Integrated Energy/Transportation Continent-wide Infrastructure Design

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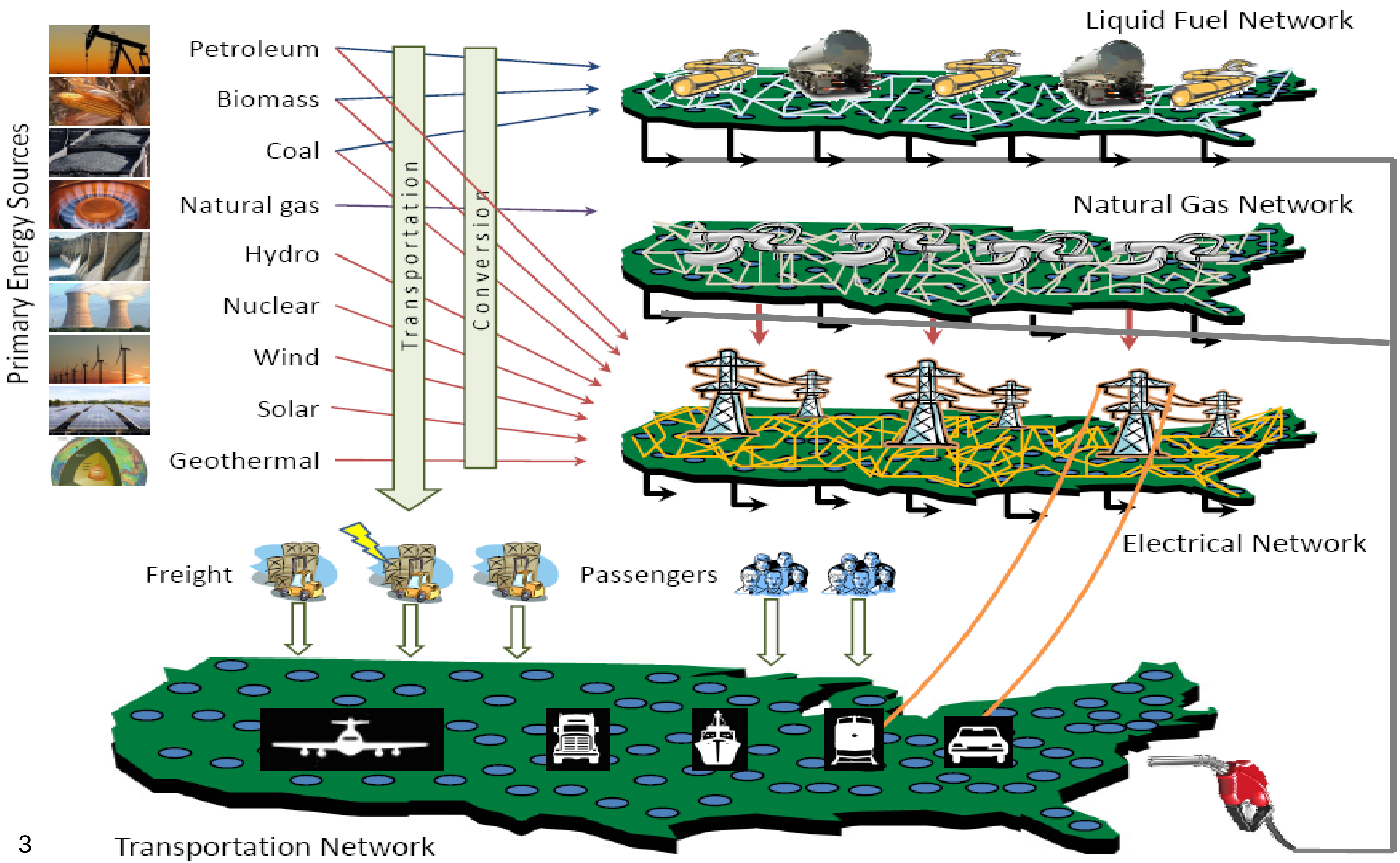
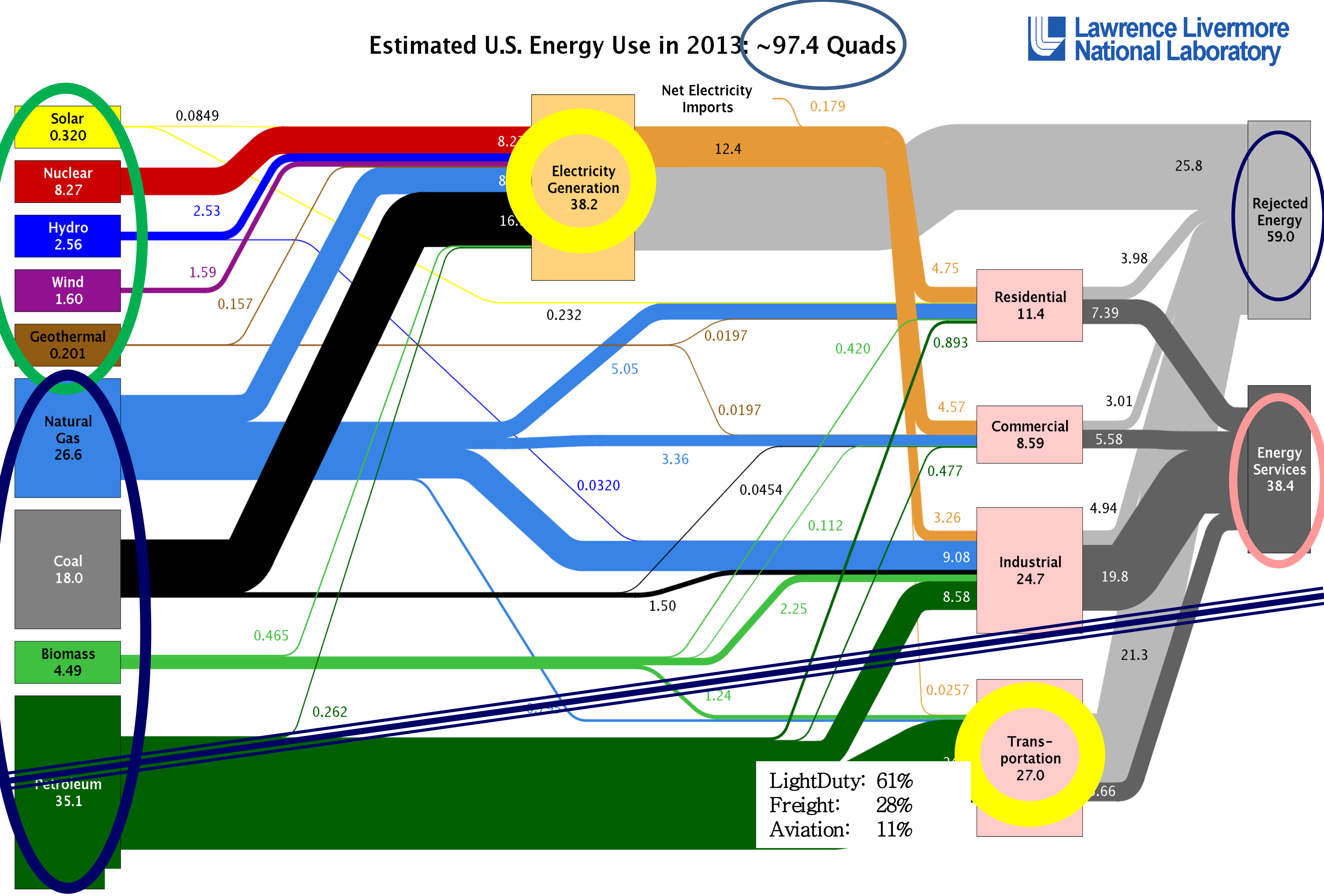
Overview

1. US energy view
2. Observations
3. US energy future: principles & approaches
4. Computational models
5. Conclusions: policy & awareness

Infrastructure view: Multi-sector (fuel, electric, transportation), continental, long-term planning





US Energy View: 2013

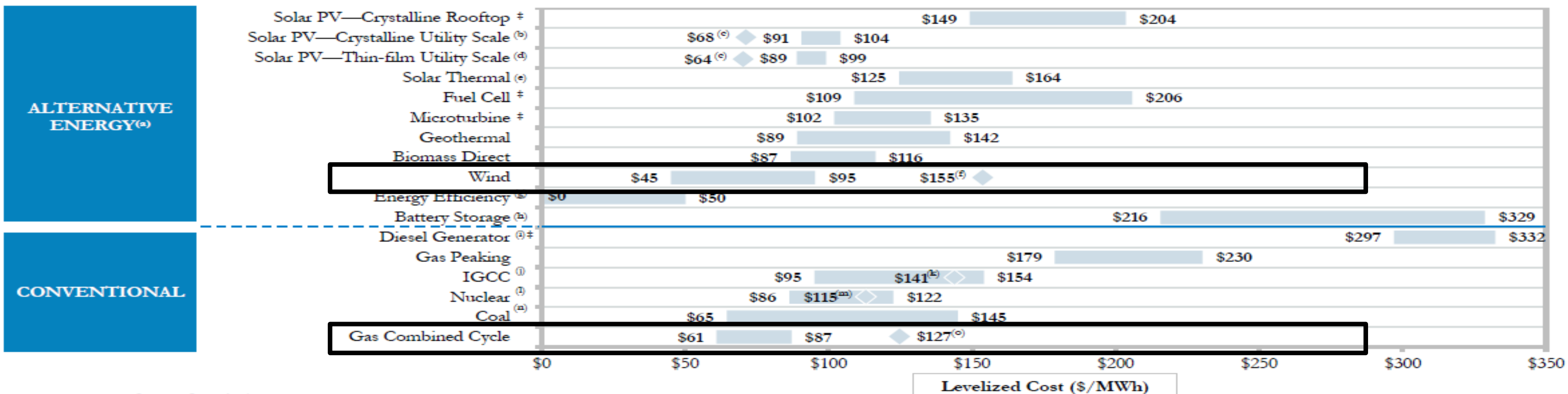
https://flowcharts.llnl.gov/index.html

Observations: efficiency

1. **Overall efficiency:**
   - **Electric gen: 12.4/38.2=32.5%**
   - **Transportation: 5.66/27=21%**
2. **Technology efficiencies:**
   - **Electric gen:**
     - **Thermal: 35%**
     - **Wind: 80%**
   - **Transport:**
     - **ICE: 17% (tank to wheel)**
     - **EV: 80% (plug to wheel)**
3. **Total US energy need:**
   - **Today: 97.4 Quads**
   - **100% wind electric/100% EV for LDV: 61.5 Quads**

Observations: least-cost technologies are inland wind & NGCC

$$LCOE = \frac{\text{Levelized Annual Revenue Requirements}}{\text{Average Annual Energy Production}}$$



Source: *Lazard estimates.*

Note: Assumes 60% debt at 8% interest rate and 40% equity at 12% cost for conventional and Alternative Energy generation technologies. Assumes Powder River Basin coal price of $1.99 per MMBtu and natural gas price of $4.50 per MMBtu. As many have argued, current solar pricing trends may be masking material differences between the inherent economics of certain types of thin-film technologies and crystalline silicon.

‡ Denotes distributed generation technology.

(a) Analysis excludes integration costs for intermittent technologies. A variety of studies suggest integration costs ranging from $2.00 to $10.00 per MWh.

(b) Low end represents single-axis tracking. High end represents fixed-tilt installation. Assumes 10 MW system in high insolation jurisdiction (e.g., Southwest U.S.). Not directly comparable for baseload.

(c) Diamonds represent estimated implied levelized cost of energy in 2015, assuming $1.50 per watt for a crystalline single-axis tracking system and $1.50 per watt for a thin-film single-axis tracking system.

(d) Low end represents single-axis tracking. High end represents fixed-tilt installation. Assumes 10 MW fixed-tilt installation in high insolation jurisdiction (e.g., Southwest U.S.).

(e) Low end represents solar tower without storage. High end represents solar tower with storage capability.

(f) Represents estimated midpoint of levelized cost of energy for offshore wind, assuming a range of $3.10 – $5.00 per watt.

(g) Estimates per National Action Plan for Energy Efficiency; actual cost for various initiatives varies widely. Estimates involving demand response may fail to account for opportunity cost of foregone consumption.

(h) Indicative range based on current and future stationary storage technologies; assumes capital costs of $400 – $750/KWh for 6 hours of storage capacity, $60/MWh cost to charge, one full cycle per day (full charge and discharge), efficiency of 66% – 75% and fixed O&M costs of $5 to $20 per KWh installed per year.

(i) Low end represents continuous operation. High end represents intermittent operation. Assumes diesel price of $4.00 per gallon.

(j) High end incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

(k) Represents estimate of current U.S. new IGCC construction with carbon capture and compression. Does not include cost of transportation and storage.

(l) Does not reflect decommissioning costs or potential economic impact of federal loan guarantees or other subsidies.

(m) Represents estimate of current U.S. new nuclear construction.

(n) Based on advanced supercritical pulverized coal. High end incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

(o) Incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

Lazard's levelized cost of energy analysis- Version 7.0, August 2013, available
http://gallery.mailchimp.com/ce17780900c3d223633ecfa59/files/Lazard_Levelized_Cost_of_Energy_v7.0.1.pdf

Observations: inland wind vs natural gas?

Yellow is winner

	WIND	NATURAL GAS
Overall cost (see last slide)	Low	Low
Fuel production - land	None	Some
Fuel production - water	None	Much
Fuel production – GHG emissions	None	Some (methane)
Fuel transport - land	None	Some
Fuel transport – public resistance	None	Some
Power plant - land	Some	Some
Power plant - water	None	Much
Power plant – CO_2 emissions	None	Some
Power plant - other	Bats and birds	None
Electric transmission - land	Much	Some
Electric transmission – public resistance	Much	Some
Future risk (see next slide)	Little	Much

Observations: inland wind vs natural gas?

Risks of heavy gas portfolio:

1. Gas price goes up due to
   - ***gas demand increase***: pwr plnts, trnsprtn, exports
   - ***gas supply decrease***: gas depletion will occur but may happen sooner due to fracking impact: ➔water/earthquake
2. GHG-induced climate change occurs rapidly re-quiring gas use reduction

Risks of heavy wind portfolio:

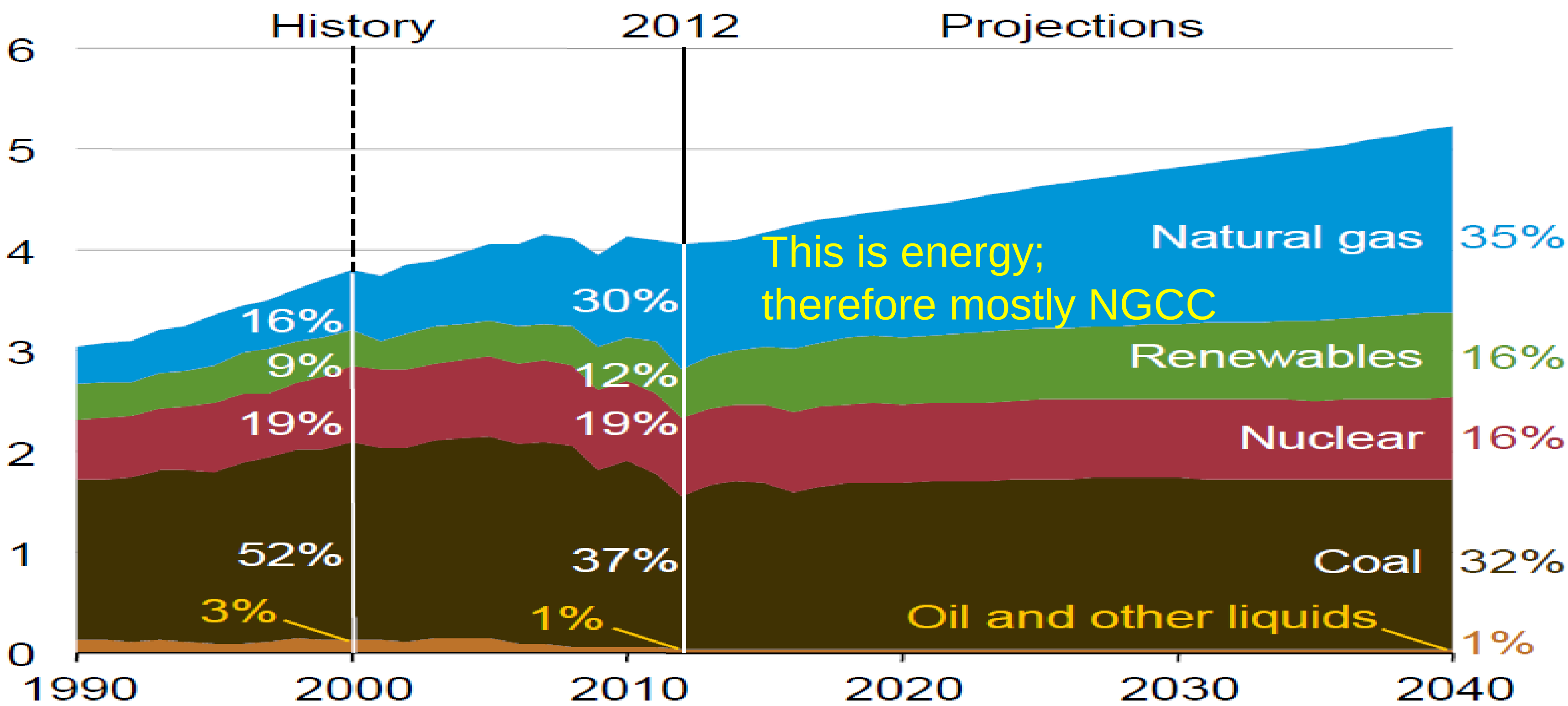
1. Climate change reduces wind speeds
2. Major bat/bird impact
3. LCOE increases
4. No new transmission

Observations: do renewables need gas?

- **Wind/solar need flexibility, provided by:**
  - **Demand side control**
  - **Wind and solar control**
  - **Storage**
  - **Hydro**
  - **Transmission:**
    - **Geo-diversity of wind & solar**
    - **Regulation/contingency reserve sharing**
  - **Combustion turbines**
- **Natural gas combined cycle units:**
  - **motivated by GHG constraints to provide energy**
  - **not a renewable need**
  - **to what extent should NGCC grow?**

Observations: Electric sector gas growth

Electric energy generation by fuel, 1990-2040 (trillion kW-hrs)



US Energy Information Administration, "Annual Energy Outlook 2014: Early Release Overview," available http://www.eia.gov/forecasts/aeo/er/pdf/0383er(2014).pdf.

US Energy Future: Principles & Approach

Three principles:

1. **Minimize cost**
2. **Minimize GHG**
3. **Increase resilience and adaptability: diversify and interconnect**

Approach:

1. **Electric generation portfolio:**
   a. **Maintain NGCC fleet (but do not grow it)**
   b. **Grow wind, solar, deep geothermal, nuclear**
   c. **Grow US hydro (65GW potential[(1)])**
   d. **Grow Canadian hydro (163GW potential total, 68GW in south[(2)])**
2. **Passenger transportation:**
   a. **Diversify energy sources:**
      - **increase use of CNG (LDVs) & LNG (freight)**
   b. **Diversify modes: build high-speed rail**
3. **Build transmission**

(1) http://energy.gov/sites/prod/files/2014/04/f15/New%20Stream-Reach%20Development%20Potential%20April%202014.pdf
(2) file:///C:/Users/jdm.IASTATE/Downloads/CHA%20MRC%20-%20RETECH%20Presentation%2017OCT2012.pdf

Light-duty vehicles and generation costs

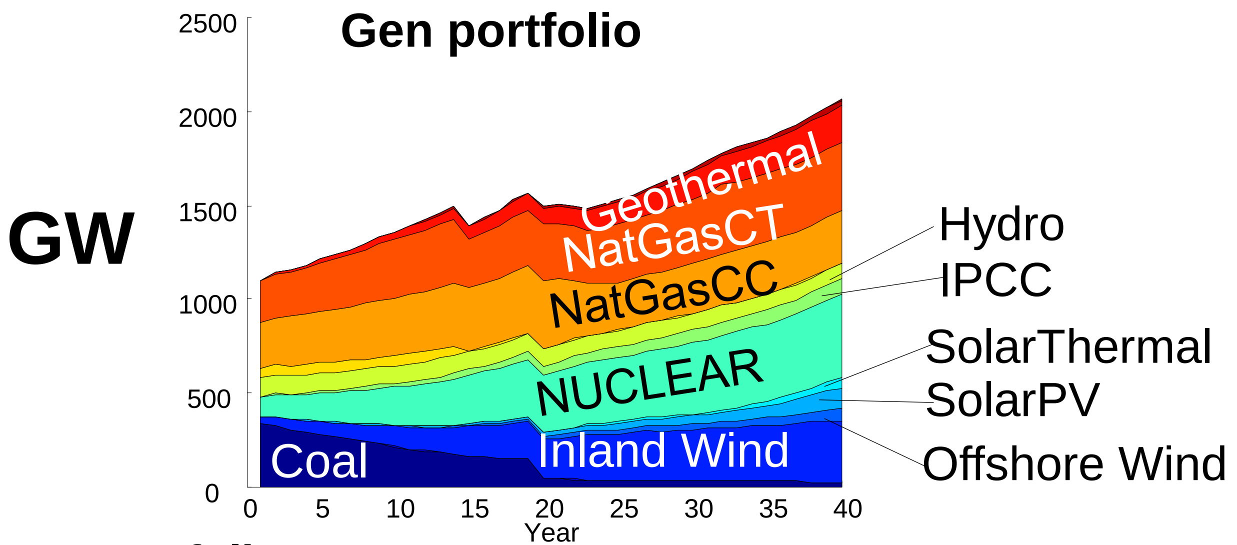
Passenger Vehicles		
	Year 1	Year 20
Gasoline	$24,000	$24,000
Conventional Hybrid	$28,000	$26,000
Plugin Hybrid,20m	$35,000	$31,000
Plugin Hybrid,40m	$41,000	$34,000
Plugin Hybrid,60m	$50,000	$36,000
Battery Elctrc,100m	$45,000	$35,000
Compressed Nat Gas	$27,000	$27,000

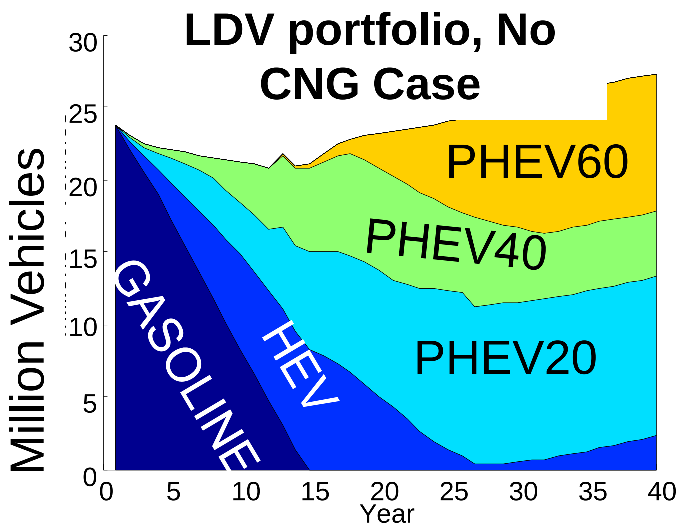
Gasoline	$3.80/Gallon
Natural gas	$3/MMBTU

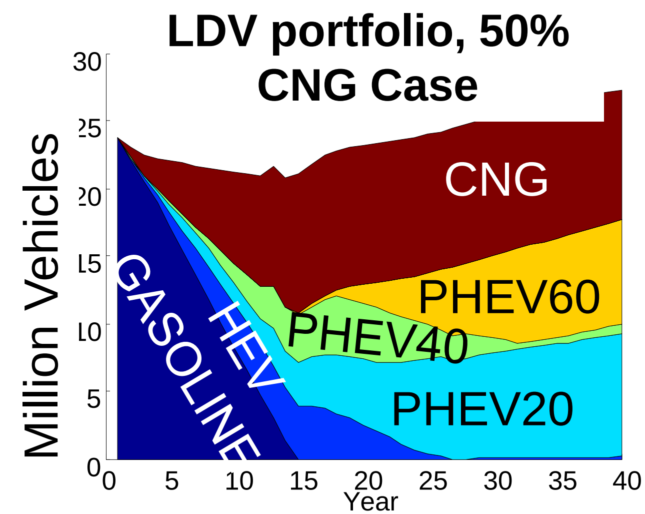
Both increase 1.25%/year

Electric generation ($/kW)	
Coal	2844
IGCC	3221
NGCC	1003
Gas Turbine	665
Nuclear	5339
Onshore Wind	2438
Offshore Wind	5975
Oil	1655
IPCC	3311
Solar PV	4755
Solar Thermal	4692
Geothermal	4141
Tidal Power	18286
Oceanic Thermal	6163

Design: natural gas (NG) & light-duty vehicles (LDV)





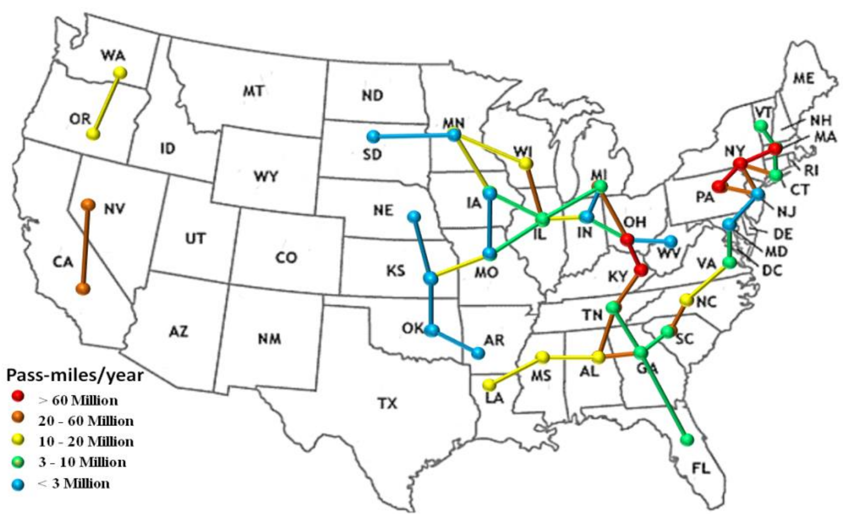


- ➔Total 40 year cost is 8% less for the 50% CNG case.
- ➔Total 40 year CO_2 emissions is 2% less for the 50% CNG case.
- ➔We obtain desirable diversification while improving cost & emissions.

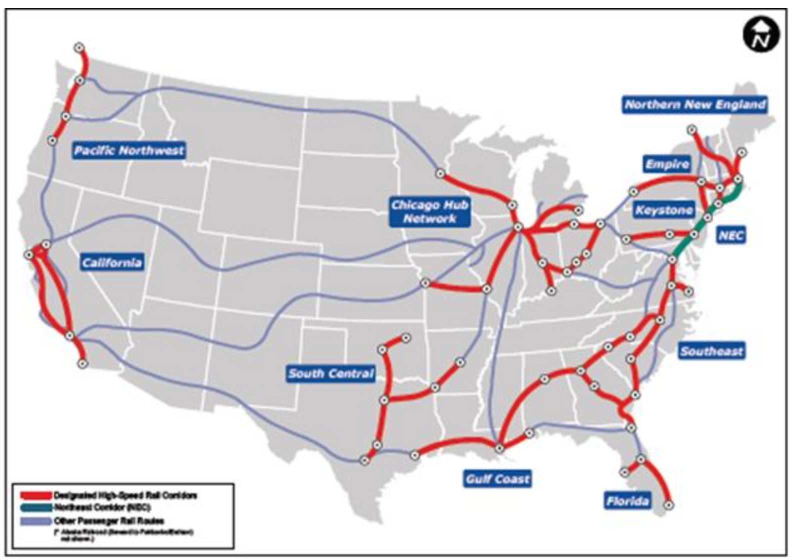
Design: High-speed rail (HSR)

- Long-distance travel only: 95 state-state + 140 additional heavily-traveled routes
- Possible travel modes are highway, air, HSR
- Travel time penalized 24$/hr for all modes in optimization but reported separately

Attribute	No HSR	With HSR
HSR penetration (%)	0	30.5
Total Cost (T$)	11.61	11.15
Emissions (e10 short tons)	2.59	2.51 (-3.1%)
Gasoline (E+3 MGallon)	29.84	19.92 (-33.2%)
Jet Fuel (E+3 MGallon)	320.55	211.25 (-34.1%)
Electric Energy (E+6 TWh)	194.23	198.24 (+2.06%)
Cost Savings (B$)	Reference	460



Our Results



DOT Designations

Computational Models

There is need to centrally ***design***, at the continental level, interdependent infrastructure systems:

1. Economies of scale (still) motivate centralized designs to avoid inefficient infrastructure investment;
2. Interdependencies are numerous; building without capturing them leads to inefficient infrastructure investment.
3. Infrastructure lives for 50 years or more, and climate impacts take decades to turn;

   ➔free markets are too short-term to adequately respond, and the consequences of getting it wrong are potentially severe.

Computational models are our means of developing, testing, assessing our designs.

Public Education and Policy

*2006 survey:

What is the impact of nuclear power plants on CO_2 emissions?

80% got it wrong

**2008 survey:

Which costs more today: electricity from wind turbines or electricity from coal-fired plants?

82% said coal

#2009 survey (women):

67% identify coal power plants as a big cause or somewhat of a cause of global warming, 54% think the same about nuclear energy;
43% don't know that coal is the largest source of US electricity.

##2003, 2007 survey:

For both survey years, "People see alternative fuels (hydro, solar, wind) as cheap and conventional fuels as expensive."

+2011 survey:

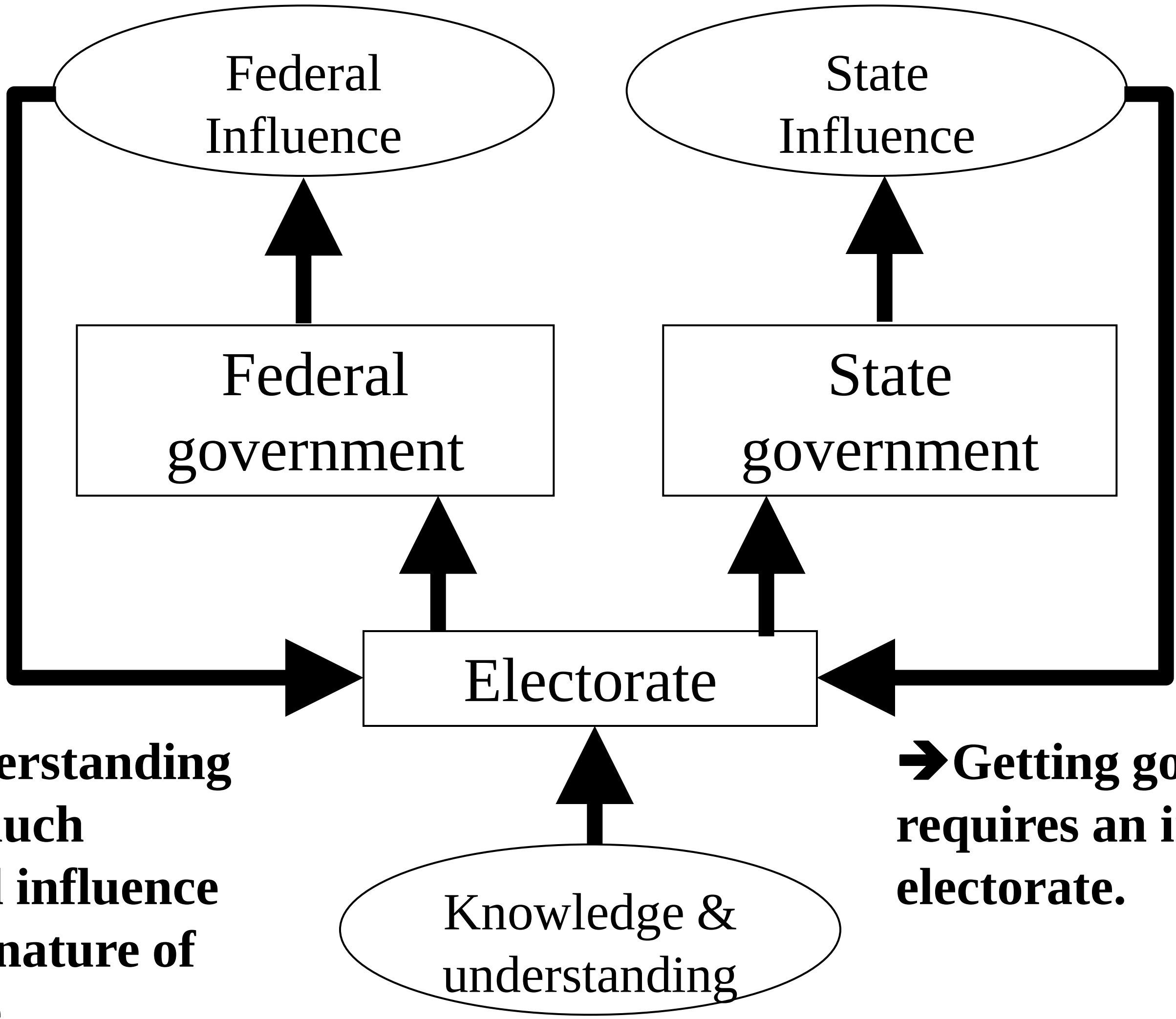
59% did not know hydro is our leading renewable resource for electricity

++2013 survey:

60% (in Texas!) did not know what hydraulic fracturing is.

*T. Curry, et al., "A survey of public attitudes towards climate change and climate change mitigation technologies in the United States: Analyses of 2006 Results," Publication LFEE 2007-01-WP, MIT Laboratory for Energy and the Environment.
#M. D;Estries, "Survey: Women fail on energy knowledge," July 3, 2009, report on a survey commissioned by Women Impacting Public Policy and Women's Council on Energy and the Environment.
**H. Klick and E. Smith, "Public understanding of and support for wind power in the United States,"Renewable Energy, Vol. 35, July 2010, pp. 1585-1591.
S. Ansolabehere, "Public attitudes toward America's energy options," MIT-NES-TR-008, June 2007.
+B. Southwell, J. Murphy, J. DeWater, and P. LeBaron, "Americans' perceived & actual understanding of energy," Aug., 2012. RTI Press
++S. Kirshenbaum, "University of Texas at Austin Energy Poll," April 30, 2014.

Public Education and Policy



➔**Public understanding affects how much governmental influence occurs & the nature of that influence.**

➔**Getting good policy requires an informed electorate.**

➔ **We can help electorate (& policy-makers) see the impact on their lives of various infrastructure designs.**

Conclusions: policy/awareness

Major infrastructure development requires:

- **Computational models to inform;**
- **Good policy, which depends on public awareness;**
- **Decision-making entities having political will to pursue change & authority to make it happen.**

"When a reporter approaches, I generally find myself wishing for a martini."

-- Jonas Salk, Nobel Prize winner

"It seems as if the whole scientific establishment has absent-mindedly misplaced English somewhere between high school graduation and the awarding of the Ph.D."

-- Katie Coe, TV science beat reporter, 2003