that the EPA conduct new assessments.

assessments on are included in the final regulation. Refeasible to analyze all potential existing pathways and that there will be new pathways requiring assessment in the future, the final rule includes a process in 40 CFR §80.1416 for parties to request that EPA conduct new assessments and make future determinations. This document provides guidance regarding this process.

-17



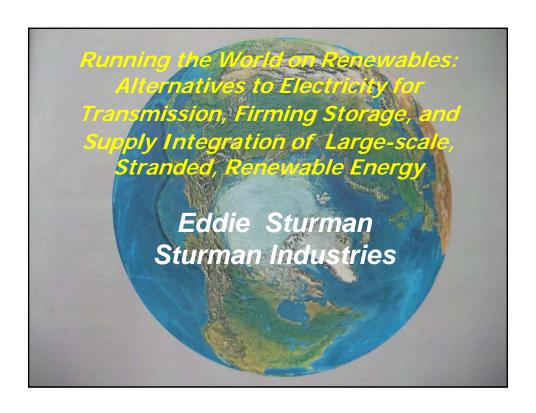
CONTACT INFORMATION

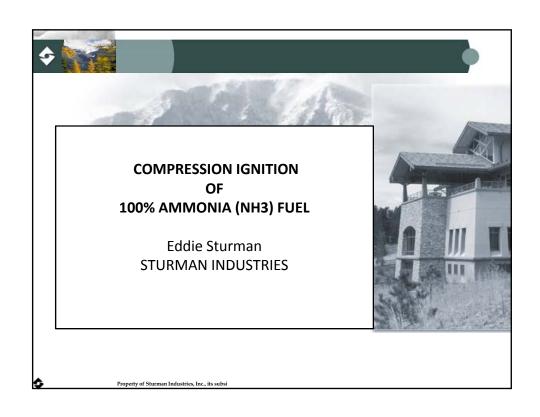
Stephen Crolius

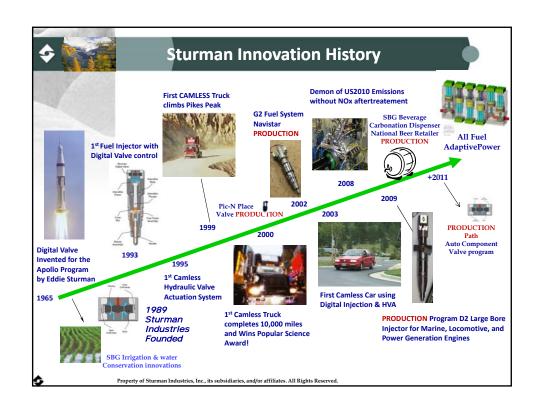
scrolius@clintonfoundation.org

+1-401-952-4944

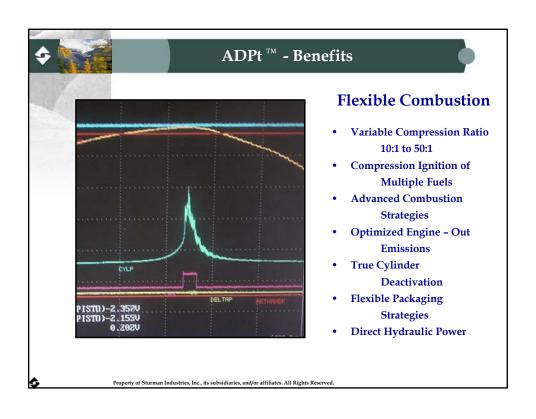




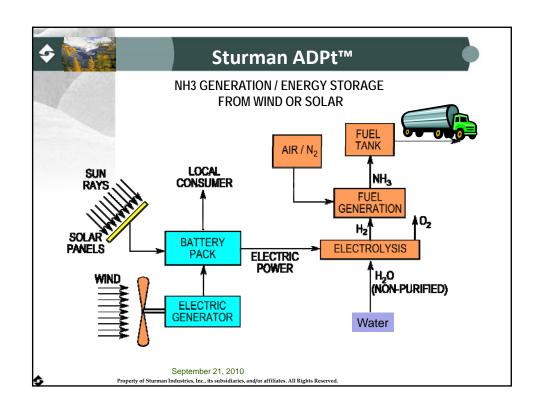


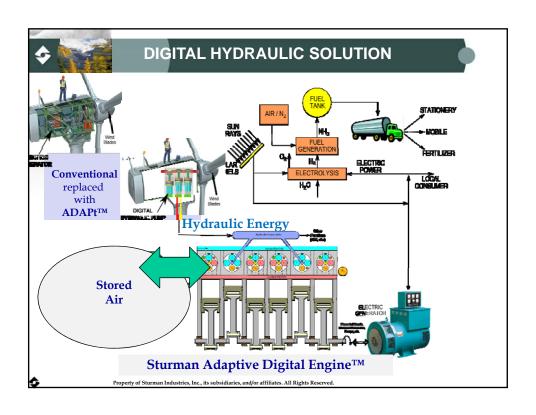


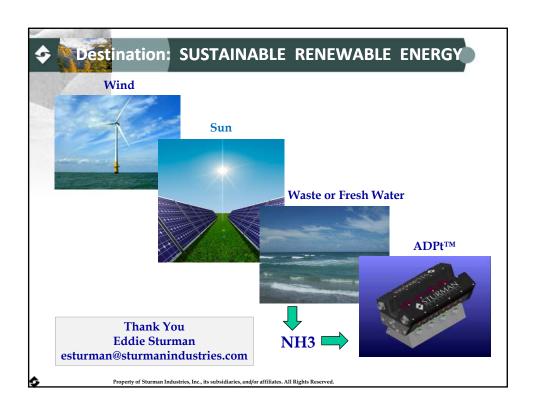


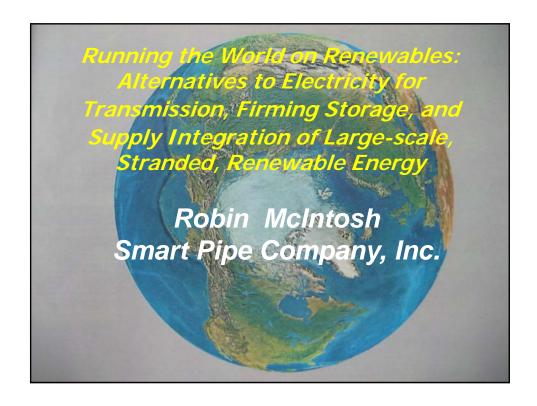














"Energy Transmission Pipelines"

Robin McIntosh Smart Pipe Company, Inc. Houston, Texas

14th May 2012



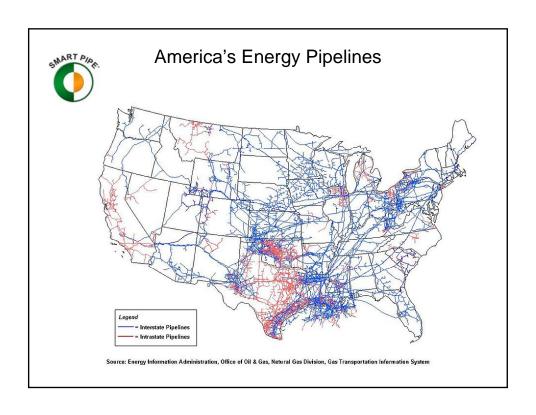
Today's Agenda

- Overview of America's Pipeline System
- Construction of Pipelines
- Renewable Energy Pipelines
- Composite Pipelines

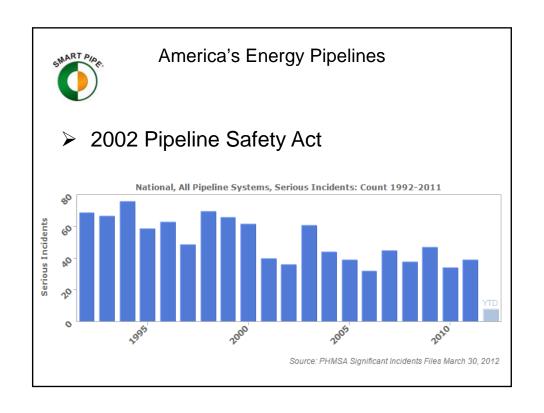
SMART A/A

America's Energy Pipelines

- 2.4 million Miles of Pipeline
- Vast Majority Steel
- > 50% Exceeded Original Lifespan
- 70,000 miles in High Consequence Areas (HCA's)
- ➤ INGAA 30,000 to 60,000 miles required by 2030



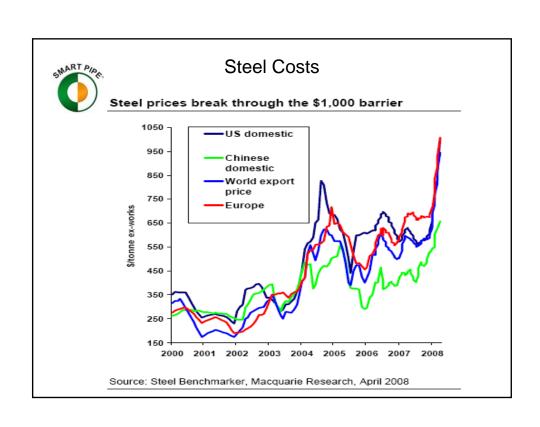






Pipeline Construction Variables

- > Permitting
- Right of Way (ROW)
- Capital Cost
- Maintenance





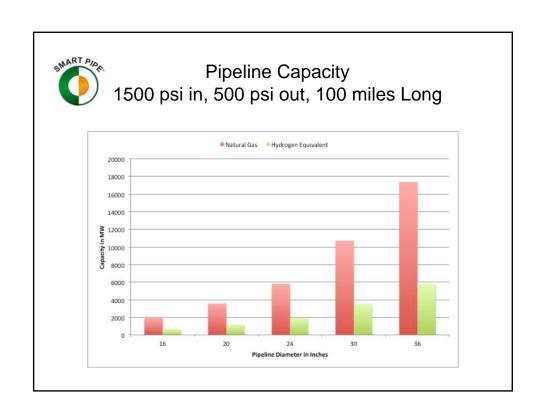
Renewable Energy Pipeline Options

- New Pipelines
- Natural Gas Pipeline Conversion/Blending
- > Additional Compression



Capital Cost/Mile of Pipeline

Diameter	Steel Pipeline	H2 Pipeline
6"	\$500,000	\$900,000
10"	\$800,000	\$1,440,000
12"	\$1,000,000	\$1,800,000
14"	\$1,200,000	\$2,160,000





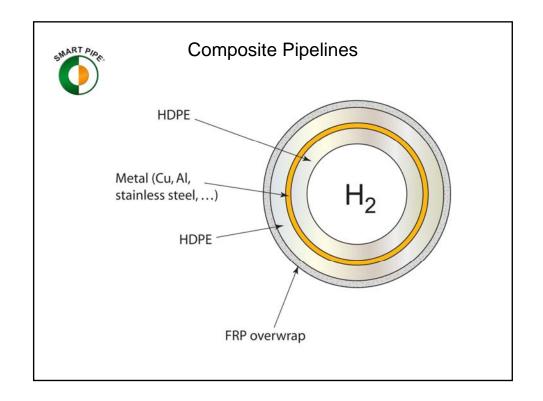
Relative Maintenance Costs

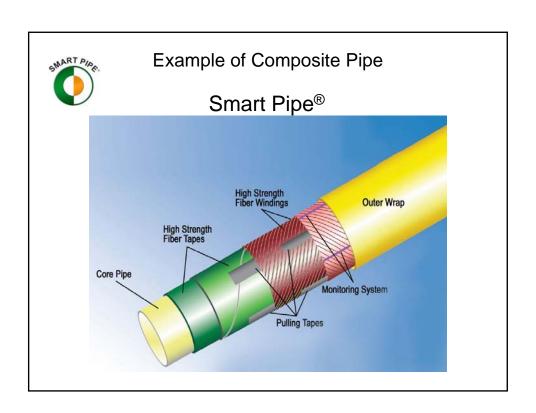
Issue	Natural Gas Pipeline	H2 Pipeline	NH3 Pipeline
Corrosion	High	Higher	Highest
Cleaning	Low	Low	Low
Monitoring	High	Higher	Highest
Overall Score	High	Higher	Highest

SMART PIAR

Composite Pipelines

- Minimizes Corrosion
- Eliminates Hydrogen Embrittlement Problem for Hydrogen
- Less Maintenance Issues and Costs
- Public Safety
- Alternatives (Monitoring, Environment)







Smart Pipe Company, Inc.

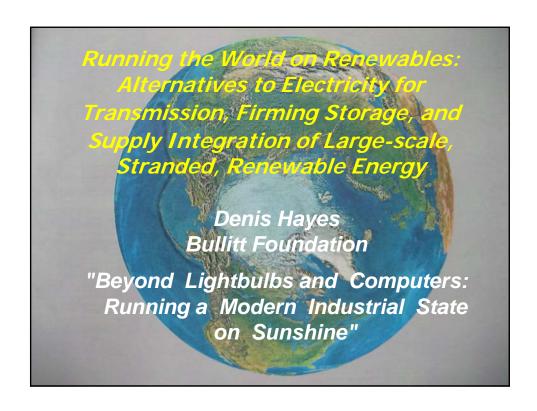
1426 Vander Wilt Lane, Katy, TX 77449

Robin McIntosh

Telephone: (1) 713 858-4923

Email: robin.mcintosh@smart-pipe.com

Website: www.smart-pipe.com

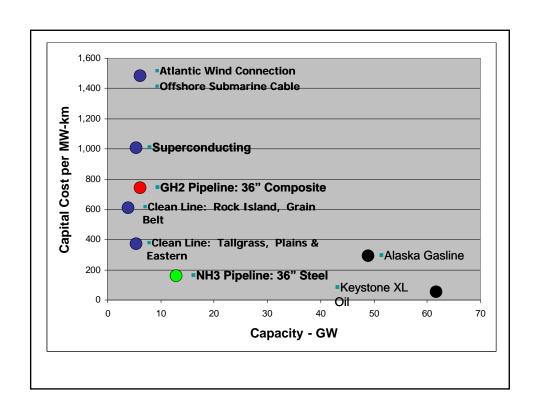




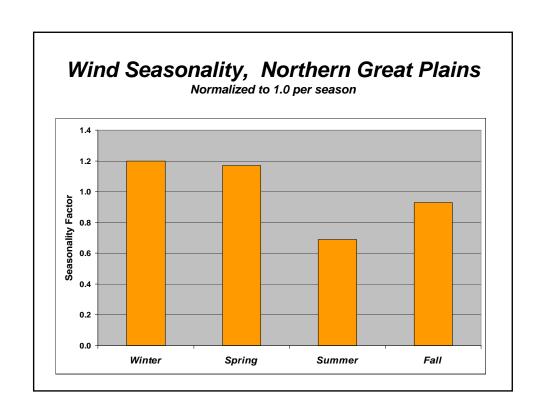


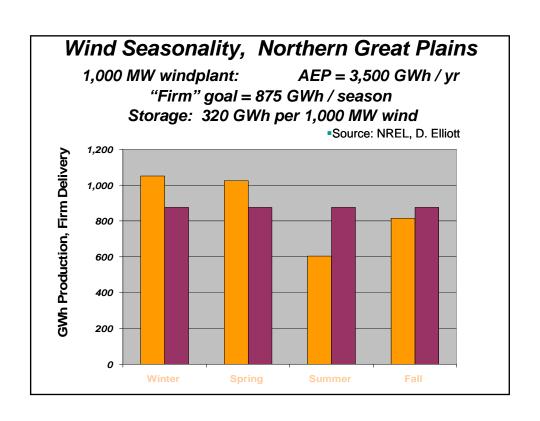
End of panel presentations

The following slides are supplemental to Bill Leighty intro presentation.



Сар	ital Co	ost per G	iW-mile
Electricity:		Capacity	
	<u>KV</u>	MW	\$M / GW-mile
• SEIA:	765	5,000	1.3
	345	1,000	2.6
• AEP-AWEA	765	5,000	3.2
Consensus ?		2.5	
Hydrogen pipeli	ne:		
36", 100 bar, 500	miles,	no compres	ss 0.3
Ammonia pipelii	ne:		
10" , liquid, 500		ith pumpin	a 0.2





320 GWh Annual firming for 1,000 MW wind

- CAES (compressed air energy storage)
 - O&M: \$46 / MWh typical
 - lowa: Power = 268 MW

Energy capacity = 5,360 MWh

268 MW @\$800 / kW = \$214 M Capital:

Storage @ \$40 / kWh = \$13 Billion

Storage @ \$1 / kWh = \$325 Million

- VRB flow battery
 - O&M: 80% efficiency round-trip
 - Capital: \$500 / kWh = \$160 Billion

320,000 MWh storage Annual firming of 1,000 MW wind

- Electricity
 - VRB (Vanadium Redox Battery)
 - O&M: 80% efficiency round-trip
 - Capital: \$500 / kWh = \$ 160 Billion
 - CAES (Compressed Air Energy Storage)
 - O&M: \$46 / MWh typical
 - Iowa Stored Energy Park:
 - Power = 268 MW
 - Energy capacity = 5,360 MWh
 - Capital: 268 MW @ \$ 1,450 / kW = \$ 390 M

@\$ 40 / kWh = \$ 13 Billion

@ \$1 / kWh = \$ 325 Million

- GH2 (3 hydrogen caverns) Capital
- NH3 (2 ammonia tanks)

\$ 70 Million

Capital

\$ 30 Million

