Global Hydrogen Resource Analysis
(Hydrogen Implementing Agreement, Task 30A)

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Sandia National Laboratories
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Project ID: AN038

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Timeline

- Project start date: June 2010
- Project end date: December 2013
- Percent complete: 80%

Barriers

- Barriers addressed
  - Costs of producing and delivering hydrogen.
  - Economic and investment hurdles
  - Understanding of hydrogen production options

Budget

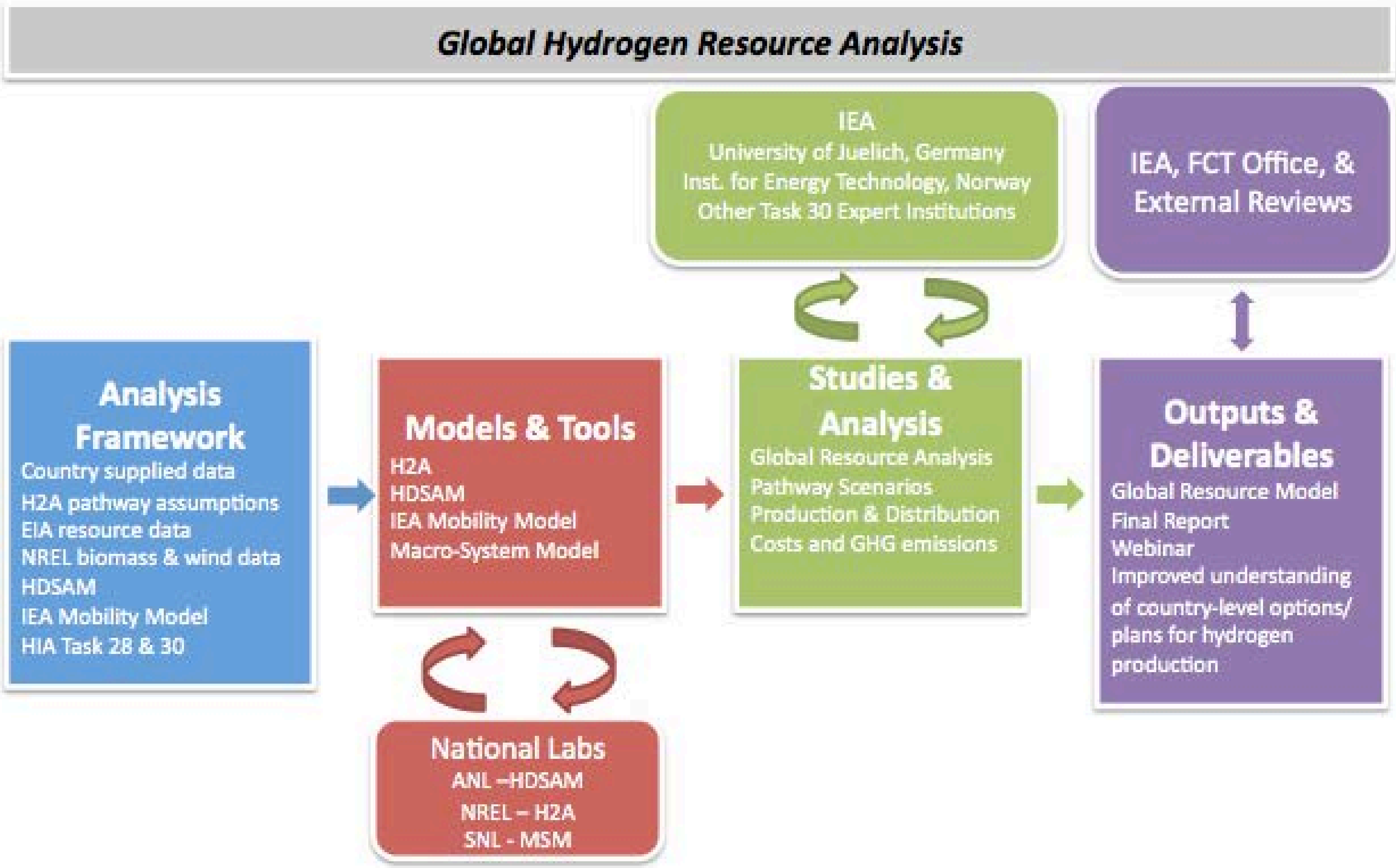
- Total project funding
  - DOE share: $233K
  - Contractor share: $0K
- Funding received in FY12: $50K
- Funding for FY13: $183K

Partners

- Susan Schoenung (Task 30 Co-operating Agent)
- Jochen Linssen (Task 30 Co-operating agent)
- Task 30 country experts
- Project lead: T. Drennen

Project Overview

Approach



Technical Approach

Relevance

- This project is a subtask of the larger IEA Hydrogen Implementing Agreement **Task 30 (Global Hydrogen Systems Analysis).** Task 30 overall goal:

  "Perform comprehensive technical and market analysis of H_2 technologies and resources, supply and demand related to the projected use of H_2 in a low-carbon world."

- Task 30 Structure (subtask leaders)
  - **Subtask A** (T. Drennen, Sandia National Laboratories, US): Global Hydrogen Resources
  - **Subtask B** (J. Linssen, Research Center Juelich, Germany): Harmonized hydrogen technology database
  - **Subtask C** (K. Espegren, Institute for Energy Technology, Norway): Collaboration with IEA Analytics
  - **Subtask D** (M. Quemere, Électricité de France and Alain le Duigou, CEA, France): Hydrogen for Energy Storage
- Participants
  - France, Germany, Italy, Japan, Norway, Spain, Sweden, United Kingdom, United States
- Timing
  - June 2010 through December 2013
  - Expert meetings two times per year in person; regularly scheduled web meetings

Objectives

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Relevance

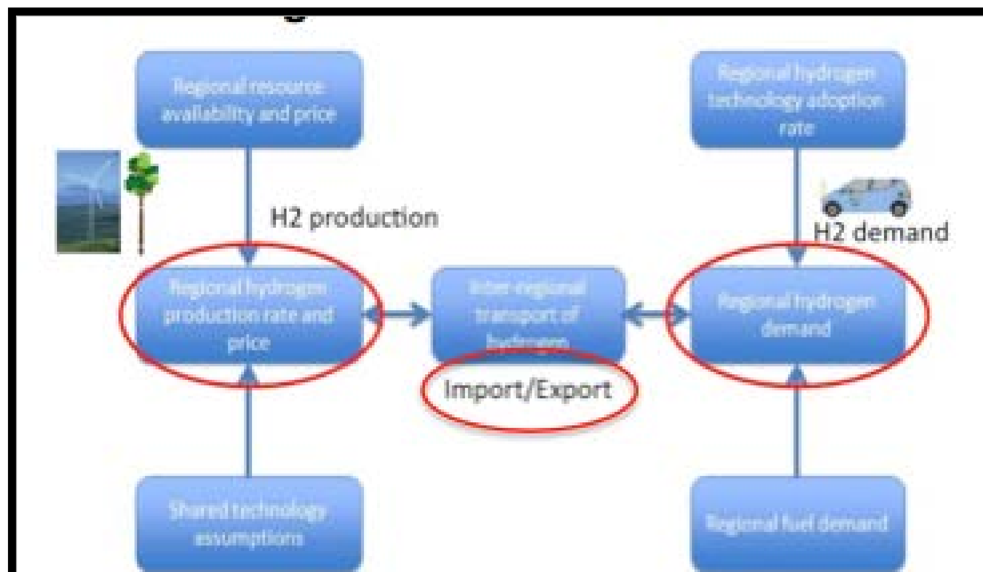
The specific objectives of Task 30 Subtask A are:

1. To analyze potential hydrogen production and distribution pathways for participating countries
2. To develop a user-friendly pathways analysis tool that allows users the ability to:
   - Understand the resource options and constraints to meeting future hydrogen demand for various fuel cell vehicle market shares; and to
   - Estimate potential petroleum savings and greenhouse gas emission reductions associated with various scenarios.
3. To collaborate with IEA (Paris) analysis processes and support the HIA Executive Committee in the liaison with IEA analysts

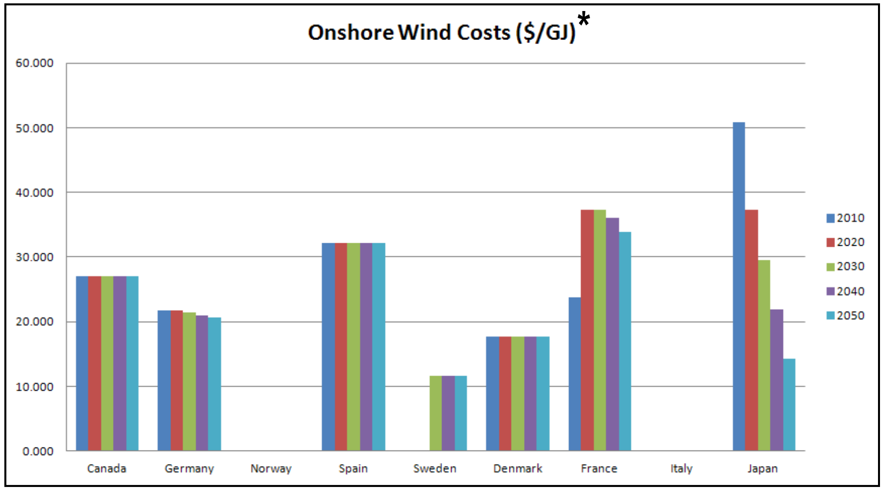
Technical Approach

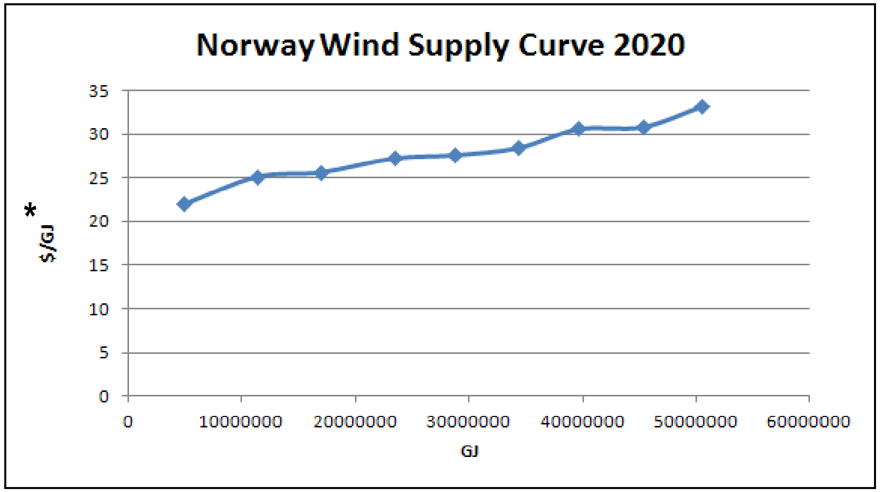
- **Developed dynamic H_2 pathways analysis tool that:**
  - Projects H_2 demand by country specific fuel-cell vehicle vehicle scenarios
  - Calculates least-cost pathways for H_2 supply by country, including feedstock, production, distribution (regional and long-distance), and carbon costs leveraging existing H2 production and distribution models (H2A, HDSAM, MSM)
  - Estimates petroleum savings and transport-related GHG emission reductions
  - Compares feedstock use for H_2 production through 2050 with 2010 primary energy consumption

- **Data input**
  - Country-level data supplied by country experts (Task 30A)
  - Where country-level data not available, U.S.-based analysis estimates used.
  - Integration with Task 30B (Technology Database) and Task 28 (Distribution) expected by year end



- Required data from participating countries includes:
  - Feedstock availability for H_2 production by type, cost, and quantity from 2010 to 2050
  - H_2 production technology assumptions (efficiencies, cost)
- Iterative process with countries to improve data consistency.
  - Example shown: Self-reported onshore wind costs by country available for H_2 production
  - Some countries (U.S. and Norway) provided supply curves for wind; many countries provided static estimates (not dependent on quantity demanded)





*1 GJ H_2 (LHV) = 8.33 kg H_2

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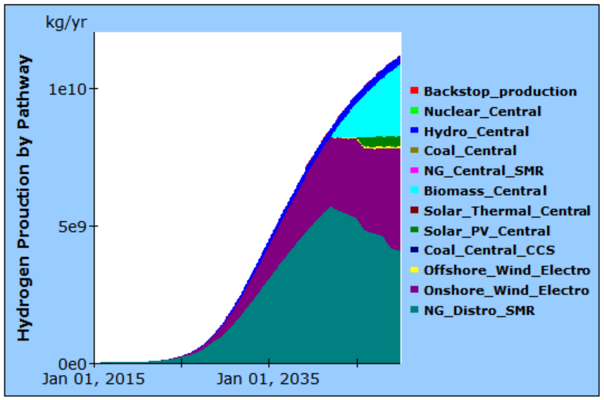
Accomplishments and Progress

Results summarized by region (Europe, Pacific, North America) and then participating country. Example shown here is for H_2 demand by European country and least-cost pathways.

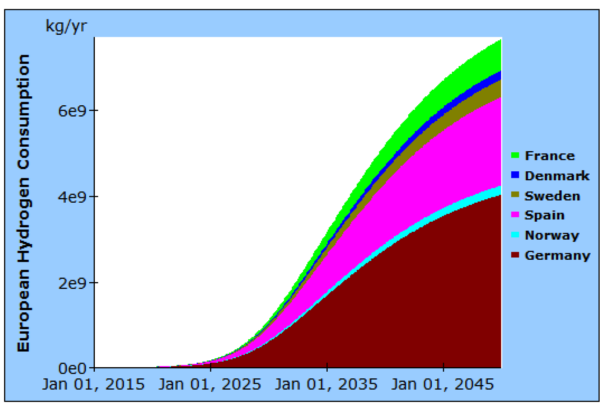
INTERNATIONAL
PACIFIC
JAPAN
EUROPE
FRANCE
DENMARK
SWEDEN
SPAIN
NORWAY
GERMANY
NORTH AMERICA
CANADA
UNITED STATES

Europe



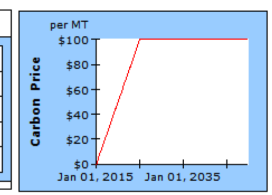
Delivered H2 Price	Germany	Norway	Spain	Sweden	Denmark	France
Germany	51.40	81.90	81.33	75.61	121.93	100.86
Norway	79.34	53.96	87.99	66.97	120.79	112.33
Spain	92.56	101.78	40.16	94.92	131.14	101.04
Sweden	82.56	77.30	90.65	44.44	121.31	114.59
Denmark	75.90	77.32	73.87	68.32	97.43	107.88
France	78.30	92.34	67.25	85.08	131.35	73.95

Columns are Supply and Rows are Consumption (Vertically it is the price supplied to the horizontal country)



Carbon Pricing

initial carbon price	$0.00 per MT
first level carbon price	$100.00 per MT
first level year	2025
second level carbon price	$100.00 per MT
second level year	2050



Germany meets projected H_2 demand for 40% HFV 2050 market share with natural gas (SMR) and centralized coal w/o CCS. Increased natural gas demand a small fraction (6%) of current natural gas consumption.

INTERNATIONAL

PACIFIC

JAPAN

EUROPE

FRANCE

DENMARK

SWEDEN

SPAIN

NORWAY

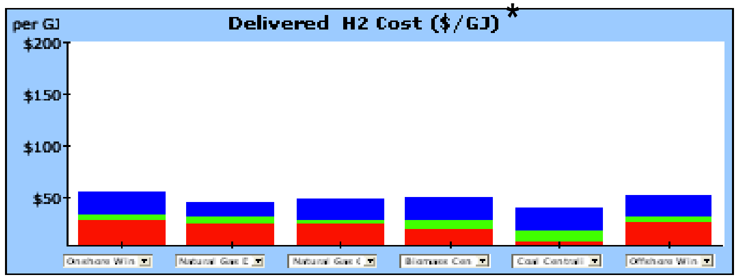
GERMANY

NORTH AMERICA

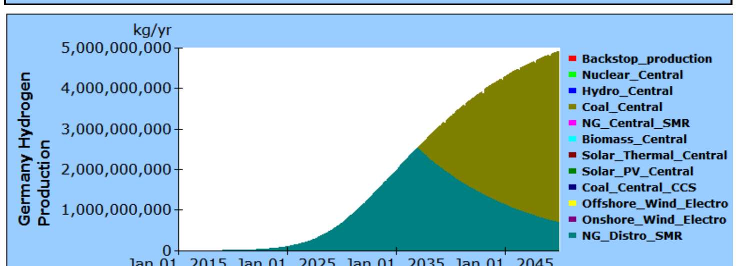
CANADA

UNITED STATES

Germany



Feedstock	Supply Available for H2	Price
Natural Gas Distributed	1,390,820,423,281,740 GJ/yr	$17.89 per GJ
Natural Gas Centralized	1,375,515,659,339,170 GJ/yr	$17.89 per GJ
Coal Centralized	1,865,669,876,670,310 GJ/yr	$4.28 per GJ
Coal Centralized CCS	1,865,669,876,670,310 GJ/yr	$4.28 per GJ
Solar PV	0 GJ/yr	$9,999.00 per GJ
Solar Thermal	0 GJ/yr	$0.00 per GJ
Biomass	3,366,935,483.87 GJ/yr	$10.11 per GJ
Onshore Wind	365,536.55 GJ/yr	$20.61 per GJ
Offshore Wind	2,350,899.31 GJ/yr	$19.06 per GJ
Hydro	0 GJ/yr	$9,999.00 per GJ
Nuclear	0 GJ/yr	$9,999.00 per GJ



Feedstock | Conversion | Distribution | GHG Tax

Distrubution Cost

	Price
Natural Gas Distributed	$13.75 per GJ
Natural Gas Centralized	$21.50 per GJ
Coal Centralized	$21.50 per GJ
Coal Centralized CCS	$21.50 per GJ
Solar PV	$21.50 per GJ
Solar Thermal	$21.50 per GJ
Biomass	$21.50 per GJ
Onshore Wind	$21.50 per GJ
Offshore Wind	$21.50 per GJ
Hydro	$21.50 per GJ
Nuclear	$21.50 per GJ

Feedstock Multipliers

	Price	Supply
Natural Gas	1.00	1.00
Onshore Wind	1.00	1.00
Offshore Wind	1.00	1.00
Coal	1.00	1.00
Solar PV	1.00	1.00
Solar Thermal	1.00	1.00
Biomass	1.00	1.00
Hydro	1.00	1.00
Nuclear	1.00	1.00

Policy Type: Renewables / Non-GHG Emissions

Policy Percentage Effected	0.00 %

*1 GJ H_2 (LHV) = 8.33 kg H_2

Pathways Analysis (Germany w/ $100 GHG Tax)

Accomplishments and Progress

With $100 GHG tax, Germany continues to meet demand domestically but H_2 production shifts away from coal to biomass gasification.

INTERNATIONAL

PACIFIC

JAPAN

EUROPE

FRANCE

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SWEDEN

SPAIN

NORWAY

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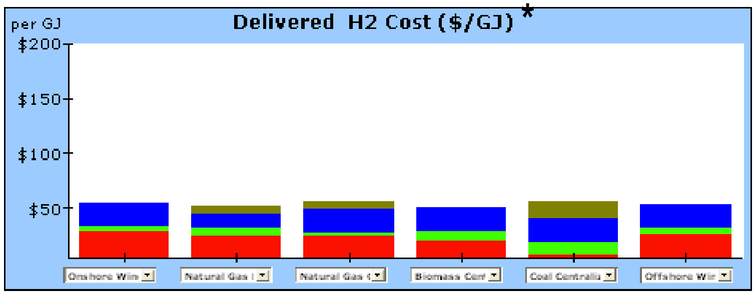
NORTH AMERICA

CANADA

UNITED STATES

Germany



Feedstock | Conversion | Distribution | GHG Tax

Feedstock	Supply Available for H2	Price
Natural Gas Distributed	1,390,820,265,742,800 GJ/yr	$17.89 per GJ
Natural Gas Centralized	1,375,515,503,533,810 GJ/yr	$17.89 per GJ
Coal Centralized	1,865,671,641,791,040 GJ/yr	$4.28 per GJ
Coal Centralized CCS	1,865,671,641,791,040 GJ/yr	$4.28 per GJ
Solar PV	0 GJ/yr	$9,999.00 per GJ
Solar Thermal	0 GJ/yr	$0.00 per GJ
Biomass	2,091,393,628.12 GJ/yr	$10.11 per GJ
Onshore Wind	365,536.55 GJ/yr	$20.61 per GJ
Offshore Wind	2,350,899.31 GJ/yr	$19.06 per GJ
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Feedstock Multipliers

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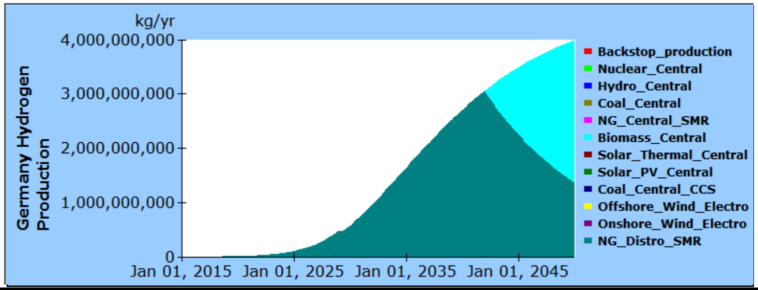
Solar Thermal	1.00	1.00
Biomass	1.00	1.00
Hydro	1.00	1.00
Nuclear	1.00	1.00



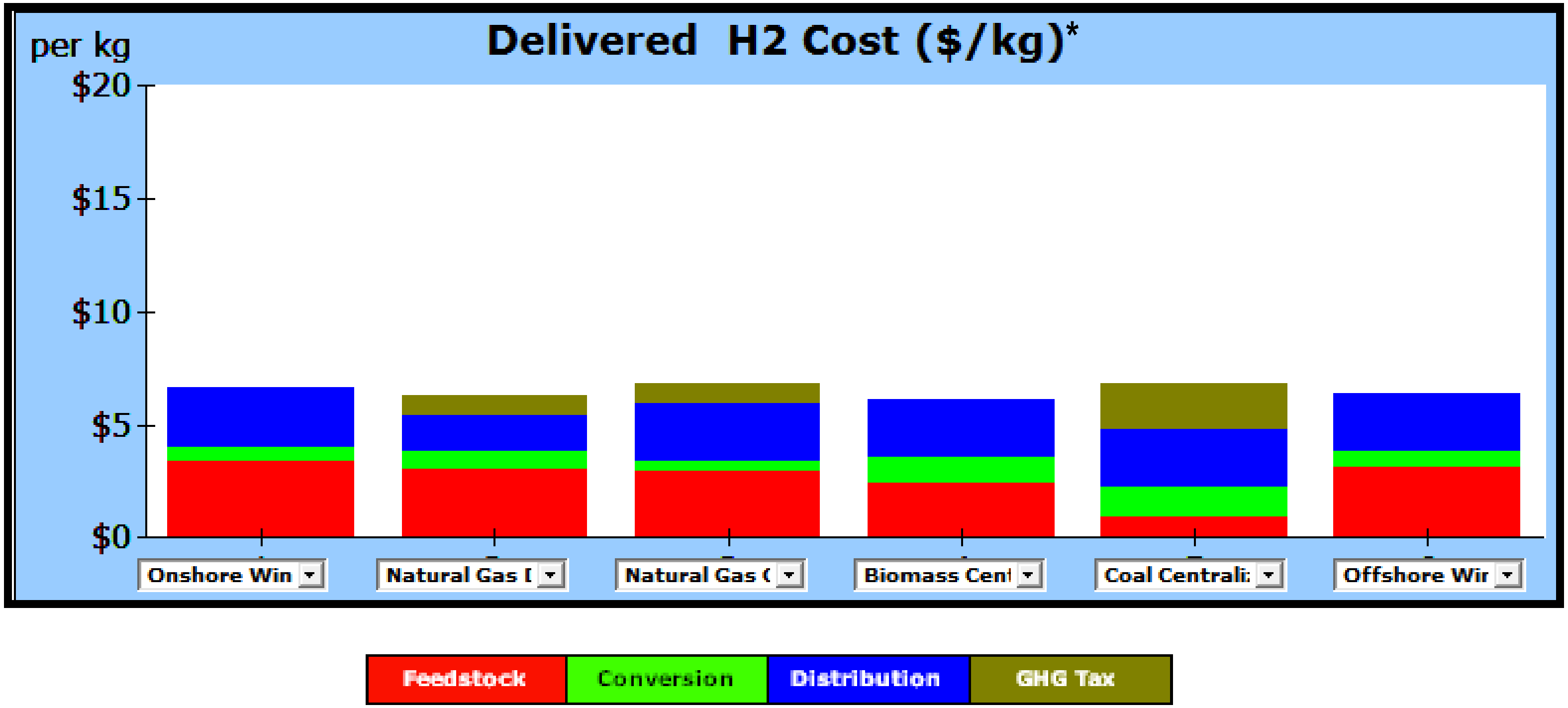
Policy Type: Renewables / Non-GHG Emission:

Policy Percentage Effected	0.00 %

*1 GJ H_2 (LHV) = 8.33 kg H_2

Cost Analysis for Germany with $100 GHG Tax

Country-specific pages show time-dependent hydrogen production and distribution costs, broken down by feedstock (red), conversion (green), distribution (blue), and carbon taxes (brown).



*1 GJ H_2 (LHV) = 8.33 kg H_2

US Analysis

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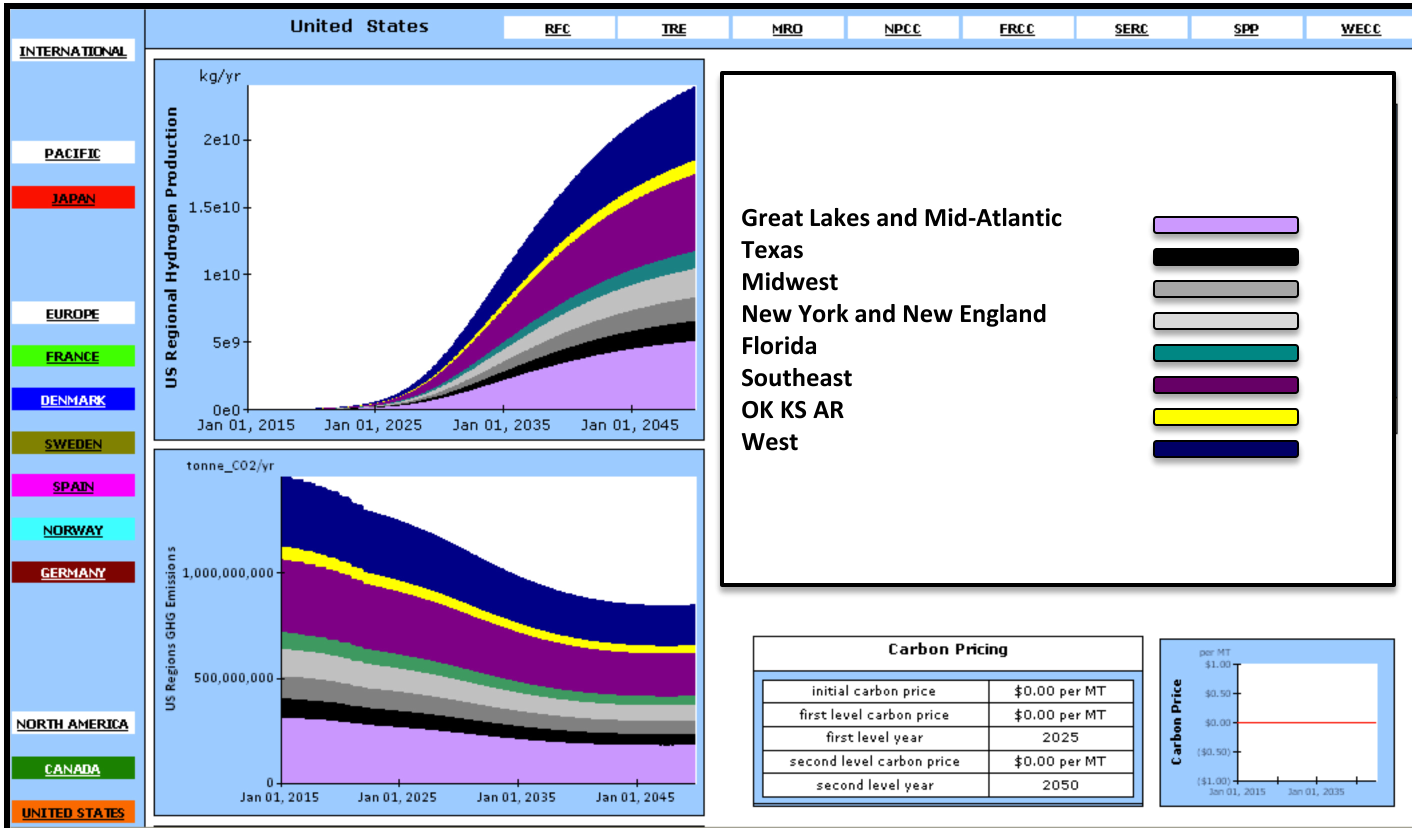
Accomplishments and Progress

U.S. broken down into 8 regions. For the base case, natural gas is the primary feedstock; GHG emissions from vehicles are decreased 42% from 2015 by 2050. Natural gas consumed for H_2 production for 128 million HFV is 20% of current U.S. consumption.



Next Steps

- Results presented at Task 30 workshop (March, 2013)
- Final iteration of comments & data with countries (March 2013)
- Replace all U.S.-supplied production and distribution costs with country or region specific data (June 2013)
  - Production costs: Task 30B (Harmonized hydrogen production database)
  - Delivery costs: Task 28 (Large Scale Hydrogen Delivery Infrastructure)
- Present draft report to DOE program office and Task 30 participants (October, 2013)
- Final report (December 2013)
- Share results and insights with IEA Hydrogen Analysts (Dec 2013)
- Prepare paper for journal publication (December 2013)

Final Report Outline

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Accomplishments and Progress

I. Introduction (objectives, participants, process)

II. Approach (assumptions, data sources, model description)

III. Country-specific pages (current expectations/policies/goals for HFV)

IV. Results (with and without interregional trading, with and without carbon taxes, specific country requirements)

V. Sensitivity Analysis (vehicle mix, resource mandates/constraints, resource prices)

VI. Lessons Learned (from the process, from the results)

VII. Conclusions and Recommendations

VIII. Appendix 1. Data Sets

IX. Appendix 2. Results from incomplete data sets

X. References

XI. Acronyms, Conversion Factors

Lesson Learned

- Iterative data collection and pathway analysis a valuable exercise.
  - Several countries have revised data inputs after comparing inputs from other countries and results from analysis tool.
  - Process led to valuable discussion about role of off-peak electricity, integration of renewables, trade-offs between alternative uses of feedstocks, and role of imports of natural gas and other fossil fuels.
- Results show there are a large number of potential pathways for providing hydrogen to fuel significant HFV fleet**: resource availability is not the limiting factor in hydrogen economy**.
- Country experts agree that the tool facilitates discussion, providing insight about possible pathways, even if tool does not provide the definitive answers.
- Every country has identified multiple options for producing hydrogen domestically.

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Collaborations

Subtask A Participants (each responsible for supplying country-level data and analysis)

- Tom Drennen (Subtask leader, Sandia National Laboratories, U.S.)
- Susan Schoenung (Task 30 Co-Cooperating Agent, Longitude 122 West Inc., U.S.)
- Jochen Linssen (Task 30 Co-Cooperating Agent, Subtask 30b leader, Forschungszentrum Juelich, Germany)
- Kari Espegren (Subtask 30c leader, Institute for Energy Technology, Norway)
- Clemens Trudewind (Forschungszentrum, Germany)
- Alain Le Duigou (CEA, France)
- Marie-Marguerite Quemere (EDF, France)
- Paul Lucchese (CEA, France)
- Maria del Pilar Argumosa (INTA, National Institute for Aerospace Technology, Spain)
- Javier Dufour (IMDEA, Madrid Institute for Advanced Studies, Spain)
- Diego Iribarren (IMDEA, Madrid Institute for Advanced Studies Spain)
- Isamu Yasuda (Tokyo Gas, Japan)
- Bengt Ridell (Grontmij AB, Sweden)
- Marco Brocco (ENEA, National Agency for New Technologies, Italy)
- Eugenio Caló (ENEA, National Agency for New Technologies, Italy)
- Rupert Gammon (Inst of Energy & Sustainable Development, De Montfort University, UK)

Summary

1. The Global Hydrogen Resource Analysis work is a subtask of the IEA Hydrogen Implementing Agreement Task 30 (Global Hydrogen Systems Analysis).
2. Main objective is to analyze potential hydrogen production and distribution pathways for participating countries.
3. Developed a user-friendly pathways tool to help participants understand resource options and constraints to meeting future hydrogen demand for various scenarios. Tool leverages several existing models.
4. Task 30 is scheduled to complete all tasks by December, 2013.
5. Results show there are a large number of potential pathways for providing hydrogen to fuel significant HFV fleet**: resource availability is not the limiting factor for a hydrogen economy**.
6. Will continue to inform IEA analysts about key findings.
7. Global pathways analysis tool adaptable for inclusion of other countries, pathways, and policy levers.

Acronyms

Accomplishments and Progress

- ANL Argonne National Laboratory
- CCS Carbon Capture and Sequestration
- CEA Commissariat à l'énergie atomique et aux énergies alternatives
- EIA Energy Information Administration
- GHG Greenhouse Gas
- GJ Gigajoule
- H2A Hydrogen Analysis Project
- HDSAM H2A Delivery Scenario Analysis Model
- HFV Hydrogen Fuel Vehicle
- HIA Hydrogen Implementing Agreement
- IEA International Energy Agency
- kWh kilowatt hour
- NREL National Renewable Energy Laboratory
- SMR Steam Methane Reforming
- SNL Sandia National Laboratory