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Renewable Resources for Hydrogen

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Conference and Expo

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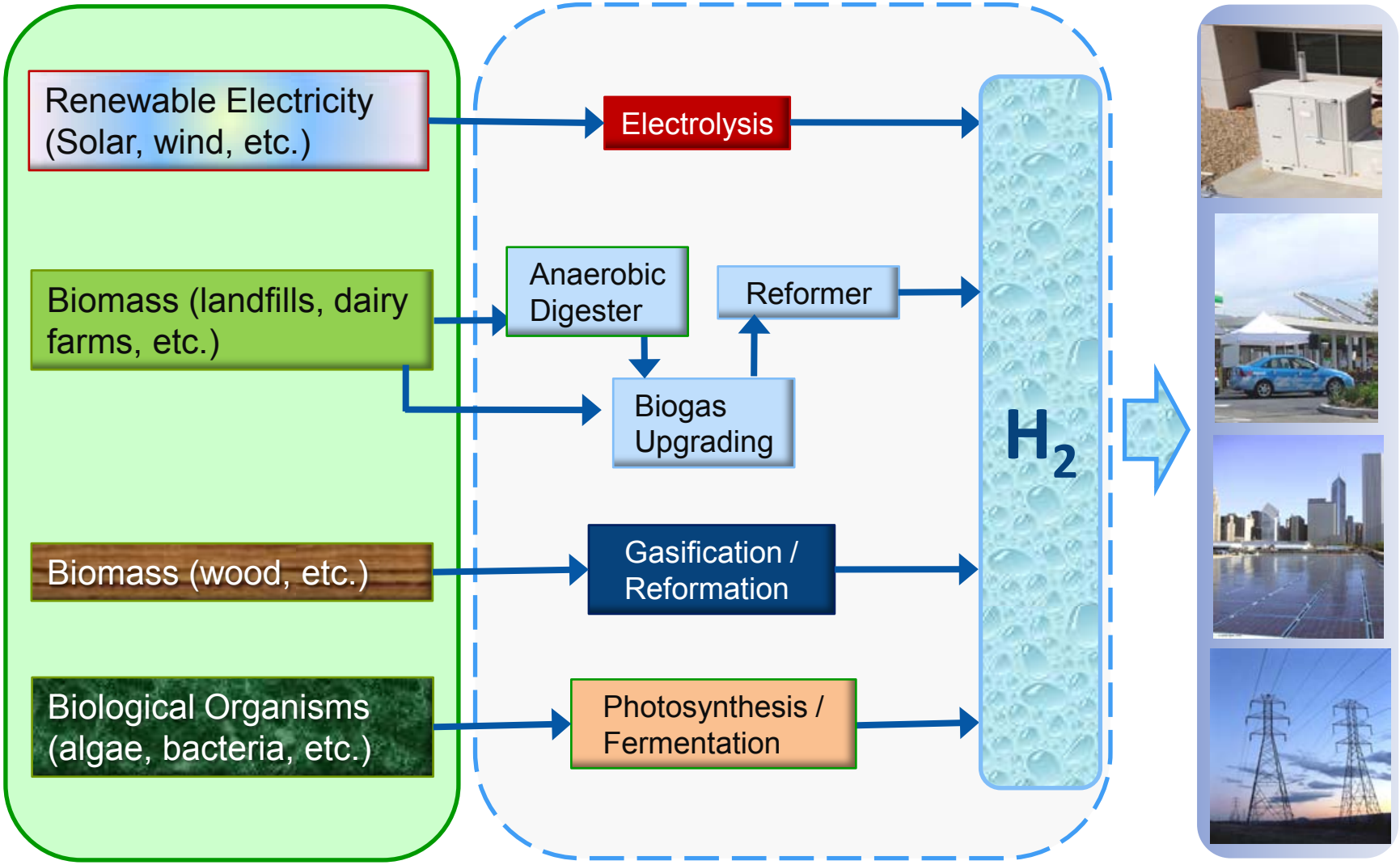
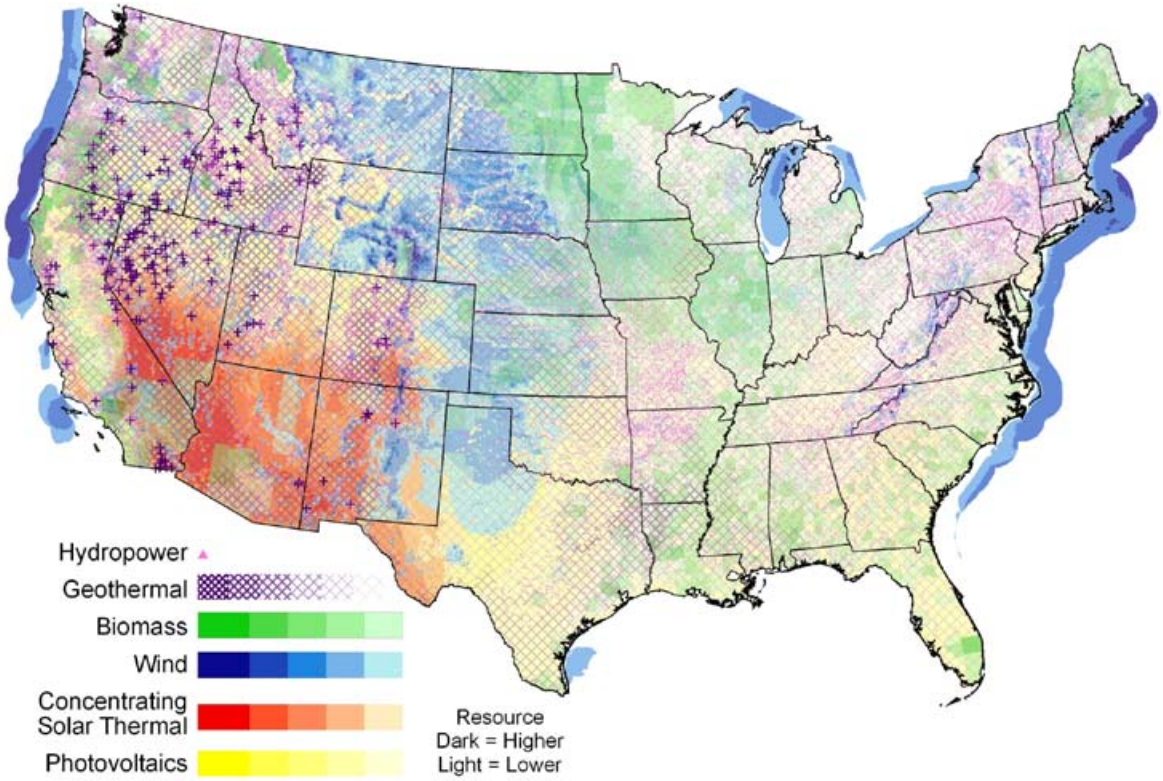
Objectives

- Provide an overview of the pathways to hydrogen production from renewables.
- Demonstrate the abundance of renewable resources for hydrogen production via GIS analyses in conjunction with the current U.S. energy consumption.
- Highlight challenges in providing renewable hydrogen.

Pathways to Hydrogen Production from Renewables



U.S. Renewable Resources



Electrical Power Potentials:

(Source: http://www.nrel.gov/gis/)

Resource	Solar PV/CSP)	Wind	Geothermal	Water Power	Biopower
Theoretical Potential	206,000 GW (PV) 11,100GW (CSP)	8,000 GW (onshore) 2,200 GW (offshore to 50 nm)	39 GW (conventional) 520 GW (EGS) 4 GW (co-produced)	140 GW	78 GW

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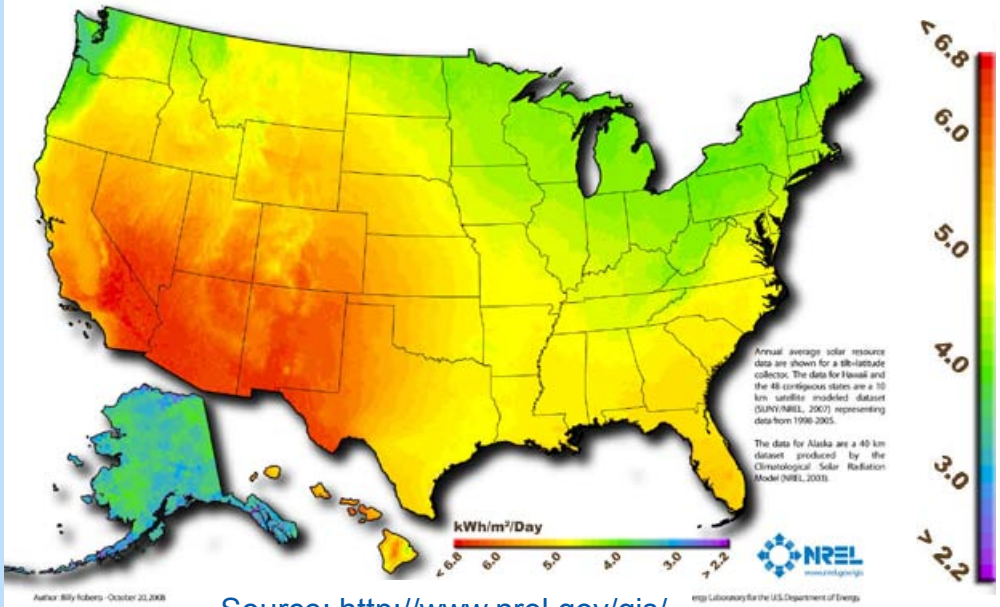
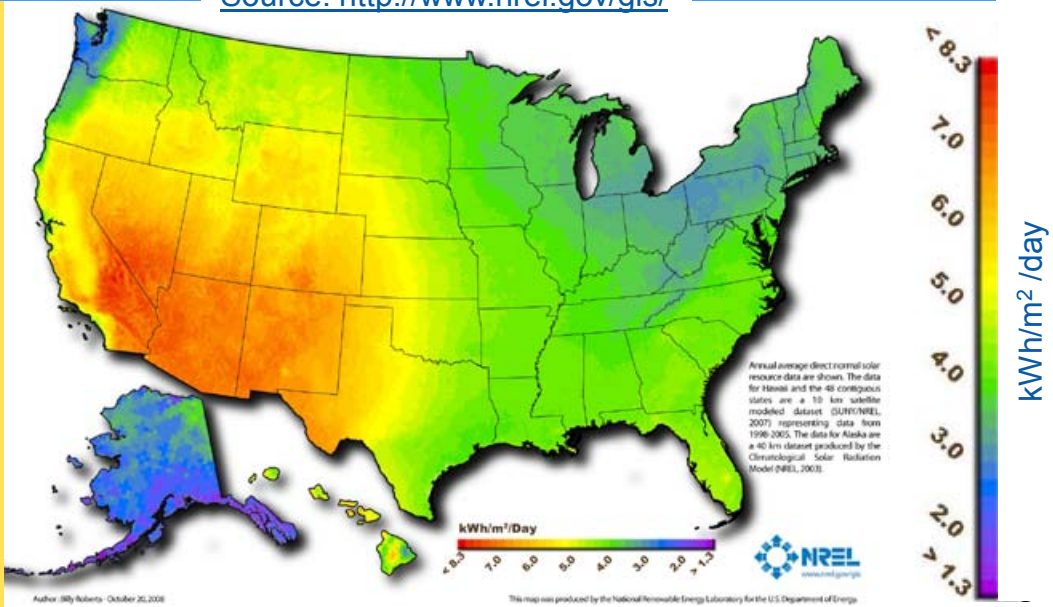
Solar Resources—PV and CSP

Photovoltaic Solar



Source: http://www.nrel.gov/gis/

Concentrating Solar



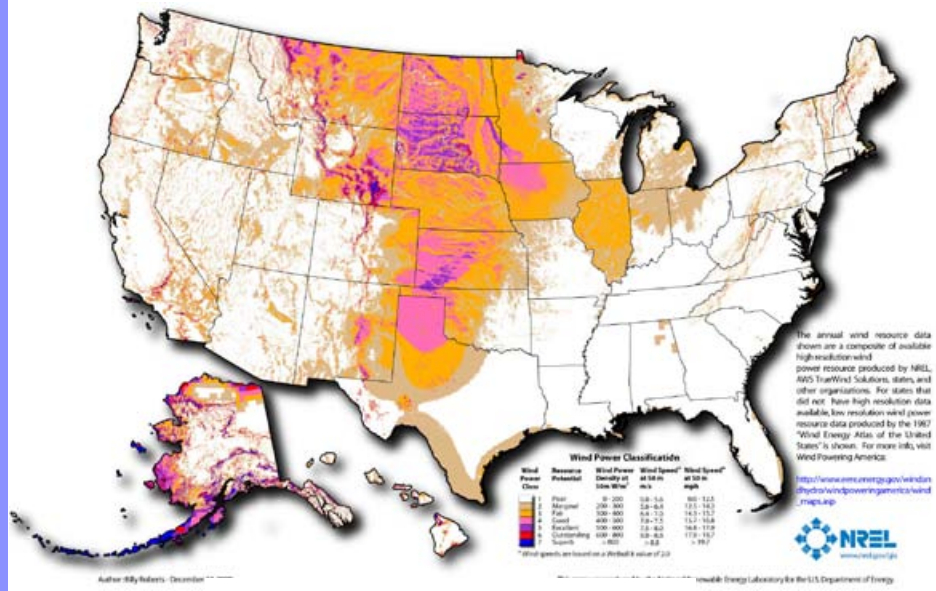
- Southwest region offers greatest solar power density.
- PV has the dominant share of solar potential.
- The existing total power generation capacity in the U.S.* comprises about 0.54 % of the PV solar theoretical potential.

* Based on EIA data (http://www.eia.doe.gov/).

Resource	Solar PV	Solar CSP
Theoretical Potential	206,000 GW	11,100 GW

Wind and Biomass Resources

Wind



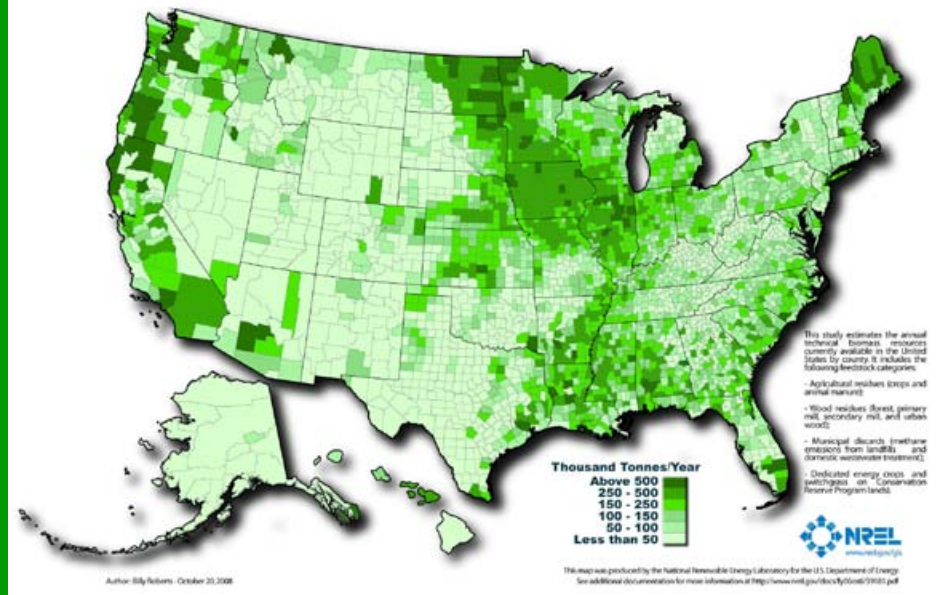
Source: http://www.nrel.gov/gis/

- Central region offers greatest wind power potential.
- The existing total power generation capacity in the U.S.* represents about 14 % of the onshore wind theoretical potential .

	Resource Potential	Wind Power Density at 50m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
1	Poor	0 - 200	0.0 - 5.6	0.0 - 12.5
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	> 800	> 8.8	> 19.7

[a] Wind speeds are based on a Weibull k value of 2.0

Biomass

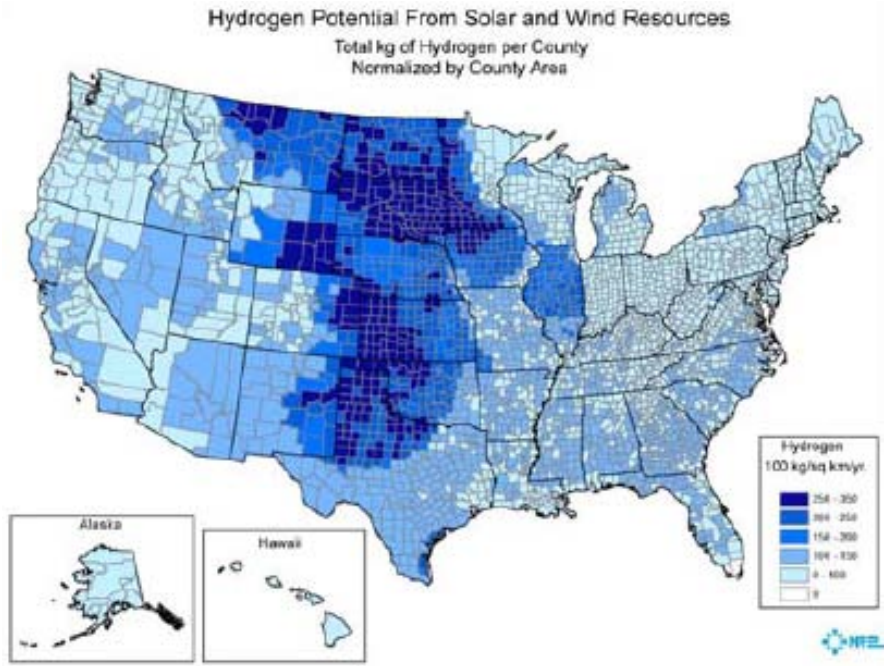


- Biomass resources are spatially more scattered and offer environmental and economic opportunities particularly at local / municipal levels.
- Production of biomethane from biomass can support the regional natural gas grid.

Thousand Tonnes/Year

Above 500
250 - 500
150 - 250
100 - 150
50 - 100
Less than 50

Hydrogen Production Potential from Solar and Wind



- Hydrogen production potential from PV and wind: 1,110 billion kg (~gallons of gasoline equivalent--gge)
- Gasoline consumption for US transportation in 2005: 128 billion gallons.
- The potential for hydrogen production is more than 8 times the transportation fuel consumption.
- (The remaining potential is sufficient to meet the energy requirements of stationary applications in the U.S.)

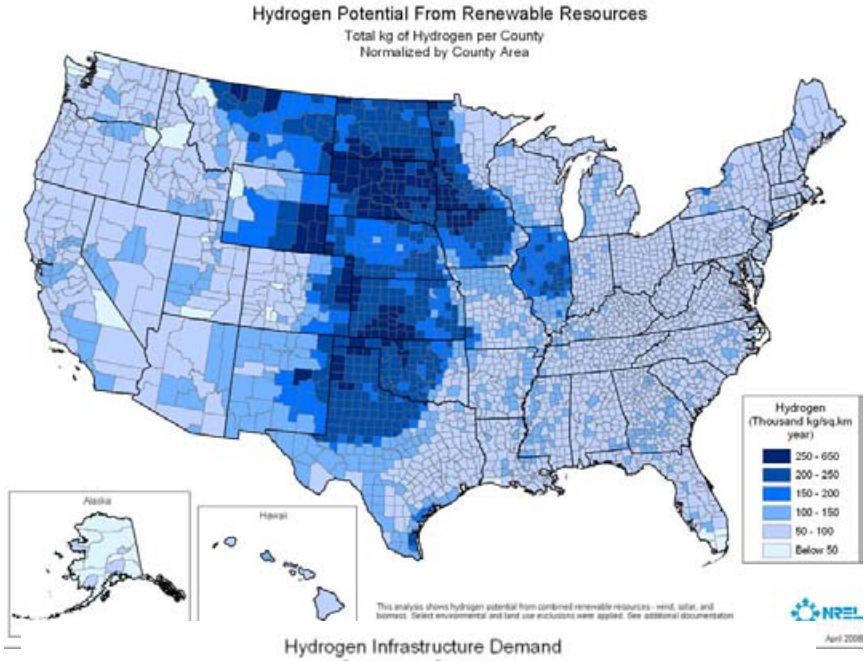
Key Assumptions:

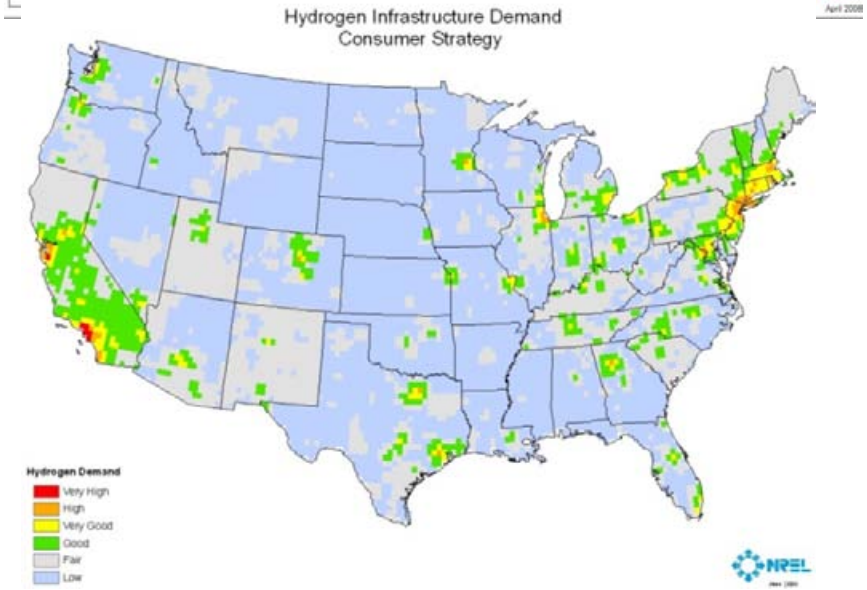
- Wind Class of 3 or better
- PV efficiency: 10%
- Land coverage for PV: 3% of available lands (accounting for excluded areas)
- Installation of 5 MW of wind turbine per square km
- Overall electrolysis efficiency: 75% (HHV).

Source:

Levene, J. I.; Mann, M. K.; Margolis, R.; and Milbrandt, A. 2005. "An Analysis of Hydrogen Production from Renewable Electricity Sources." ISES 2005 Solar World Congress, Orlando, Florida, August 6-12.

Hydrogen Supply vs. Demand in Spatial Domain





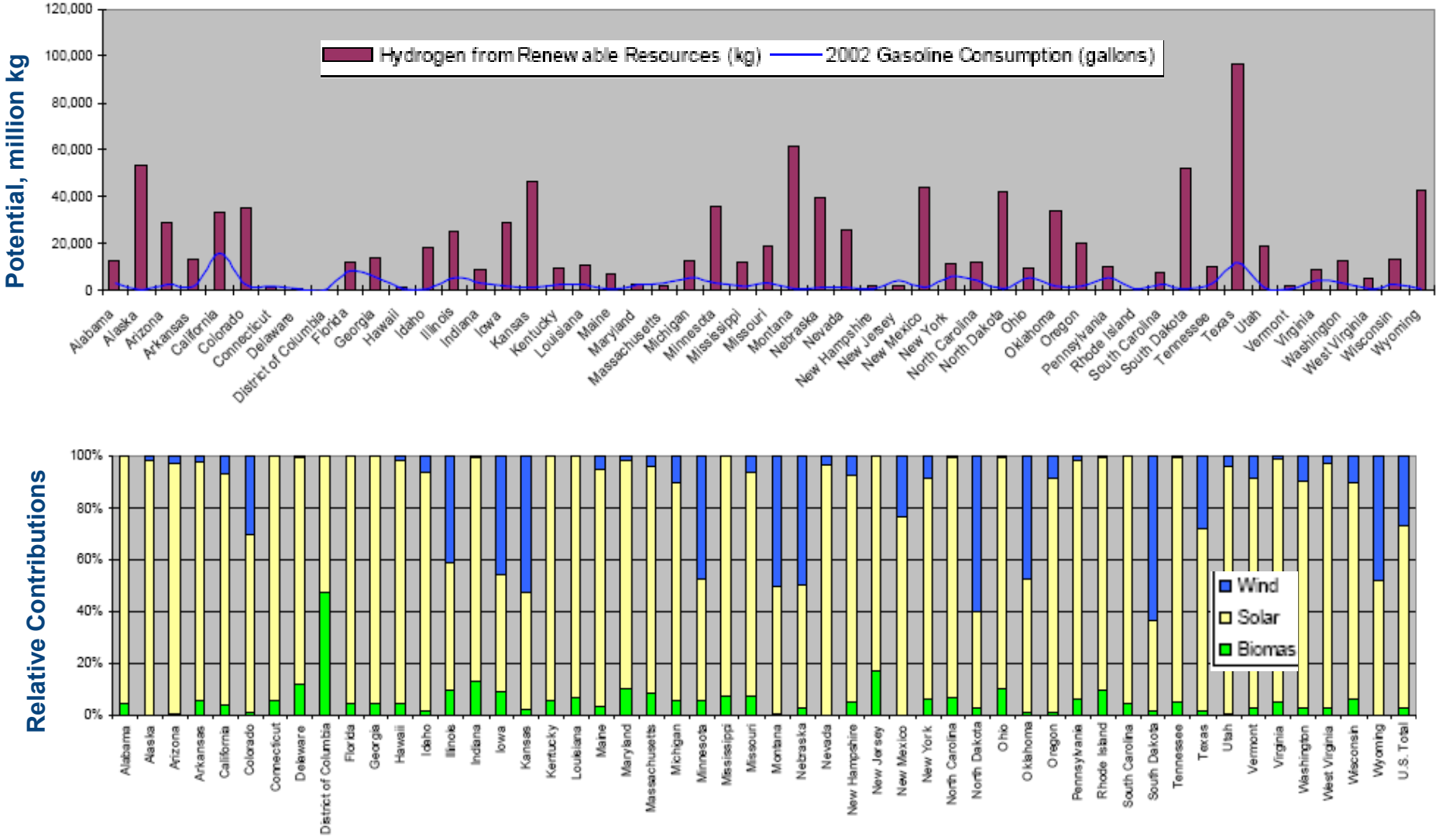
- Hydrogen production potential from key renewable resources—onshore wind, solar PV, and biomass. (~ 1 billion metric tons.)
- The Great Plains region offers the greatest potential.

Milbrandt, A.; Mann, M. (2006). Potential for Producing Hydrogen from Key Renewable Resources in the United States. 32 pp.; NREL Report No. TP-640-41134.

- Projected spatial hydrogen demand for transportation based on key attributes of consumers (e.g., education, hybrid vehicle registration)

Melendez, M.; Milbrandt, A. (2006). Geographically Based Hydrogen Consumer Demand and Infrastructure Analysis: Final Report. 35 pp.; NREL Report No. TP-560-40373.

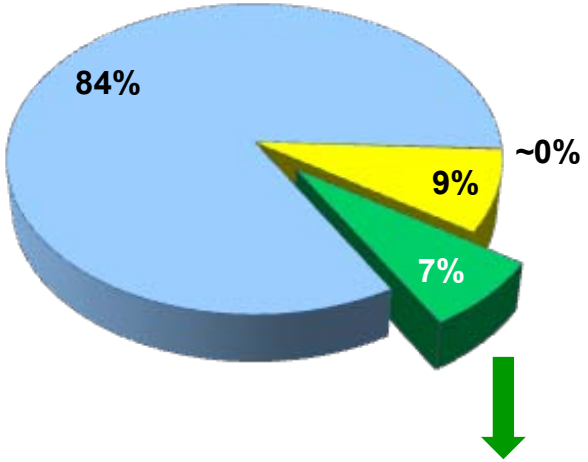
Hydrogen Potential from Key Renewable Resources



Source: Milbrandt, A.; Mann, M. (2006). Potential for Producing Hydrogen from Key Renewable Resources in the United States. 32 pp.; NREL Report No. TP-640-41134.

Energy Consumption by Source

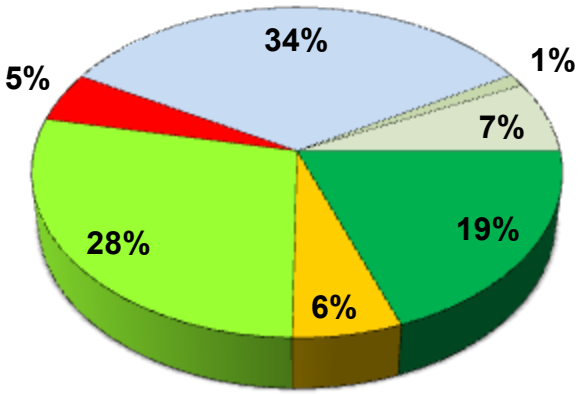
Total Energy Consumption (2008) = 99.3 quads



- Fossil Fuels
- Electricity Net Imports
- Nuclear Electric Power
- Renewable Energy

- Renewable energy plays a small role in spite of its potential.

Renewable Energy Use (2008) = 7.3 quads



Biomass
- Biofuels
- Waste
- Wood Derived Fuels
- Geothermal Energy
- Hydroelectric Conventional
- Solar/PV Energy
- Wind Energy

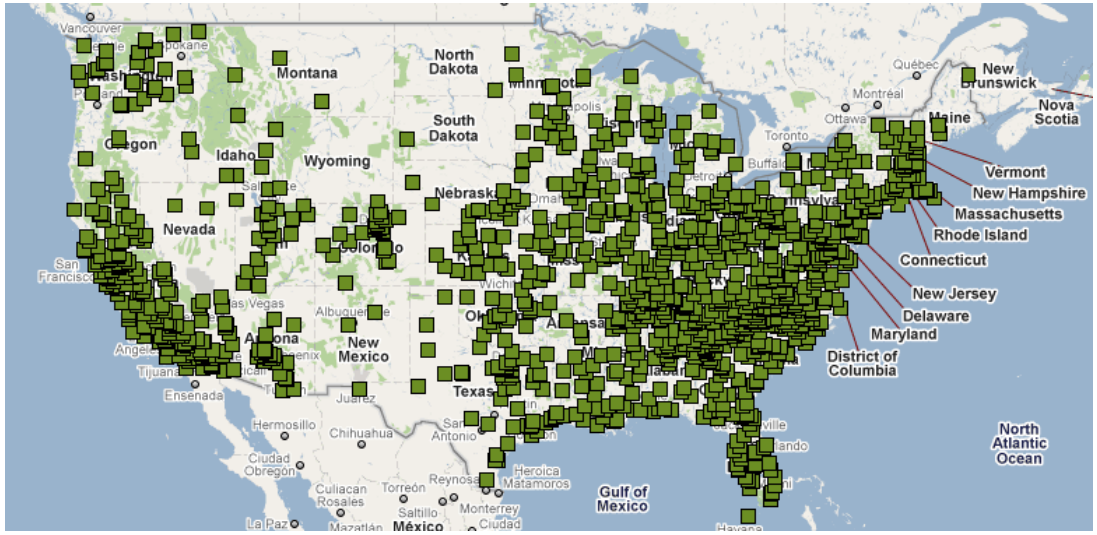
- Solar energy has disproportionately small contribution.

High costs and lack of infrastructure are plausible reasons—policies and incentives can change these.

Based on EIA data (http://www.eia.doe.gov/)

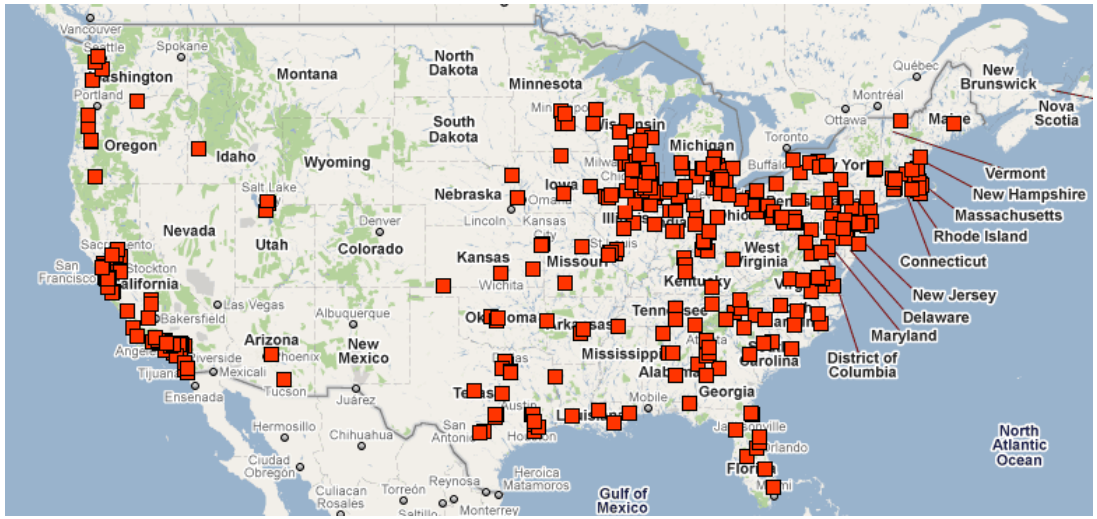
Example of Untapped Resources for Hydrogen—Landfills

Sites without Projects



Source: http://rpm.nrel.gov/biopower/biopower/launch

Sites with Projects



- Underlines significance of stranded biogas potential for onsite power generation and biomethane / hydrogen production.
- Landfills typically offer a greater biogas potential than sewage treatment facilities and dairy farms. *(In California, biogas potential from landfills is ~ 5 times as much as that of the other two combined.)*
- Economy of scale works in favor of landfills, but biogas upgrading requirements can be challenging.

Challenges

- Dependency of hydrogen production cost via electrolysis on electricity price presents an economic challenge for using renewable electricity.
- Economic competition of renewables with conventional sources of energy for hydrogen production without adequate environmental and energy policies/incentive. *(Requirements such as RPSs and SB1505 can be effective drivers for renewables.)*
- Because of spatial mismatch between hydrogen demand and production source, infrastructure is required for cost-effective transport.
- Daily / seasonal variation of energy supply capacity from renewables and temporal mismatch between supply and demand necessitate use of cost-effective energy (electricity, biomethane, hydrogen) storage***—a conduit of energy in time.***
- Optimum utilization of renewable sources of energy for hydrogen requires complex technoeconomic analyses considering key factors such as availability of renewable energy, energy costs, alignment of energy supply / demand, and infrastructure capabilities.

Conclusions

- Renewable resources for hydrogen are abundant, but their large-scale utilization requires overcoming economic challenges and infrastructural limitations arising from spatial and temporal gaps between the energy source and demand.
- Availability of various pathways to hydrogen production offers opportunities for selection of the best alternatives (integrated as well as stand-alone) at the local/regional levels in conjunction with the respective indigenous renewable energy resources.
- Well orchestrated policies and incentives, along with analyses and R&D, can help overcome these challenges.

Questions / Comments ?

Thank you!