

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

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Timeline

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

Budget

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

Barriers

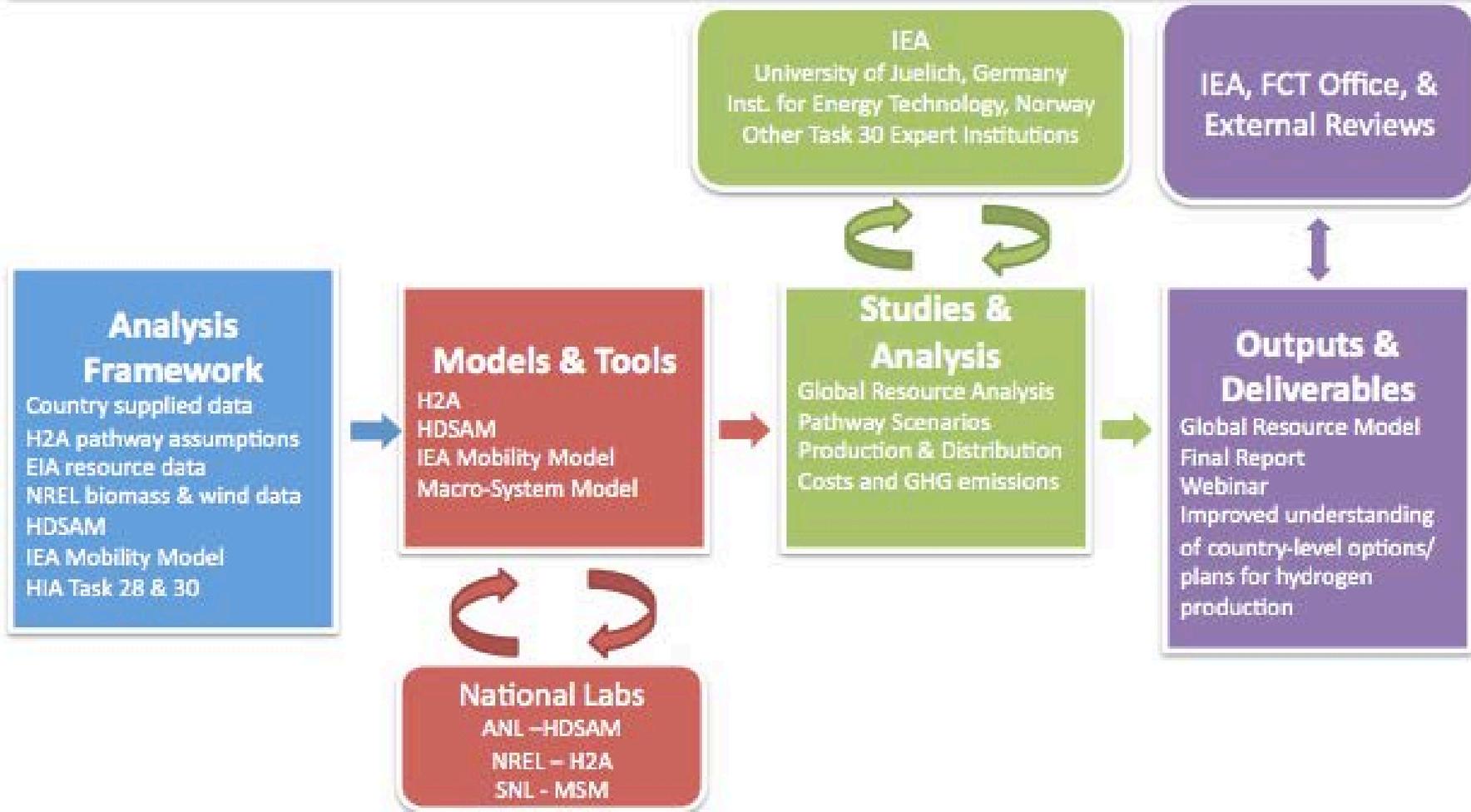
- Barriers addressed
 - Costs of producing and delivering hydrogen.
 - Economic and investment hurdles
 - Understanding of hydrogen production options

Partners

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

Approach

Global Hydrogen Resource Analysis



- 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 H₂ technologies and resources, supply and demand related to the projected use of H₂ in a low-carbon world.”

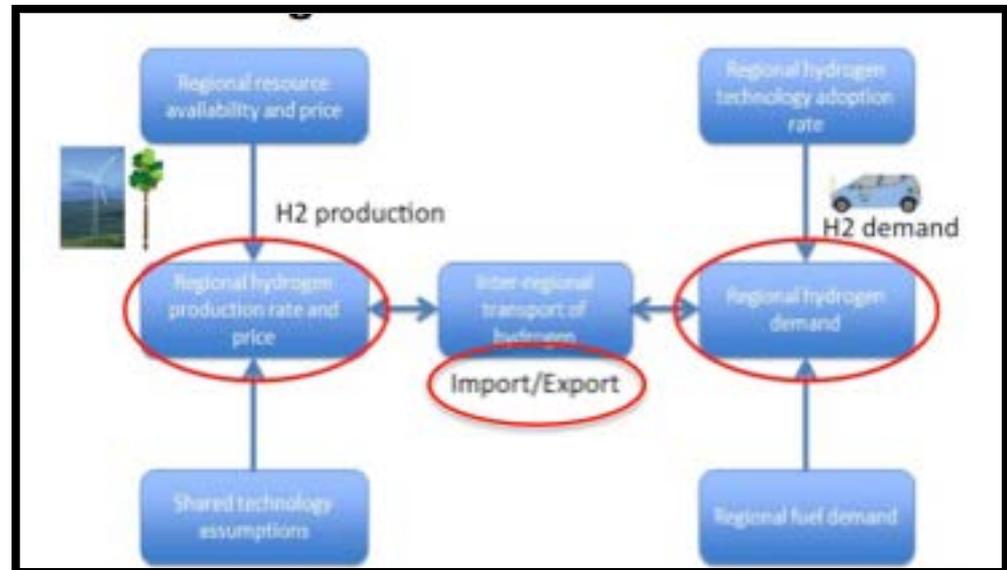
- Task 30 Structure (subtask leaders)
 - **Subtask A** (T. Drennen, Sandia National Laboratories, US): Global Hydrogen Resources
 - **Subtask B** (J. Linssen, Research Center Juelich, Germany): Harmonized hydrogen technology database
 - **Subtask C** (K. Espegren, Institute for Energy Technology, Norway): 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

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

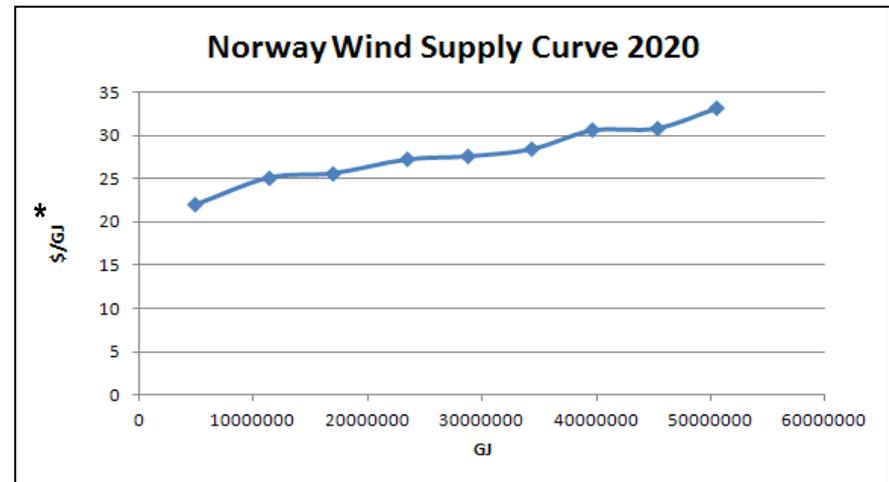
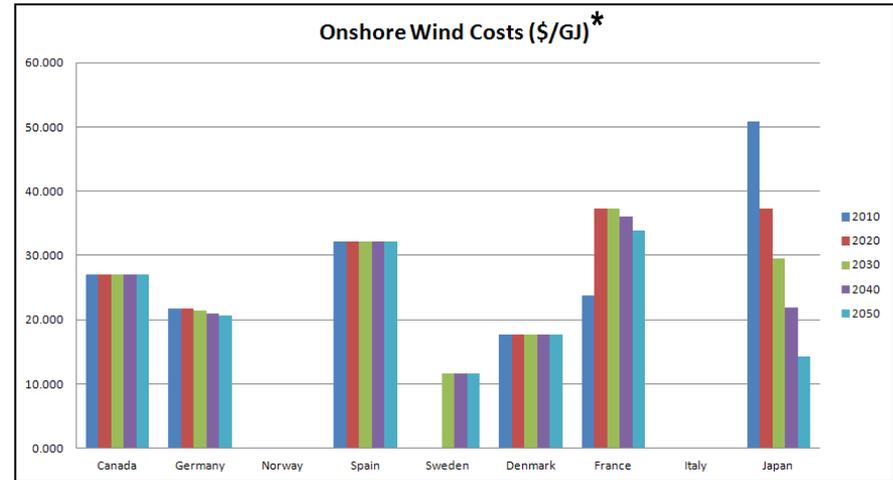
Approach

- **Developed dynamic H₂ pathways analysis tool that:**
 - Projects H₂ demand by country specific fuel-cell vehicle scenarios
 - Calculates least-cost pathways for H₂ 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 H₂ 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



Approach

- Required data from participating countries includes:
 - Feedstock availability for H₂ production by type, cost, and quantity from 2010 to 2050
 - H₂ production technology assumptions (efficiencies, cost)
- Iterative process with countries to improve data consistency.
 - Example shown: Self-reported onshore wind costs by country available for H₂ production
 - Some countries (U.S. and Norway) provided supply curves for wind; many countries provided static estimates (not dependent on quantity demanded)



*1 GJ H₂ (LHV) = 8.33 kg H₂

Results summarized by region (Europe, Pacific, North America) and then participating country. Example shown here is for H₂ 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 |

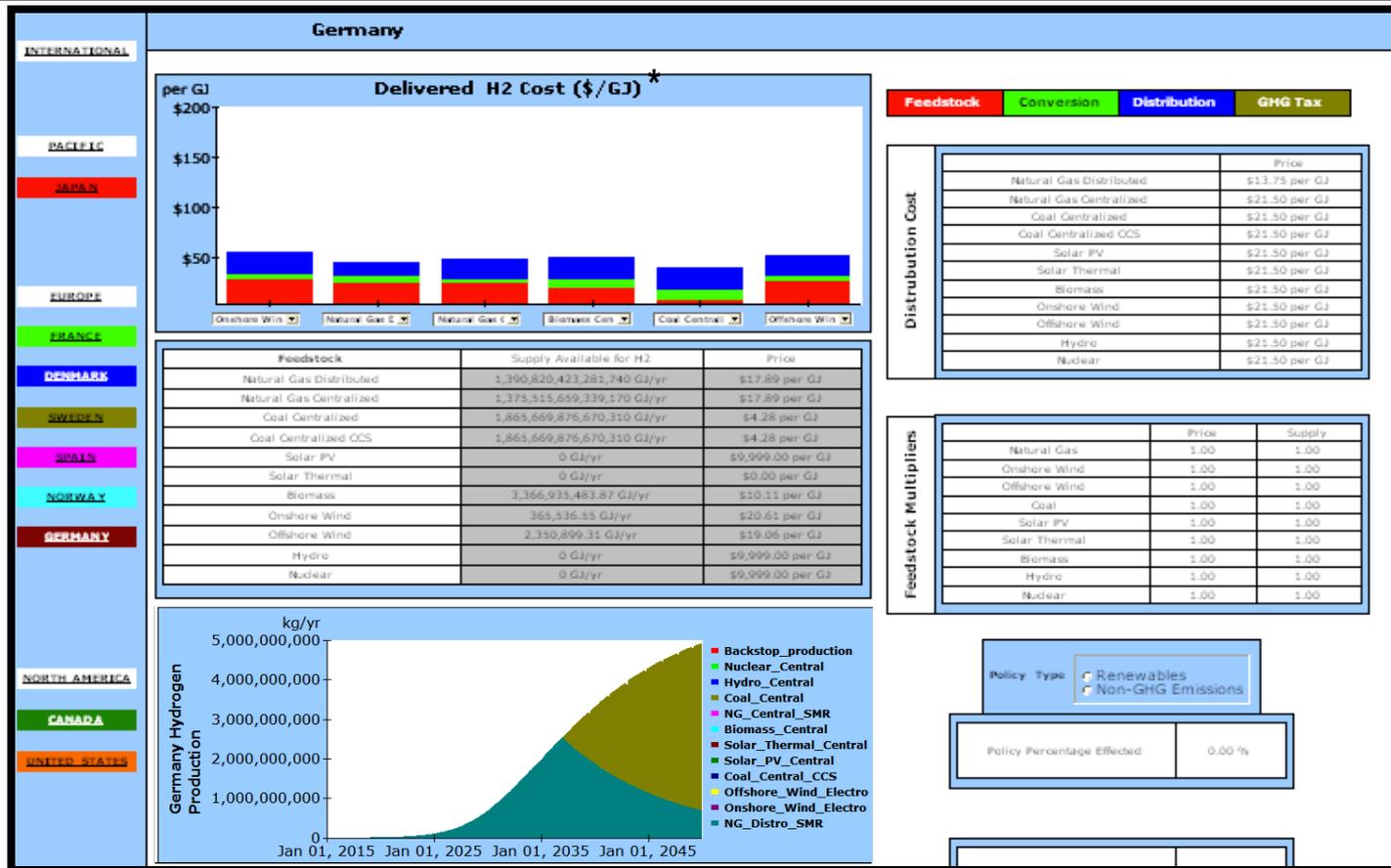
Columns are Supply and Rows are Consumption (Vertically it is the price supplied to the horizontal country)

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 |

Accomplishments and Progress

Germany meets projected H₂ 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.



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Pathways Analysis (Germany w/ \$100 GHG Tax)



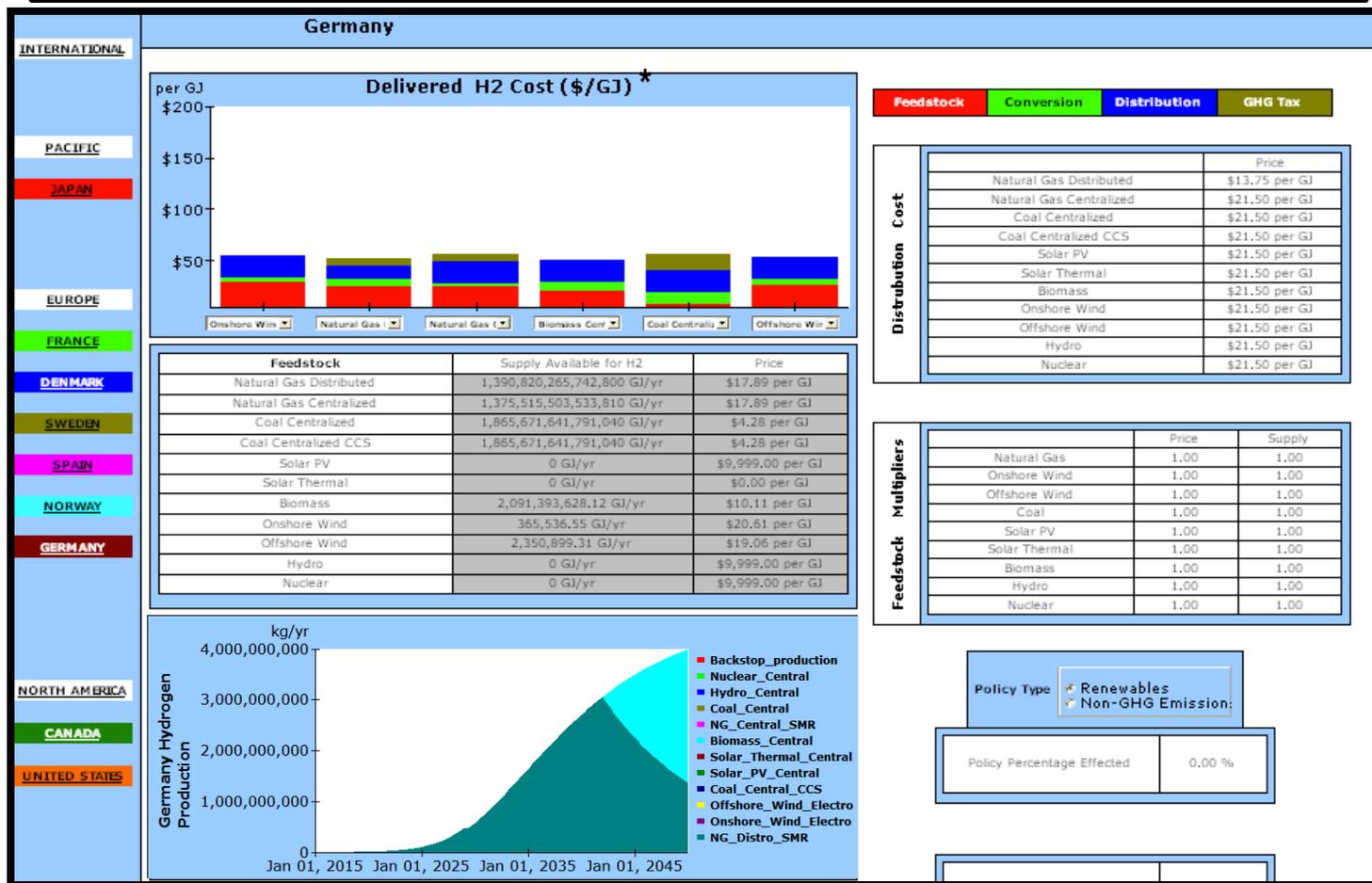
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Energy Efficiency &
Renewable Energy

Accomplishments and
Progress

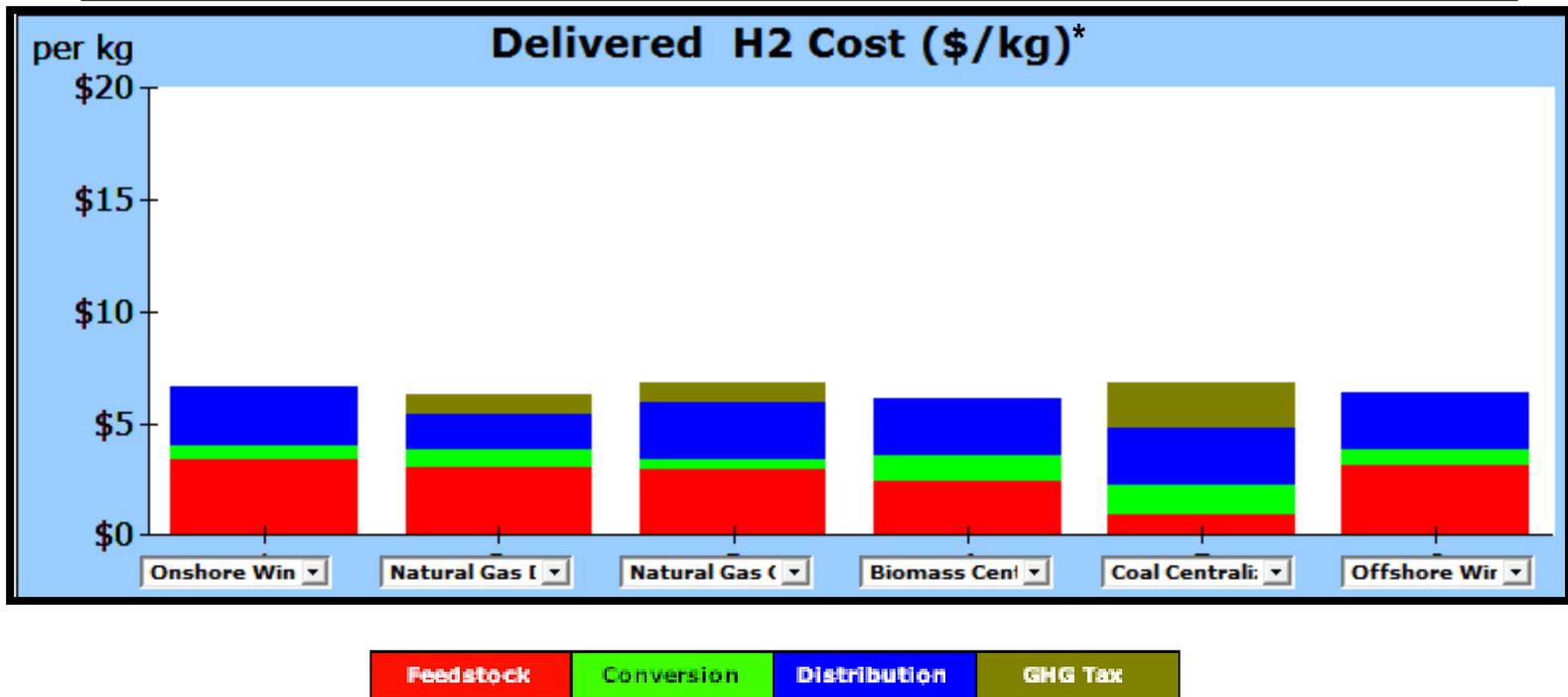
With \$100 GHG tax, Germany continues to meet demand domestically but H₂ production shifts away from coal to biomass gasification.



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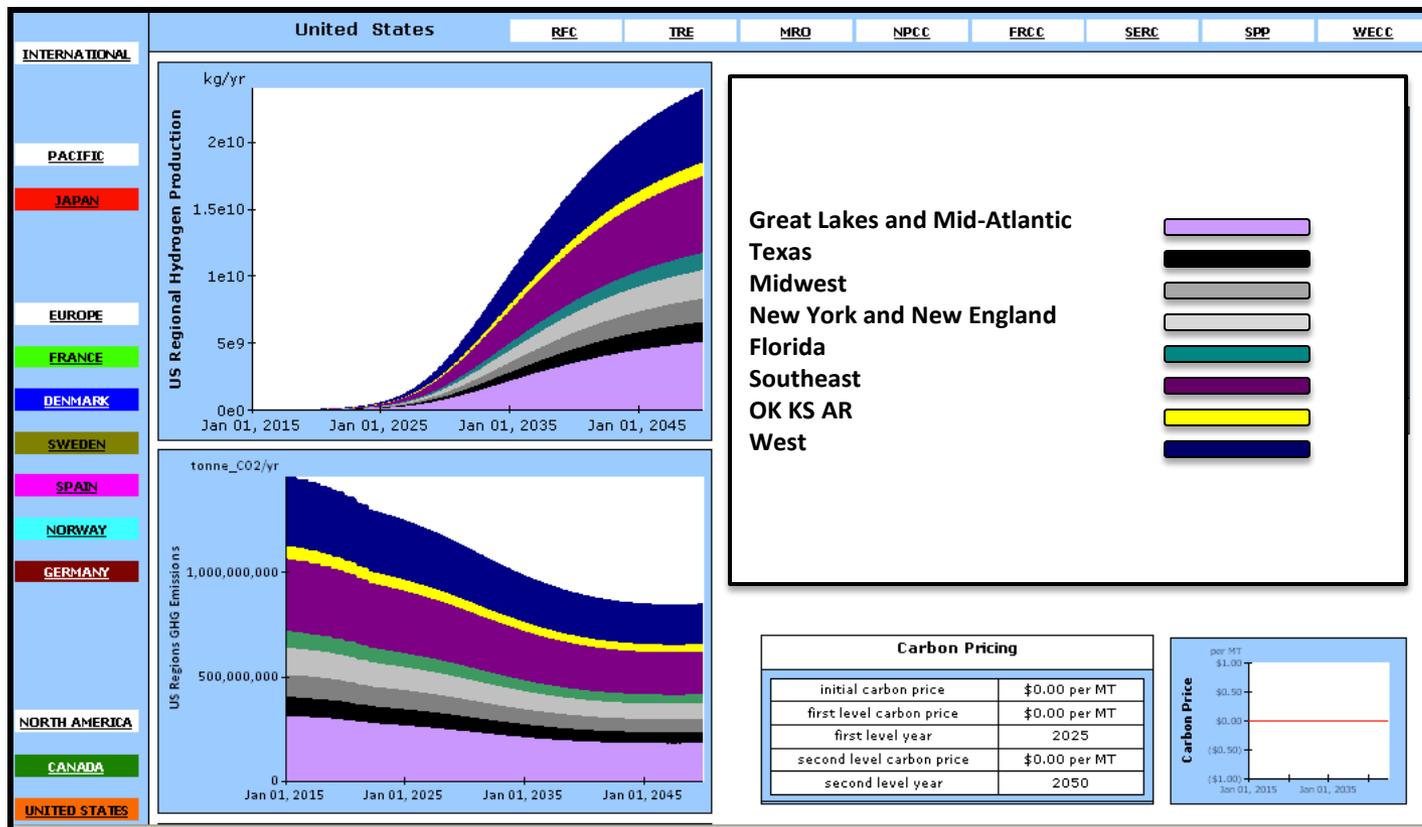
Country-specific pages show time-dependent hydrogen production and distribution costs, broken down by feedstock (red), conversion (green), distribution (blue), and carbon taxes (brown).



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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 H₂ production for 128 million HFV is 20% of current U.S. consumption.



- 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)

- 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

- 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.

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)

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.

- 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