Sustainable Transportation Energy Pathways Research

Joan Ogden

TTP Orientation Seminar

November 9, 2012
Global Population Density 1995 (persons per km²)

Click a region to see a detailed map
Earth’s Cities at Night
CHALLENGES FACING FUTURE ENERGY SYSTEM

• Growth of demand, esp. in developing countries
• Diversity/Security of Energy Supply, esp. in transportation sector
• Air Pollutant Emissions
• Greenhouse Gas Emissions (GHG)
• Water, land, materials constraints
FUEL SECTOR IS IMPORTANT

• Direct combustion of fuels for transportation and heating accounts for about 2/3 of primary energy use and GHG emissions, and a large fraction of air pollutant emissions.

• World transportation sector 97% dependent on oil.

• # vehicles projected to triple worldwide by 2050

• In US, ~28% of GHG emissions are from transportation (CA ~40%; 20% worldwide); transportation is rapidly growing GHG source in the US and globally.
Addressing Transportation Energy Challenges

Climate change, Air quality, Energy security

Reduced Vehicle Miles Traveled (VMT)
- Carpooling
- Mass transit
- Urban design
- Intelligent Transportation Systems (ITS)

Vehicle Technology
- Advanced conventional vehicles (ICE)
- Plug-in hybrid electric
- Battery electric
- Fuel cell electric

Fuel Alternatives
- Hydrogen
- Biofuels
- Electricity
- Low-carbon liquid fuels (coal / NG with sequestration)

A comprehensive energy strategy should have a “portfolio” approach with multiple solutions
STABILIZATION WEDGES (Pacala, Socolow)

ANNUAL EMISSIONS

In between the two emissions paths is the “stabilization triangle.” It represents the total emissions cut that climate-friendly technologies must achieve in the coming 50 years.

CA 2050 GHG Goal: 80% below 1990 level
Doubling vehicle efficiency could become one “wedge”, zero-carbon fuels another
POTENTIAL FOR VEHICLE ENERGY EFFICIENCY (ICEVS 2X +)

REDDUCING VMT

“Recent studies show that substantial reductions in travel and emissions of pollutants and greenhouse gases are possible (10%-30%, compared to the future base case), but only with combined transportation investment, land use, and travel pricing policies.”

POTENTIAL FOR ALTERNATIVE FUELS

• Growing imperative for alternative fuels
  ▪ Oil supply security
  ▪ Climate Change

• Search for solutions by policymakers, industry
  ▪ Innovative Policy Landscape

• Continuing tech progress in variety of alt fuel and vehicle technologies
  ▪ Biofuels
  ▪ Electricity (Plug-in Hybrid vehicles, Battery vehicles)
  ▪ H2/Fuel Cell Vehicles
  ▪ Fossil-based fuels w/Carbon Capture and Sequestration
History of alternative fuel vehicles (US)

Will the future be different? MAYBE..
History of alternative fuel vehicles (US)

Alternative Fueled Vehicles (1000s)

References: Davis, Transportation Energy Data Book (2008)
CURRENT FUEL/VEHICLE PATHWAYS (ROAD VEH.)

OIL → NAT. GAS → BIOMASS → ETHANOL → VEHICLE

Primary energy source
- PRIMARY SOURCE
  - Renewable
  - Fossil

Energy Carrier
- ENERGY CARRIER
  - Liquid Fuel
  - Gaseous Fuel

ICEV, HEV
FUTURE FUEL/VEHICLE PATHWAYS (ROAD VEH.)
Transport Fuels Today (94% petroleum-based)
CURRENT STATUS:
ALTERNATIVE FUELS AND VEHICLES

Alternatives to the internal combustion vehicles run on petroleum-based fuels have had limited success thus far.

- ICEVs >99% of the global on-road vehicle fleet
- 94% of transportation fuels come from petroleum.
- Alternative fuels are ~5-6% of total transport energy use, 2% of which is biofuels.
VEHICLE COMMERCIALIZATION TAKES TIME

Source: Cunningham, Gronich and Nicholas, presented at the NHA Meeting, March 2008.
INTRODUCING INNOVATIONS IN VEHICLES

time constants: 20-60 years

Figure 60: Market penetration rates of different vehicle technologies. Source: Automatic transmission penetration data from EPA [2006a]; Diesel penetration data from ACEA [2007].
REFUELING STATIONS FOR GASOLINE & ALTERNATIVE FUELS

Gasoline

CNG

Ethanol

Methanol

~100+ H₂ refueling stations worldwide
HISTORICAL DATA: MAJOR US TRANSPORTATION INFRASTRUCTURES
time constants: 30-70 years

FIGURE 3.8 Penetration of major U.S. transportation infrastructures. SOURCE: Adapted from Marchetti (1985); Ausubel (1996).
TRANSITIONS TAKE TIME

• Tech and cost issues for key technologies
  ▪ Fuel cells
  ▪ Advanced batteries
  ▪ Low-C fuel conversion pathways (Biofuels, renewables, fossil w/Carbon Capture and Sequestration)

• Market adoption of vehicle innovations
  ▪ Historically, 20-60 years from R&D to >35% of fleet

• Building new transportation infrastructure
  ▪ Historically, 30-70 years

• Policy driving major change (>10 years?)
NextSTEPS Program Overview

Dr. Joan Ogden, Director
Dr. Dan Sperling, Co-Director
Dr. Lew Fulton, Co-Director
Paul Gruber, Manager

www.steps.ucdavis.edu
Research consortia at ITS-Davis have evolved to consider more complex alt. fuel/vehicle rollouts

1998-2002
Fuel Cell Vehicle Modeling Program
FCV Technology

2003-2006
Hydrogen Pathways
FCVs & H2 Fuel Pathway

2007-2010
STEPS
Fuel/Vehicle Pathway Analyses & Comparisons

2011-2014
NextSTEPS
Scenarios & Transition Strategies

GOAL: Generate visions of the future grounded in technical and economic realities, a strong knowledge base for companies making long-term technology investments, and sophisticated analyses of future policies.
STEPS Program Outputs (2007-present)

• RESEARCH
  - Research papers (journals, conferences, tech. reports)
  - Sponsors’ workshops on research
  - White papers (key research results)

• OUTREACH/POLICY ENGAGEMENT
  - Service on CA, US, international panels, committees
  - Policymakers’ briefings and workshops
  - Testimony

• EDUCATION
  - 25 Graduate degrees by end of 2011 (mostly Ph.D. level); courses taught
Major Learning from STEPS: a portfolio approach is needed

Most important insight from STEPS research: **a portfolio approach** combining efficiency, alt fuels and VMT reduction will give us the best chance of meeting stringent goals for a sustainable transportation future.

Given the uncertainties, and the long timelines, it is critical to nurture a portfolio of key technologies toward commercialization and to start now.

All our work in characterizing pathways and comparing them flows toward this conclusion.
2011-2014 NextSTEPS (Sustainable Transportation Energy Pathways) Research Consortium

• Generates new insights about the transitions to a sustainable transportation energy future – Hydrogen, Biofuels, Electricity, Fossil Fuels
• Disseminates knowledge to decision-makers in industry and government
• 23 sponsors, 26 research leaders, 29 graduate students
• 120+ research projects
• Builds on the success of STEPS program (2007-2010)
NextSTEPS research focuses on: Scenarios & Transition Strategies (2011-2014)

- **Hydrogen**
  - Fuel Cell Vehicles
  - H2-ICE Vehicles

- **Biofuels**
  - Bio-ICE Vehicles
  - 2nd Gen Biofuels

- **Electricity**
  - Battery-electric
  - Plug-in hybrids

- **Fossil Fuels**
  - Bus. as usual
    - Natural Gas

  - Low-carbon fuels
    - incl. CCS

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- **Transition Dynamics**
  - (Consumer Demand & Behavior, Innovation & Business Strategy)

- **Models & Analyses**
  - (Infrastructure, Env./Energy Cost Analyses, Vehicle Tech. Eval., VMT/Travel Behavior)

- **Policy Analysis**
  - (market instruments, fuel requirements, sustainability standards)

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**Integrative Scenarios & Transition Strategies**
NextSTEPS projects are cross-comparative and focus on many geographies

19 recently completed
62 ongoing
38 proposed

= 122 projects

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* 2 or more fuels/vehicle technologies
** 3 or more regions
NextSTEPS will answer key transition questions over next 2 years (2013-2014):

- What will the *development of biofuels* look like?
- When does hydrogen become viable, and what will a *hydrogen transition* look like?
- How will *electric vehicles rollout* to consumers?
- What is the *role of natural gas* in transportation?
- What is the role and impact of *carbon capture and sequestration* in transportation?
- Which *policy mechanisms* are most effective?

**Scenarios for low carbon, sustainable futures:**

- How do *transitions vary by subsector*?
- What *mix of fuels and technologies* works for each region of the U.S. and world?
NextSTEPS analysis draws on wide range of ITS & UC Davis research

NextSTEPS (pathway comparisons, scenarios, transition strategies)

PH&EV Center (PEV modeling, consumer surveys)

China Center (consumers, infrastructure)

ULTRANS (VMT, mobility)

Contracts (NETL, NREL, CEC, CARB, Industry)

Policy Institute (energy, econ., env. policy analysis)

Energy Institute (biofuels)
23 NextSTEPS Consortium Sponsors

U.S. Department of Energy
U.S. Department of Transportation
United States Environmental Protection Agency
California Air Resources Board

State of California Energy Commission
Caltrans
South Coast Air Quality Management District
BMW
DAIMLER
Ford
Honda
GM
Chrysler
Nissan
Renault
Toyota
Volkswagen
bp
Chevron
IndianOil
Shell
Southern California Gas Company
SDG&E
NextSTEPS Program Research Highlights
Plug-in Electric Vehicles

With thanks to Dr. Tom Turrentine and Dr. Mike Nicholas

University of California, Davis
STATUS: PLUG-IN ELECTRIC VEHICLES 2012

• **OEMs:** Wide range of PEV products rolling out 2010-2013. OEMs specializing in drive trains and vehicle types (sports cars, sedan, crossovers, etc…)

• **California:** Major market launch of PEVs in 2011. PEV Collaborative formed in 2010. State plan developed in 2010. ZEV program expanding.

• **US National policy:** Significant incentives for PEVs, stimulus for US OEMs to make PEVs, Funds for manufacturing, infrastructure & rollout projects.

• **World:** Industrial policy, buyers incentives, rollouts, infrastructure development worldwide.

• **Infrastructure providers:** Emergence of many small and large firms into chargers and energy management systems.

• **Grid:** PEV charging, smart and renewable grid co-issues.

• **Batteries:** Lithium traction batteries entering mass production, prices still high, but appear to be dropping faster than many expected.

• **Consumer:** We will see. Concern on market after early buyers.
RECENT UC DAVIS RESEARCH FINDINGS: CONSUMERS AND PEVs

- Most US drivers will charge at home at night, requiring in-home chargers.
- Up to 50% of US consumers may have access to plug in at home and even more if charging at work is an option.
- Driving and charging behaviour influence the potential benefits of PEVs.
- PEV drivers like feel of vehicle. PEVs “different,” in market, harder to evaluate, our research with consumers is encouraging. Early market not a big problem.
We know that limited range of BEVs will reduce the potential market, but how much?

• Studies => that annual market for EVs (with about 100-170 km of range) in California would be around 15-20% of sales.

• Most of today’s MINI E drivers say 160 km works 90% of the time.

On average, how many kilometers did you drive the MINI E each day? (n = 102)

The PHEV market is more uncertain.

Would seem larger than BEV markets, but less studied.
How much does the lack of garage limit market?

- Berlin 7%, San Francisco 20% have a garage
- In USA, California about 50% of new car buyers have a place ~8 meters from electricity each night
Workplace charging and Public charging could enable fuller use of PEVs

- Work charging +6%
- Public “Level 2” Charging +4%
- Fast Charging +6 to 18%
Hydrogen and Fuel Cell Vehicles
FUEL CELLS: BETTER ROUTE -> ELECTRIC CAR?

$H_2$ fuel cell vehicles have zero tailpipe emissions, high efficiency, good performance, fast refueling.

Several hundred experimental $H_2$ Fuel Cell vehicles worldwide; automakers see commercial readiness ~ 2015-2020.

Source [http://www.h2cars.de/](http://www.h2cars.de/)
Automakers see H2 FCVs + Battery EVs

What is a Fuel Cell?

• A fuel cell is an electrochemical energy conversion device that combines hydrogen and oxygen in the presence of an electrolyte to produce electricity, heat and water.
How a $\text{H}_2$ Fuel Cell Works
H₂ SUPPLY PATHWAYS

Like electricity, hydrogen is an energy carrier that can be produced from widely available primary energy resources.

Wind

Solar

Biomass

Coal w/CO2 Sequestration

Natural Gas

Nuclear
Challenges on the H2 FCV Pathway

• **Technology.** (PEM) fuel cells, H2 storage on vehicles, and technologies for zero-carbon hydrogen production.

• **Logistical.** Adoption of hydrogen will require a widespread hydrogen infrastructure to fuel vehicles.

• **Transition issues / coordination of stakeholders.** H2 transition => multiple changes: new types of vehicles, new fuel infrastructure, new low-carbon primary energy resources. Compatibility w/existing fuel infrastructure more problematic for H2 than for elec. or liquid synthetic fuels. Geographic focussed rollout of early vehicles/infrastructure.

• **Resource/Sustainability Issues.** Many potential low-C resources for making H2. For full GHG benefits, need low-C H2 production.

• **Policy challenges.** It is almost certain that technology-specific policies will be needed to support a hydrogen transition. H2 should be seen as part of a broad portfolio of approaches to GHG emissions reduction, energy security.
Challenges: Building H2 Infrastructure
What Will a H2 Infrastructure Look Like?

On-site H₂ production

Existing energy infrastructure

On-site H₂ production

Central H₂ production

CO₂ capture & storage

Central H₂ Plant

Plant to city-gate transmission

Local distribution network
Challenges: Building H2 Infrastructure

Improved strategies for early H2 networks

Vehicles placed by population

Cluster strategy:
Co-locate early FCVs and H2 stations in a few cities in region

H2 Pathways CA H2 Highway Network Study 2005:
Ave. travel time to 17 optimally placed stations in LA Basin
= 16 minutes

UCD H2 Rollout Study 2010:
Ave. travel time to 16 optimally placed stations in LA Basin
= 4 minutes

Home and Neighborhood Refueling: Tri-Generation System for Residential Heat, Power, and H2

Home-size combined system, which provides Hydrogen to FCV while supplying Electricity and Heat to household.

Biofuels

With thanks to Dr. Nathan Parker

University of California, Davis
Challenges on the Biofuel Pathway

- **Sustainability challenges.** Biofuels at large scale would place large demands on scarce land and water resources.

- **Technical challenges.** Time is needed to develop and demonstrate cellulosic biofuel technologies at commercial scale.

- **Logistical challenges.** Alcohol fuels face limited market without large scale deployment and consumer acceptance of E85 in flexible-fuel vehicles.

- **Policy challenges.** Policies need to be crafted that encourage investment in cellulosic biofuels that are sensitive to the sustainability challenges.
UC Davis research on future biofuel supply

• Spatial supply chain optimization model to project future biofuel supplies

• A wide range of feedstock scenarios and technology scenarios have been considered for the 2018 to 2022 timeframe.
Feedstocks Agricultural

Residues

Historical Ag. Residues @ $50/dry ton
High Ag. Residues @ $50/dry ton
Historical Ag. Residues @ $100/dry ton
High Ag. Residues @ $100/dry ton
Historical Ag. Residues @ $150/dry ton
High Ag. Residues @ $150/dry ton

Energy Crops

Baseline Energy Crop @ $70/dry ton
High Energy Crop @ $70/dry ton
Baseline Energy Crop @ $90/dry ton
High Energy Crop @ $90/dry ton
Baseline Energy Crop @ $120/dry ton
High Energy Crop @ $120/dry ton

Biomass available (dry ton/eq. mile)
0
1 - 50
54 - 100
106 - 171
172 - 267
296 - 594
601 - 988

0
1 - 70
134 - 194
348 - 461
618 - 800
801 - 1066
1067 - 1417
Municipal Solid Waste (MSW)
Biofuels could supply 6.5% to 22% of total US Light Duty Vehicle fuel demand in 2018

- Estimates for total sustainably available biofuels vary widely.
- At $3/gge-$4/gge
  - 2-10% from wastes and residues
  - 0-7% from energy crops and pulpwood
  - 1-5.5% from corn and soy
A simulated industry to meet the US Renewable Fuel Standard (RFS)

- To achieve federal mandated volumes:
  - 200 to 250 commercial scale cellulosic biorefineries needed, costing $100-360 Billion.
  - Corn ethanol and cellulosic biofuels from MSW and forest residues are the low cost pathways.
Resource Consumption by Biorefineries
STEPS Book

• Print version Available on Amazon (or order from your local bookstore)

• Free pdf Download at http://www.its.ucdavis.edu/research/profile/stepsbook.php