U.S. Department of Energy
Office of Fossil Energy

Cross Cutting Analysis

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Hydrogen Coordination Meeting

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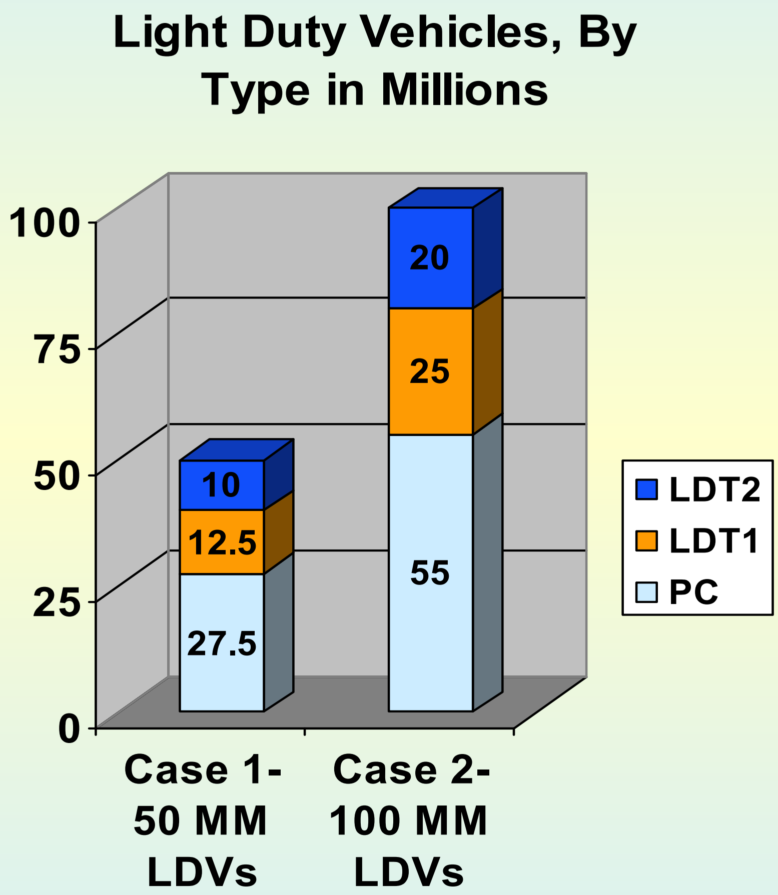
Natural Gas and Coal Derived Hydrogen FCV System Analysis

- Two scenarios were developed to estimate the impact of natural gas and coal-derived hydrogen in fuel cell vehicles (FCVs)
  - Case 1 evaluated the impact of 50 million vehicles
  - Case 2 evaluated the impact of 100 million vehicles
- Purpose was to evaluate the impact on:
  - Fossil fuel demand
  - CO_2 emissions
  - Criteria pollutants
  - Energy consumption/security
  - Number and cost of hydrogen plants needed

Hydrogen FCV System Analysis Fleet Assumptions



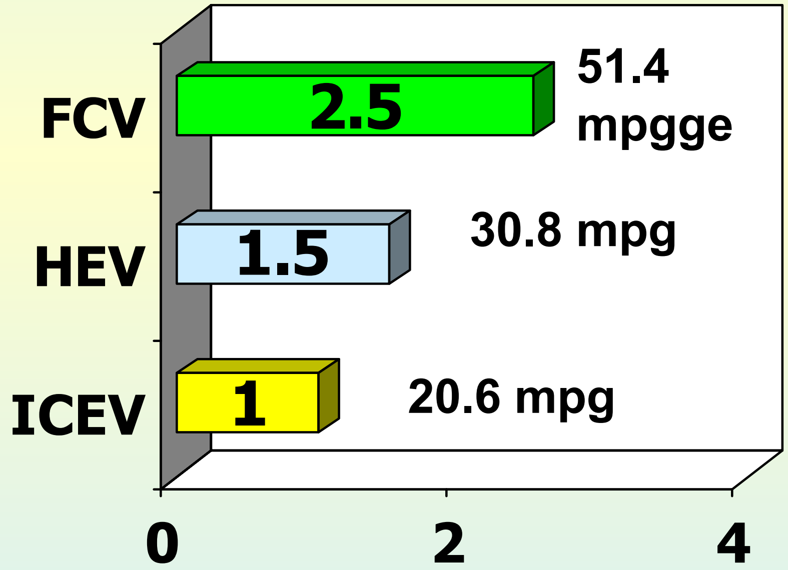
- Case 1 – 50 million light duty vehicles
- Case 2 – 100 million light duty vehicles
- Fleet composition is shown in the chart based on recent US fleet composition

PC – Passenger Cars;
LDT1 – Light Duty Truck Class 1 (up to 6,000 lbs) ;
LDT2 – Light Duty Truck Class 2 (6,001 to 8,500 lbs)

Hydrogen FCV System Analysis Efficiency Assumptions

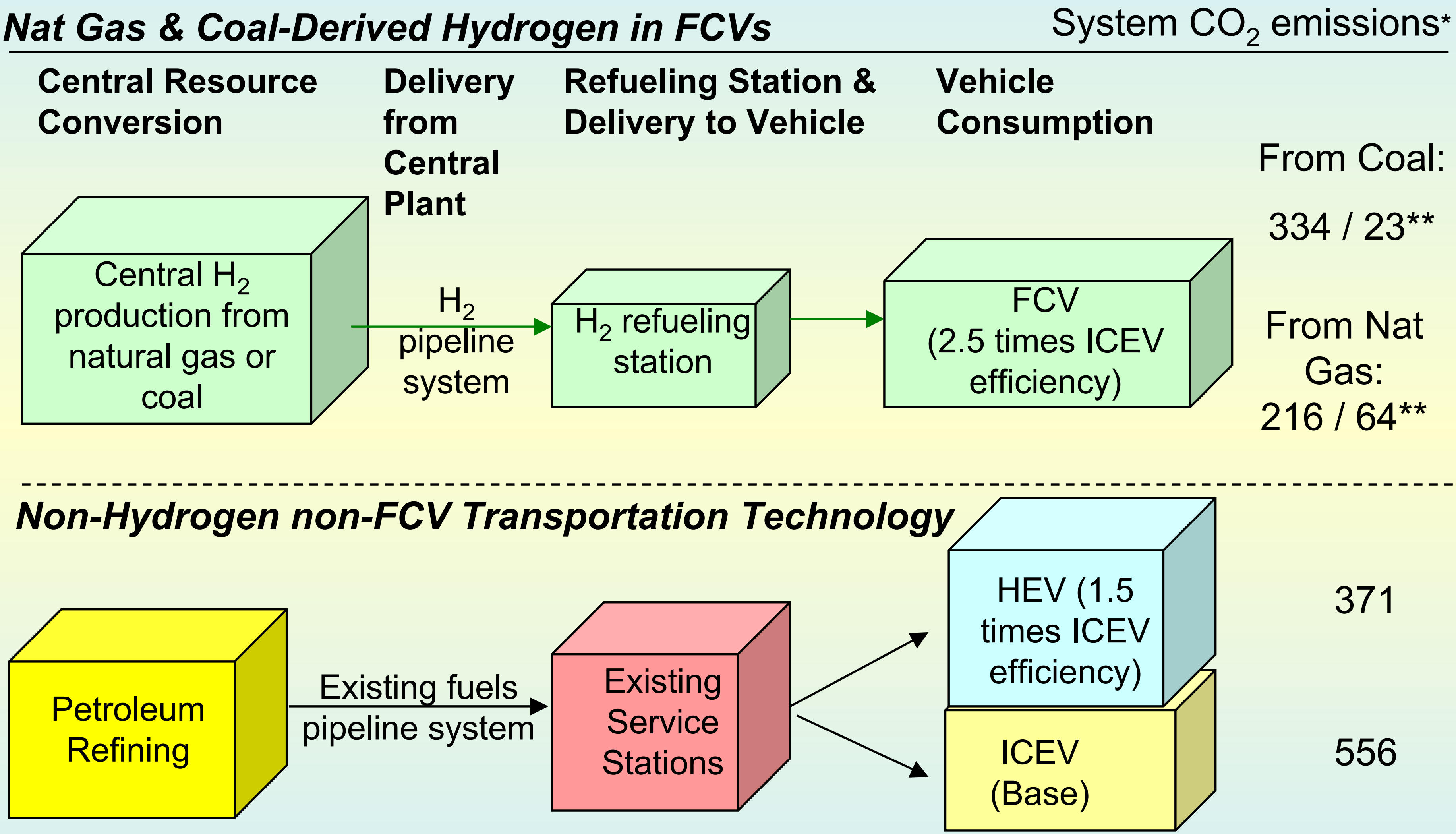
- Future internal combustion engine vehicle (ICEV) is the reference technology
- Future hybrid electric vehicles (HEV) assumed to travel 1.5 times more per Btu than ICEVs
- FCVs assumed to travel 2.5 times more per BTU than ICEVs

Relative Fleet Mile/Gal of Gasoline Equivalent



ICEV reference technology is based on the Argonne National Laboratory GREET 1.5a model for the assumed fleet mix with "Long-Term Technology". ICEV vehicle fleet operation energy consumption is 5590 Btu/mile or 20.6 mpg.

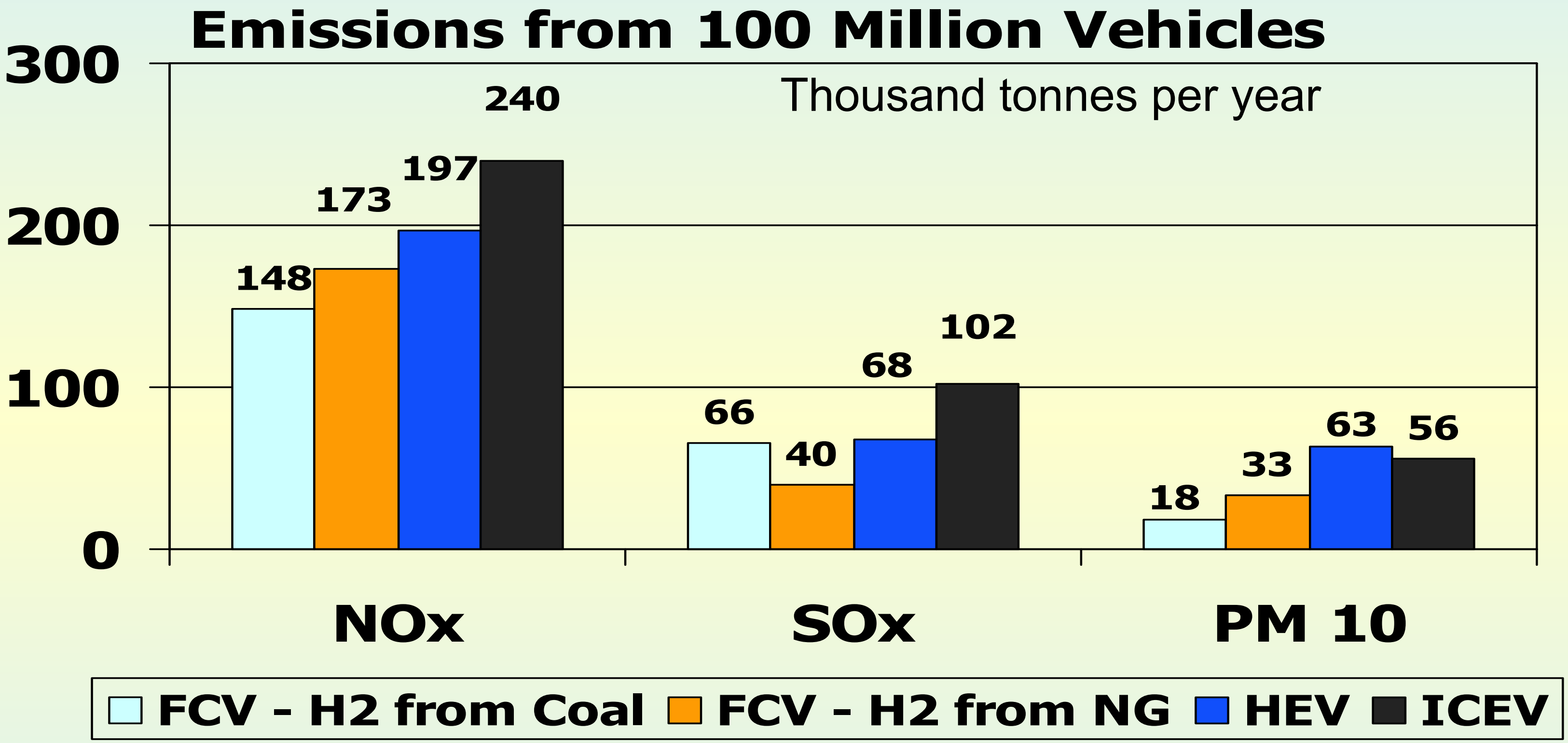
System Analysis Boundaries and Pathways



*CO_2 emissions in millions of tons per year for each 100 million vehicles

** Values are without / with CO_2 sequestration.

System Analysis Comparison of Hydrogen from Coal & Natural Gas used in FCVs versus Gasoline HEVs and ICEVs (a)



(a) FCVs (2.5 times as efficient as future ICEVs) powered by coal or natural gas-derived hydrogen compared to gasoline-powered HEVs (1.5 times as efficient as future ICEVs). Analysis performed using GREET Model 1.5a data and TMS model.

Production of hydrogen from coal and natural gas and use in FCVs will reduce criteria pollutants compared to future HEV and ICEV systems.

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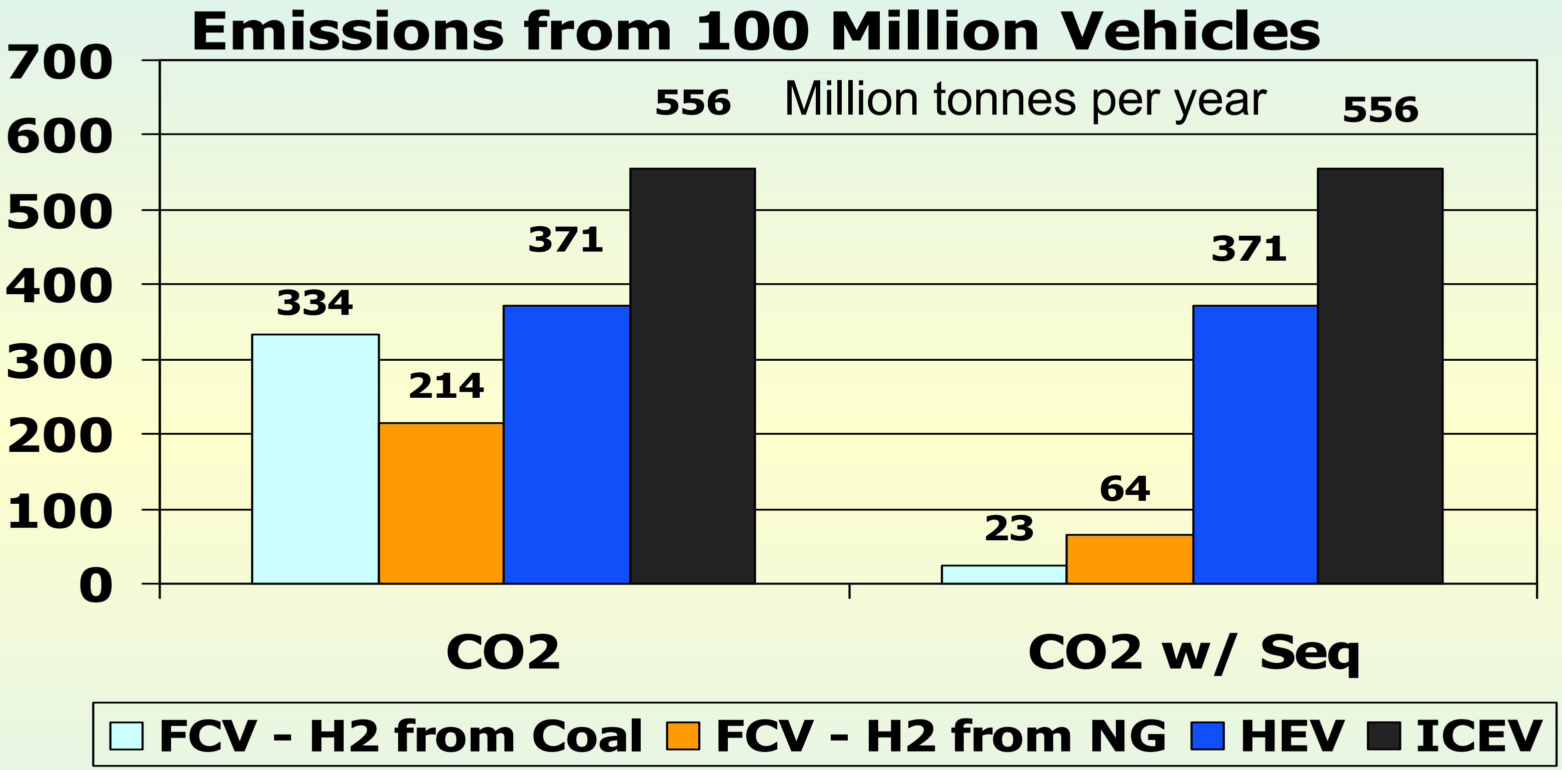

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Production of hydrogen from coal and natural gas and use in FCVs will reduce CO_2 emissions compared to future HEV and ICEV systems. With sequestration, CO_2 emissions will be nearly eliminated.

FCV and Hydrogen from Coal Cases vs. HEV and ICEV using Petroleum (a)

	Case 1	Case 2
Vehicle Miles Traveled (billion miles/year)	560	1120
Hydrogen demand for FCVs, million tons per year (b)	12.1	24.2
Number of hydrogen plants required	94	187
Total capital cost, (billion of current dollars)	40.0	79.5
Total coal required, million short tons per year	86.6	173.1
Total coal required, as % of 2001 U.S. coal demand	8.2%	16.5%
Memo: Petroleum demand for alternative technology systems (million barrels/day)		
Future HEVs - 1.5 times as efficient as future ICEVs	1.0	2.0
Future ICEVs	1.5	3.0

(a) Future hydrogen production will likely be derived from a combination of fossil, renewable, and nuclear energy. This scenario assesses the impact of coal-derived hydrogen only.

(b) Based on future FCVs that are 2.5 times as efficient as future ICEVs.

Production of low-cost hydrogen from coal will reduce reliance on imported oil and increase the proportion of domestic energy resources used in our nation's energy mix.

FCV and Hydrogen from Natural Gas vs. HEV and ICEV using Petroleum (a)

	Case 1	Case 2
Vehicle Miles Traveled (billion miles/year)	560	1120
Hydrogen demand for FCVs, million tons per year (b)	12.1	24.2
Number of hydrogen plants required	89	177
Total capital cost, (billion of current dollars)	12.6	25.1
Total natural gas required, trillion cubic feet per year	1.87	3.74
Total nat gas required, as % of 2001 U.S. demand	8.3%	16.5%
Memo: Petroleum demand for alternative technology systems (million barrels/day)		
Future HEVs - 1.5 times as efficient as future ICEVs	1.0	2.0
Future ICEVs	1.5	3.0

(a) Future hydrogen production will likely be derived from a combination of fossil, renewable, and nuclear energy. This scenario assesses the impact of natural gas-derived hydrogen only.

(b) Based on future FCVs that are 2.5 times as efficient as future ICEVs.

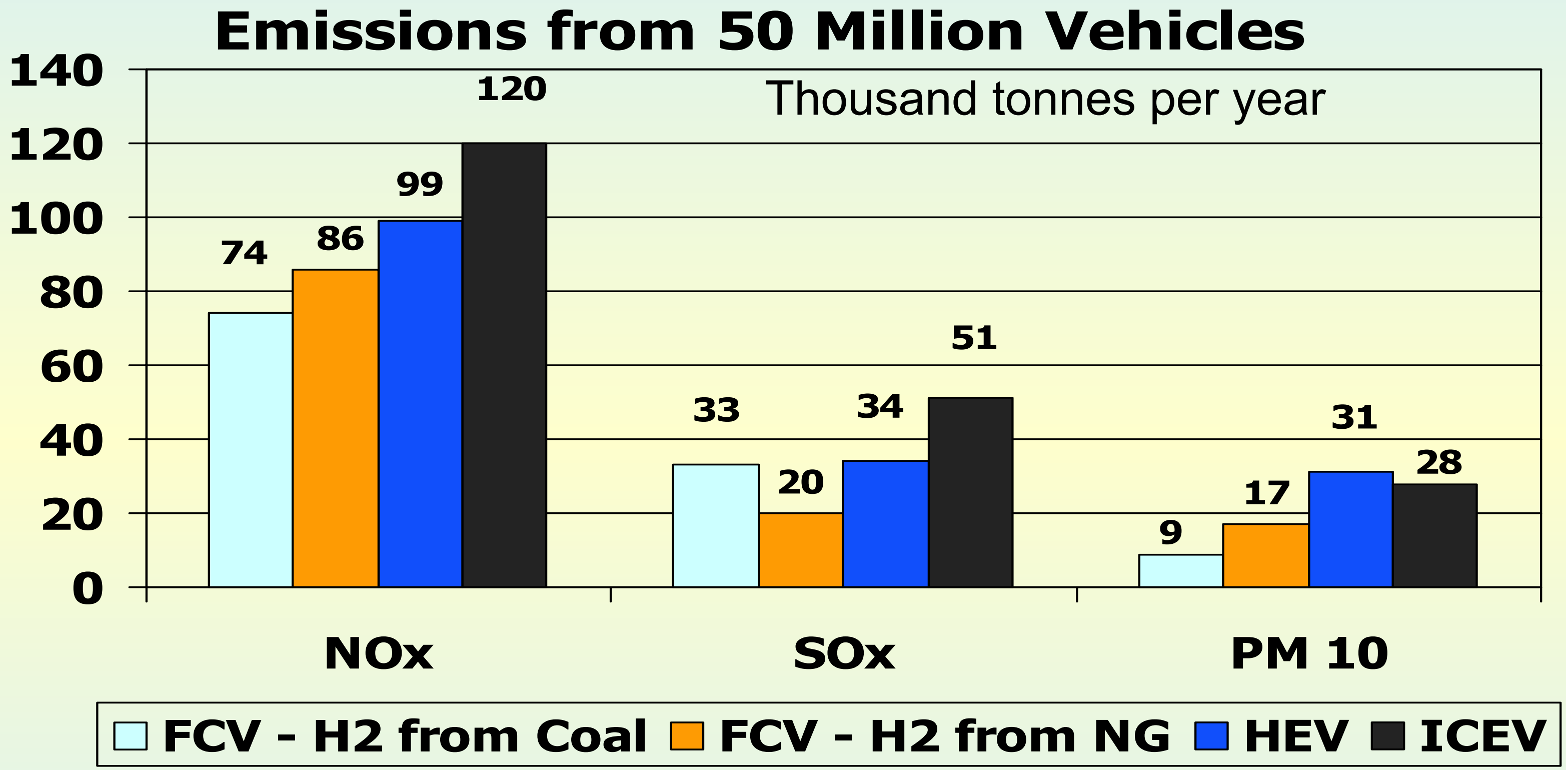
Production of low-cost hydrogen from natural gas will reduce reliance on imported oil.

Conclusions

- **Coal and natural gas-derived hydrogen and use in FCVs can:**
  - Achieve energy security,
  - Reduce criteria pollutants,
  - Reduce CO_2 emissions, when combined with carbon sequestration technology
- **Hydrogen demand for 100 million FCVs can easily be met with natural gas or domestic coal resources in new plants**
- **Systems with hydrogen derived from coal or natural gas without sequestration, used in FCVs emit less CO_2 than in future HEV systems, and significantly less CO_2 than future ICEV systems**

Back-Up

System Analysis Comparison of Hydrogen from Coal & Natural Gas used in FCVs versus Gasoline HEVs and ICEVs (a)



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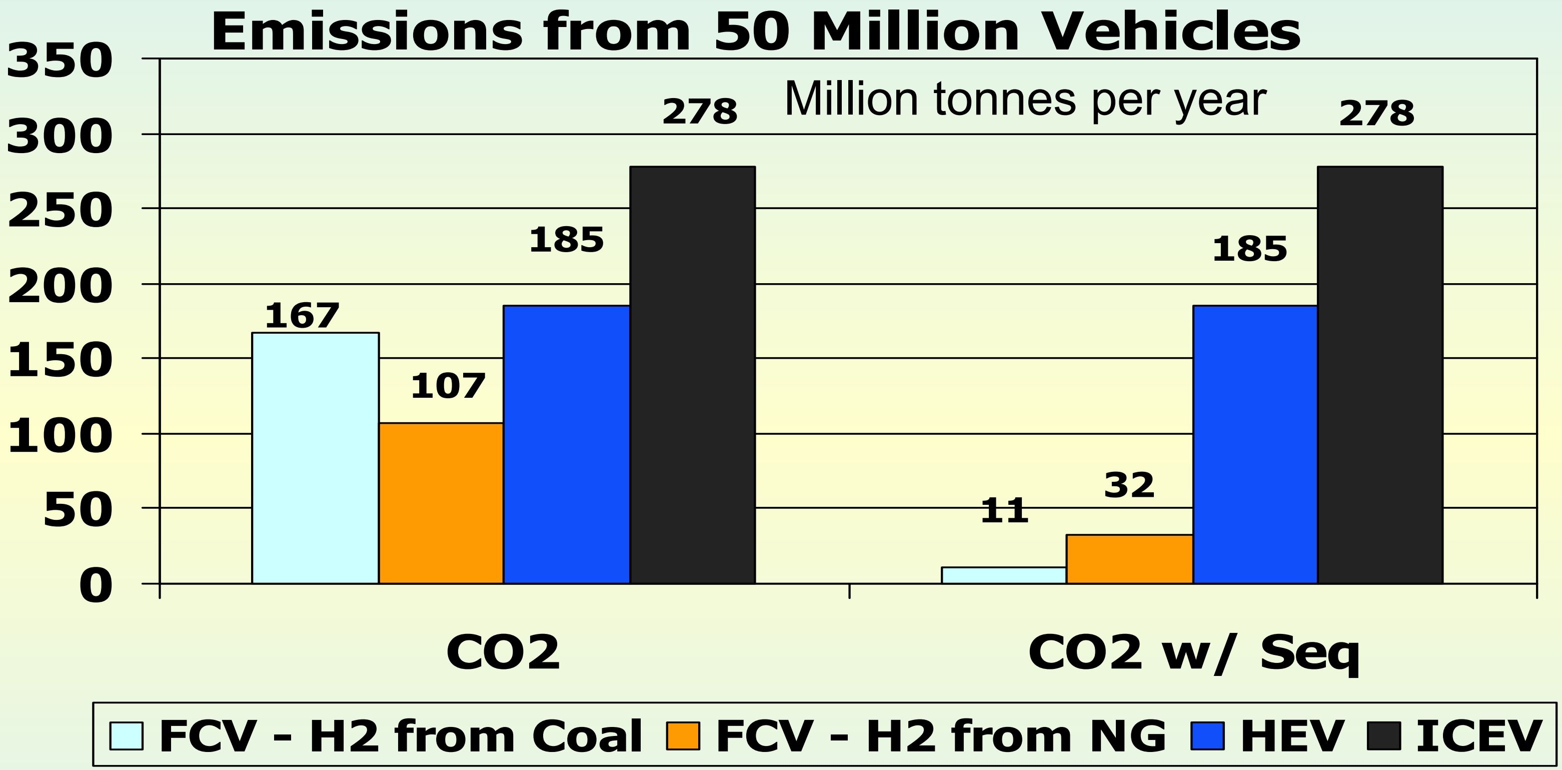

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Future Hydrogen from Coal Plant Performance and Cost Assumptions

	Hydrogen from Coal Plant Mitretek Case 3(a)
Carbon sequestration	Yes
Hydrogen Plant Capacity (million scf/stream day)	158
Hydrogen Plant Operating Factor	85%
Hydrogen, million tons/year per plant	0.13
Coal, short tons/day (as received) per plant	3000
Coal, million short tons/year per plant	0.931
Capital cost, $million (current dollars)	425

(a) Advanced E-gas gasifier plant with membrane separation based on Mitretek Systems estimates.

Source: *Hydrogen from Coal;* Mitretek Technical Paper, MTR 2002-31, Case 3

Hydrogen from Natural Gas Plant Performance and Cost Assumptions

	Hydrogen from Natural Gas Plant (a)
Carbon sequestration	75% with SMR
Hydrogen Plant Capacity (million scf/stream day)	150
Hydrogen Plant Operating Factor	90%
Hydrogen, million tons/year per plant	0.137
Natural Gas, million scf/day per plant	65.5
Natural Gas, billion scf/year per plant	21.5
Capital cost, $million (current dollars)	142

(a) Steam methane reformer (SMR) plant.

Sources:

1) *Hydrogen Production Facilities Plant Performance and Cost Comparisons*, Final Report, March 2002, Parsons Infrastructure and Technology Group, Inc.

2) TMS, Inc. model

FE System Analysis Boundary Definitions

- **Fuel**
  - Consists of central resource conversion to fuel, and fuel delivery to refueling stations
- **Vehicle Operations**
  - Consists of refueling station delivery of fuel to vehicle, and fuel consumption in the vehicle
- **This system analysis does not include resource extraction and delivery to a central conversion plant**
  - Preliminary review indicates that conclusions will not be materially affected with the addition of the resource extraction step
  - Resource extraction will be added in subsequent FE analyses

Energy Use Assumptions Long-Term Technologies - LHV Basis(a)

	Fuel	Vehicle Operation	
	Btu/mi	Btu/mi	mpgge (b)
Used in FE Analysis	Yes	Yes	Yes
ICEV	1226	5590	20.6
HEV (1.5 times as efficient)	817	3728	30.8
FCV (2.5 times as efficient)	1019 (c)	2236	51.4
Memo: Near-term technology energy use			
ICEV	1366	6159	18.7

Stages used in FE Analysis: Fuel – resource conversion at production plants and delivery to refueling station; Vehicle Operation – from refueling station, delivery to vehicle and use.

(a) Assuming light duty vehicle fleet of 55% passenger cars, 25% Light Duty Truck Class 1 (LDT1) and 20% LDT2, using long-term technology. Based on Argonne National Laboratory's GREET model 1.5a for ICEVs. HEV and FCV efficiencies have been adjusted to 1.5 and 2.5 times better (MPG basis), respectively, in vehicle operation than ICEVs.

(b) Miles Per Gallon of Gasoline Equivalent (mpgge) based on 115,000 Btu (LHV) per gallon of gasoline.

(c) Based on steam methane reforming hydrogen production.