Benchmarking of European and U.S. Hydrogen Roadmapping Efforts (HyWays-IPHE): Hydrogen Pathway Analysis

Christoph Stiller (LBST)

on behalf of the HyWays-IPHE consortium

Roadmap Workshop, Changsha 05 August 2008

Outline

HyWays - IPHE
Benchmarking of Hydrogen Energy Roadmaps

- Methodology and scope of comparison
- Results: Costs
- Results: Energy use
- Results: GHG emissions
- Uncertainty analysis
- Conclusions

Hydrogen energy pathways - comparison

- Hydrogen energy pathway analysis is a key component of a hydrogen roadmapping activity
- Models used and compared:
  - E3database (EU)
  - H2A Production/HDSAM/GREET (U.S.)
- Costs, energy use and GHG emissions compared (deterministic values and partially Monte Carlo analysis)
- 9 representative Well-To-Tank pathways compared (electrolysis, SMR, CTH; onsite/central, pipeline, trucked-in LH2)
- 1 pathway considering stationary use of H2 from coal (GT)

- **Detailed report available online**

  http://www.hyways-iphe.org/publications/publications01.html

Pathways that we compared

HyWays - IPHE
Benchmarking of Hydrogen Energy Roadmaps

Nº	Timeframe	Production	Delivery	End use
1	Near term (~2007)	Onsite SMR	n.a.	Fuelling station
2		Onsite Electrolysis		
3		Central Biomass	GH_2 pipe	
4	Mid term (~2015)	NG SMR	LH_2 truck	Fuelling station
5		NG SMR	GH_2 pipe	
6		Wind electrolysis		
7		Coal gasificat. w/CCS		
8	Long term (~2030)	NG SMR w/CCS	GH_2 pipe	Fuelling station
9		Coal gasificat. w/ CCS electricity byproduct	LH_2 truck	

General findings

- **Different viewpoints for economic calculations**: investor's point of view (U.S.) vs macro-economic point of view (EU)
- **Pipeline configuration**: high-pressure pipeline with upstream compression, geologic storage, and a ring architecture (US) vs. medium-pressure pipeline (plant outlet pressure), no geologic storage, and a tree-like architecture (EU).
- **Model layout**: U.S.: Split into production and delivery, costs (H2A) and energy/emissions (GREET), using predefined *pathways.* EU: E3database is a stand-alone relational database with a graphic user interface and is a general and fully flexible tool for the modeling of energy chains.

Outline

- Methodology and scope of comparison
- Results: Costs
- Results: Energy use
- Results: GHG emissions
- Uncertainty analysis
- Conclusions

Fundamental Differences – Financial Parameters

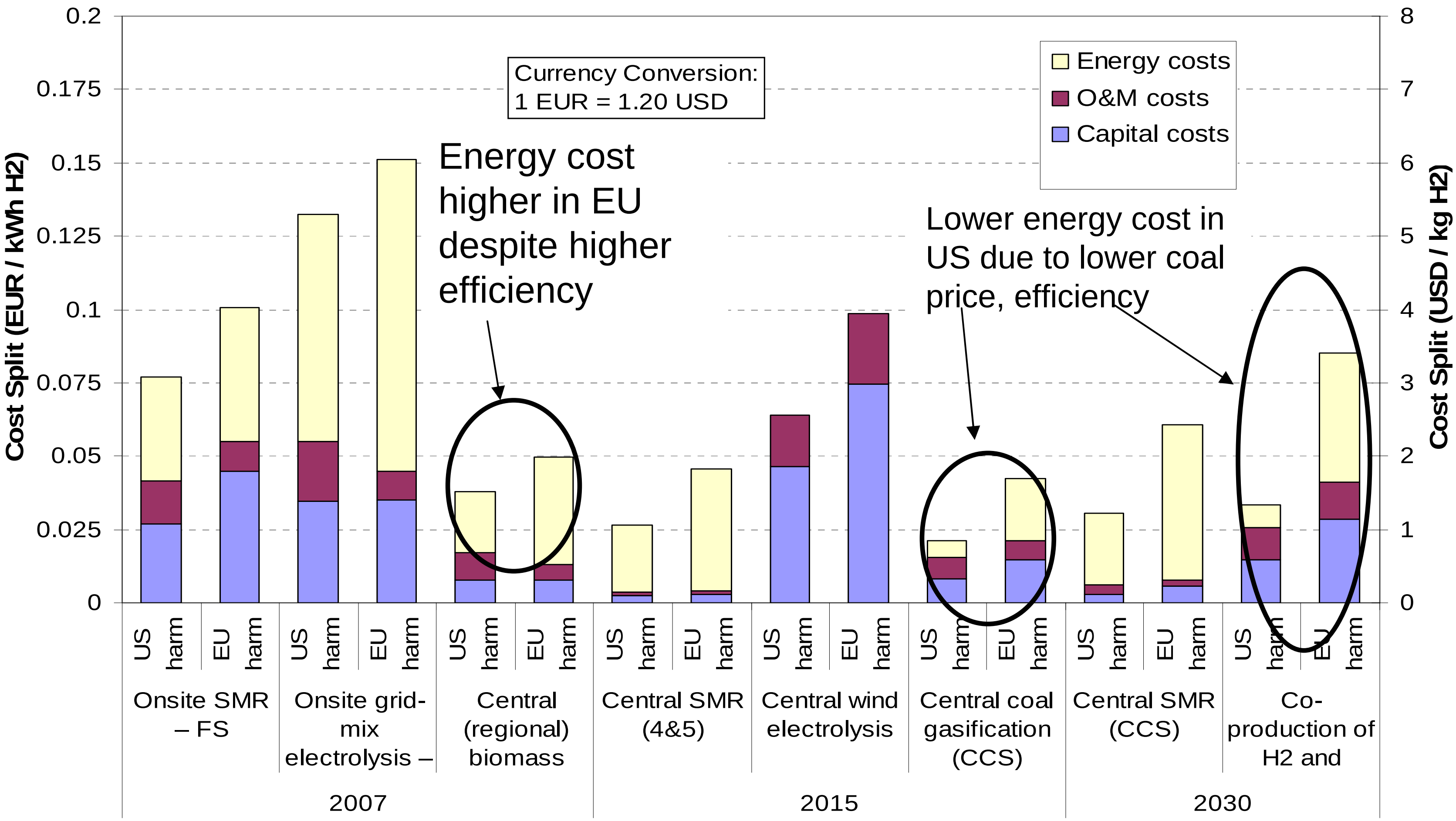
HyWays - IPHE
Benchmarking of Hydrogen Energy Roadmaps

	H2A	E3database	Harmonized
Financing	100% Equity @ 10% DCFROR	100% Debt @ 8% Interest	100% Debt @ 8% Interest
Taxes	35% Federal 6% State	None	None
Working Capital	15%	0%	0%
Construction	1-4 years	0 years	0 years
Depreciation	MACRS as allowable by law	Straight Line over analysis period	Straight Line over analysis period
Analysis Period	20 to 40 years	17.5 to 25 years	20 y (1,2,3,6) 40 y (4,5,7,8,9)

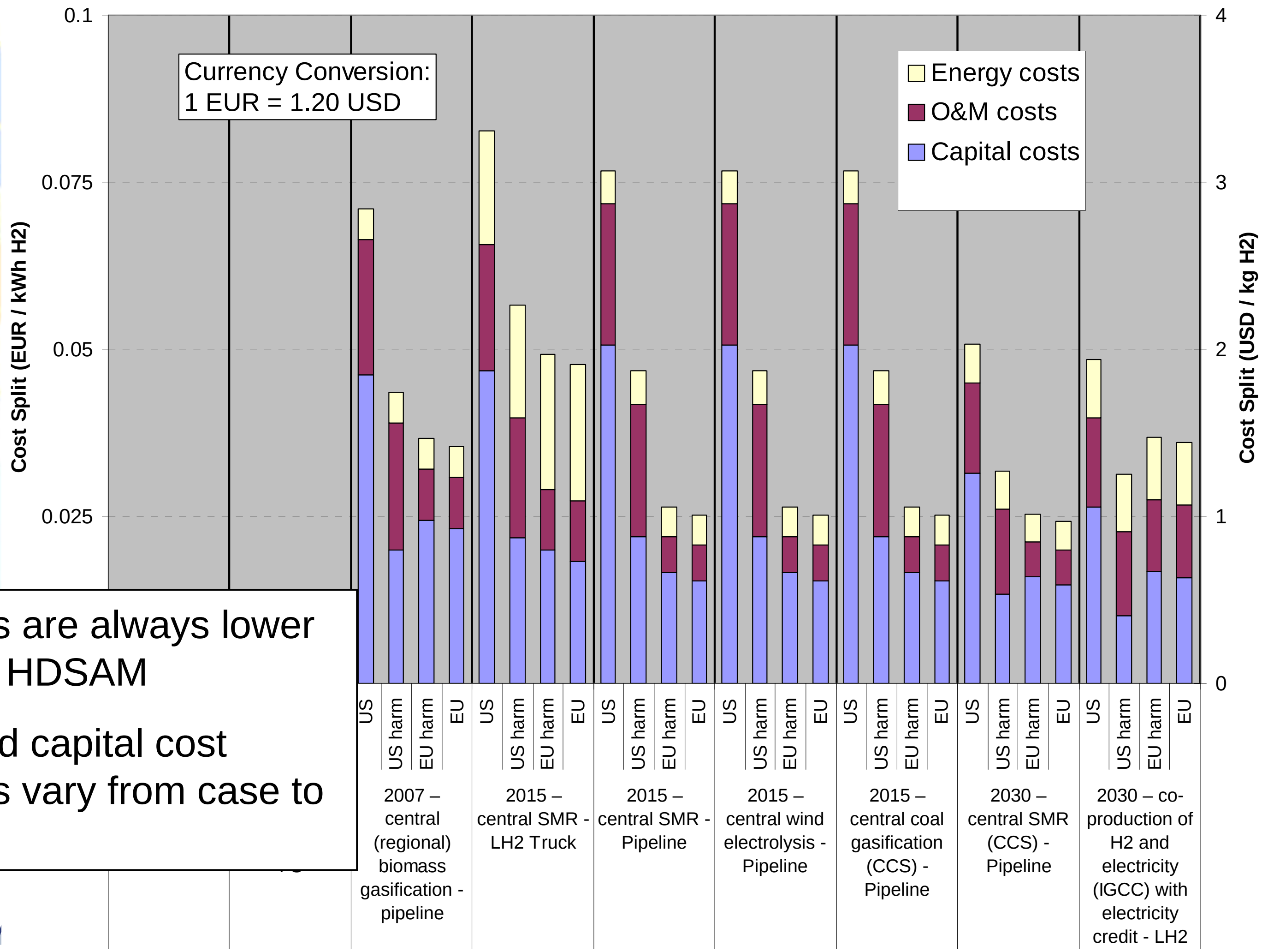
Harmonization reduces the cost of capital in H2A

Levelized costs of production (financially harmonized chains)

HyWays - IPHE
Benchmarking of Hydrogen Energy Roadmaps



Levelized costs of delivery

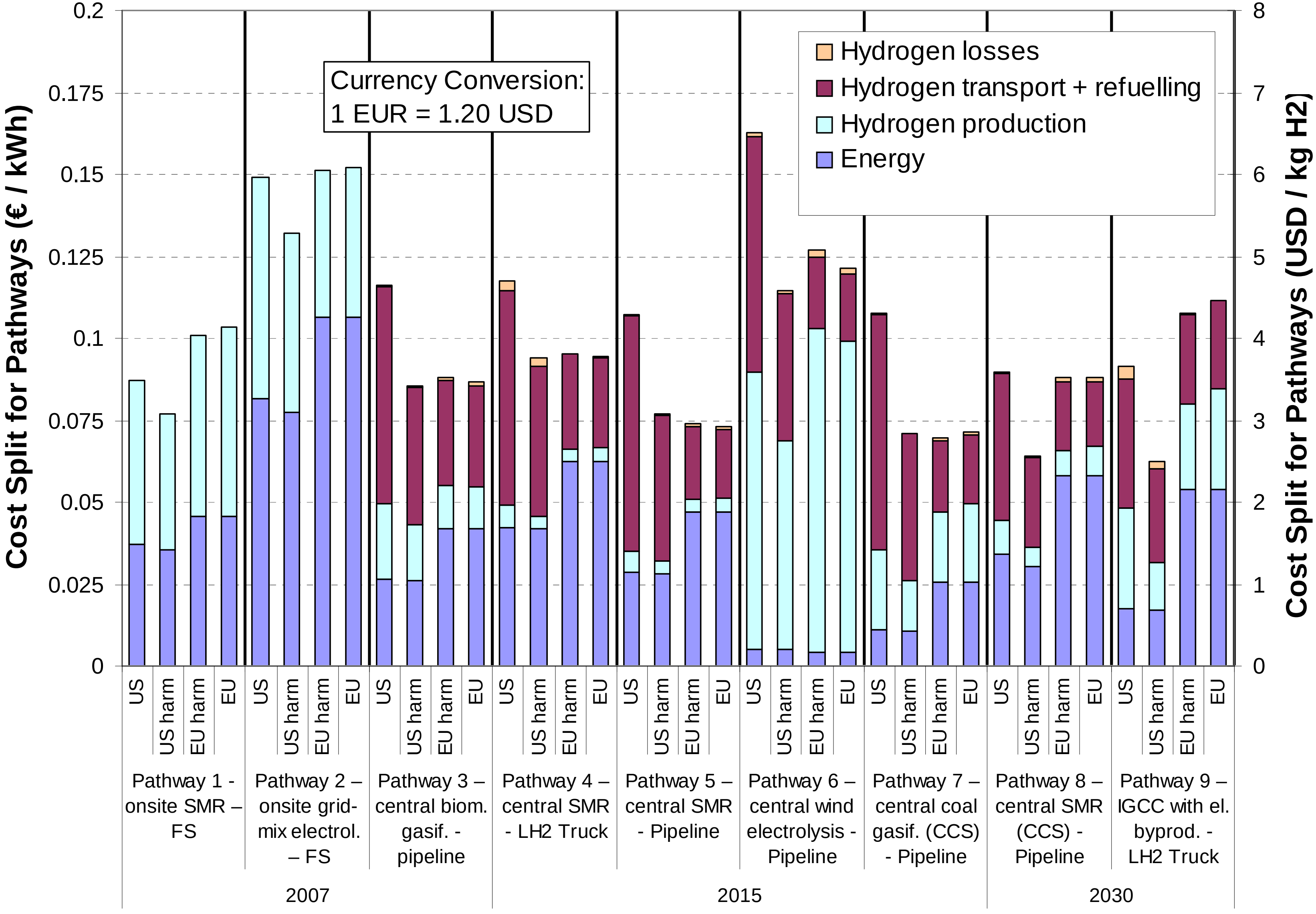


O&M costs are always lower in E3 than HDSAM

Energy and capital cost differences vary from case to case

Levelized costs of entire pathway

HyWays - IPHE



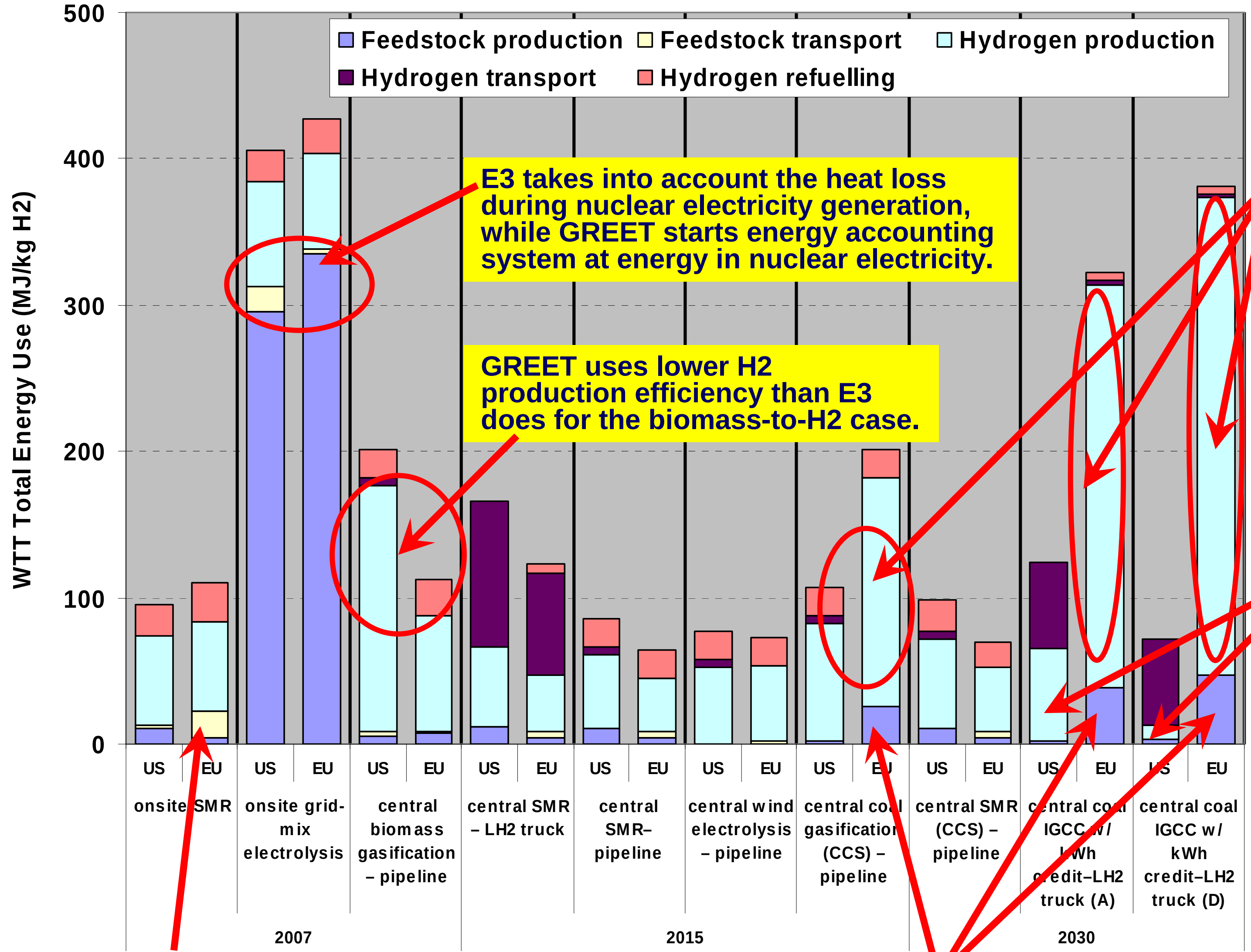
Financial and cost differences

- **Financial assumptions**: U.S.: High taxes (total tax rate of 39%) and high internal rate of return (10%) (U.S.); EU: no taxes, 8% interest rate.
  - ⇒ higher costs of capital for the U.S. in the original cases (not in the financially harmonized cases).
- **Energy price assumptions**: the future NG, biomass and coal price assumptions are substantially lower on the U.S. side.
  - ⇒ Higher energy cost contributions in the EU.
- **Pipeline cost degression**: U.S.: Cost reductions through technological progress for gas pipelines assumed; EU: pipelines are mature technology.
  - ⇒ Significant decrease of pipeline delivery cost estimation over time for the U.S. case.
- **Delivery O&M costs**: higher O&M costs in U.S. models for all hydrogen delivery cases, due to different approaches to determine the costs.

Outline

- Methodology and scope of comparison
- Results: Costs
- Results: Energy use
- Results: GHG emissions
- Uncertainty analysis
- Conclusions

WTT Comparisons:
Total Primary Energy Use



E3 takes into account the heat loss during nuclear electricity generation, while GREET starts energy accounting system at energy in nuclear electricity.

GREET uses lower H2 production efficiency than E3 does for the biomass-to-H2 case.

E3 uses a lower H2 production efficiency than GREET does for coal-to-H2 cases.

Displacement method gives Case 9 a large credit due to high electricity co-generation rate (0.44 kWh/kWh H2).

E3 has longer distance for NG transport than GREET does.

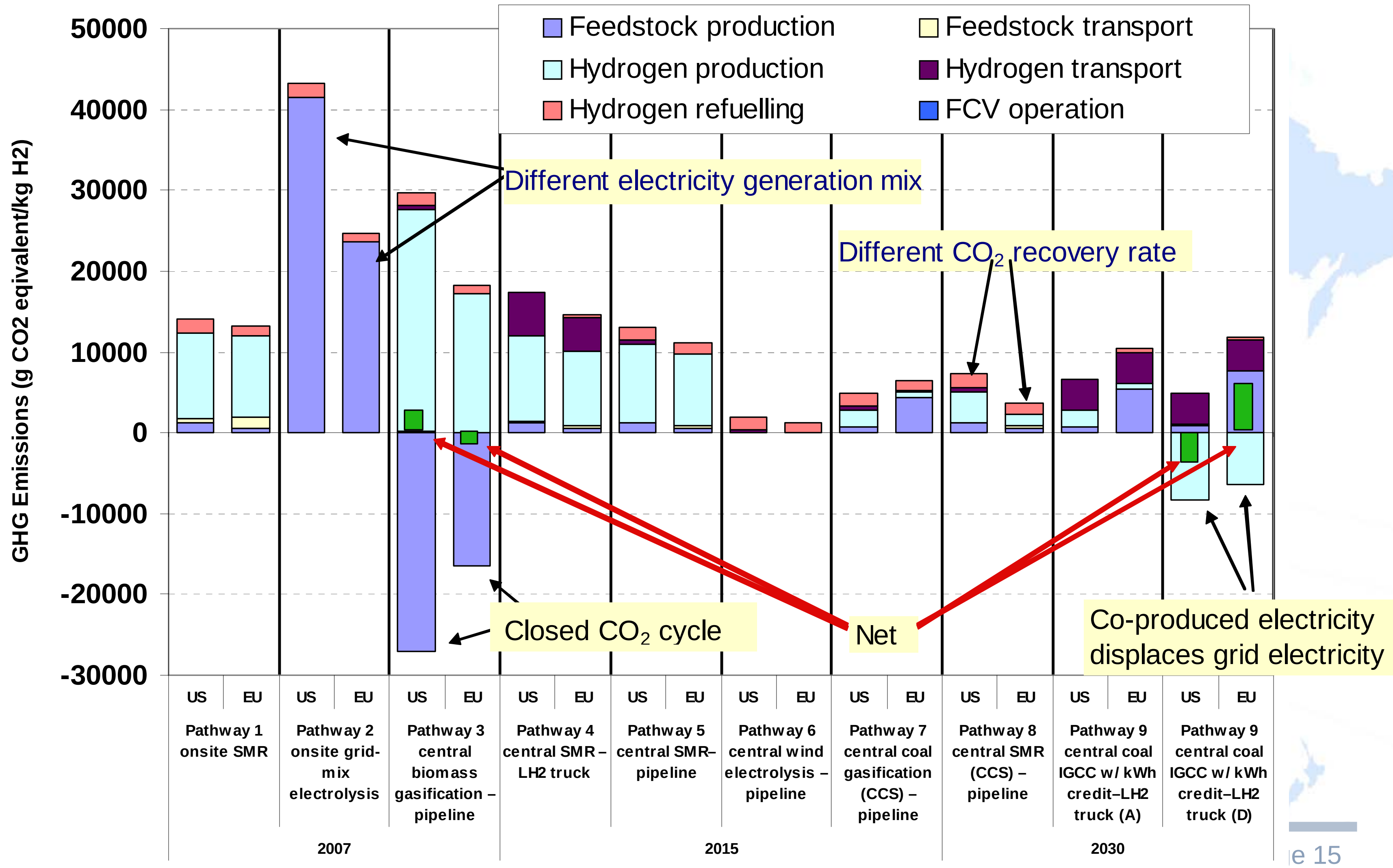
E3 has a lower recovery/clean efficiency than GREET does for coal.

Outline

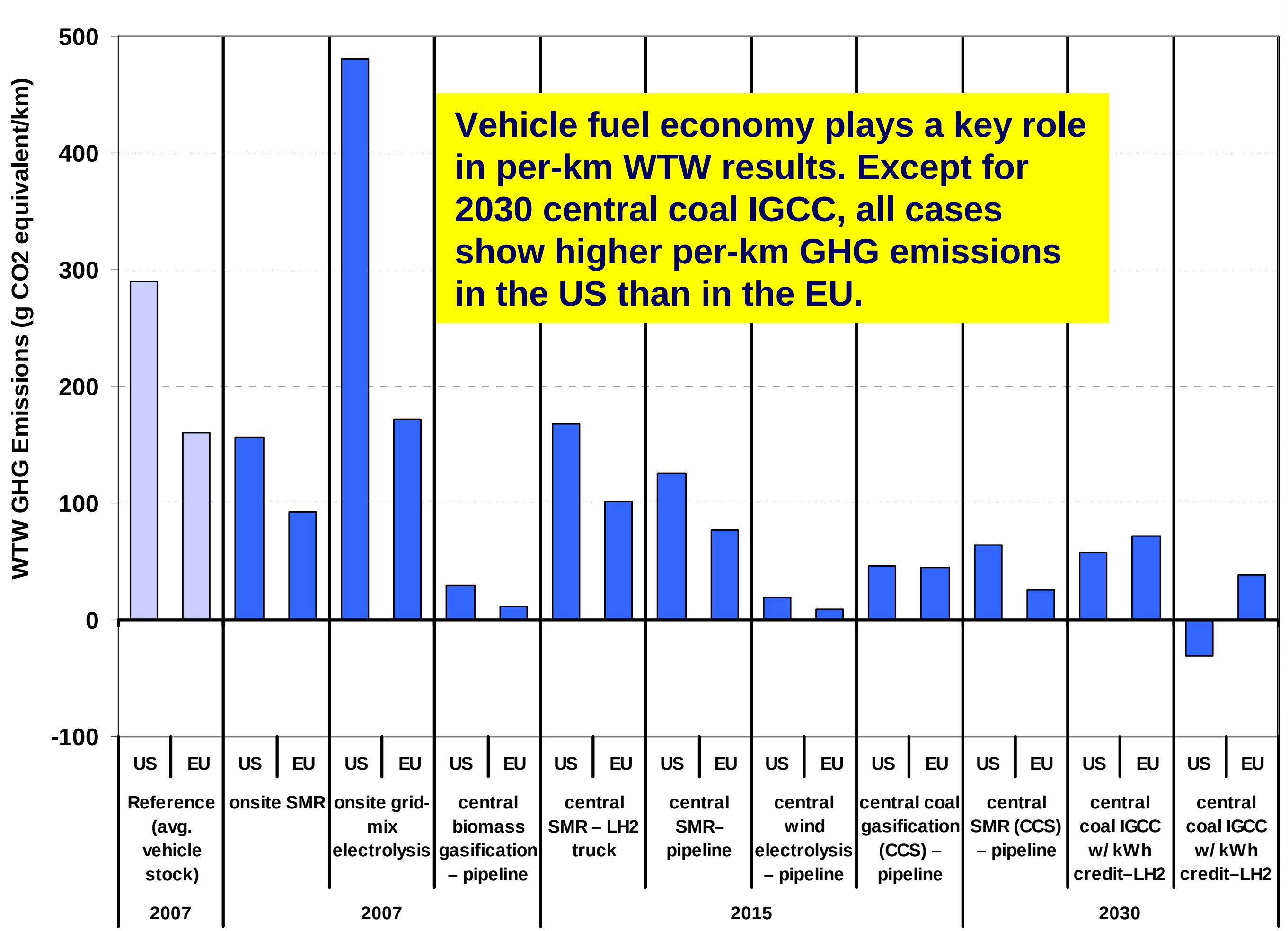
- Methodology and scope of comparison
- Results: Costs
- Results: Energy use
- Results: GHG emissions
- Uncertainty analysis
- Conclusions

WTT Comparison: GHG emissions

HyWays - IPHE
Benchmarking of Hydrogen Energy Roadmaps



WTW Comparison: GHG Emissions (km driven)



Techno-economic differences

- **Vehicle fuel economy**: U.S.: lower fuel economy for fuel cell vehicles than EU.
  - Reason: partially size of the assumed vehicles

  ⇒ Higher costs and GHG emissions per km in the U.S.
- **Biomass/coal gasification efficiency**: EU uses higher biomass gasification efficiency (due to different gasifier efficiency, PSA recovery rate, and compression). U.S. uses higher coal gasification efficiency (through lower CO2 recovery rate).

  ⇒ Affects energy use and costs of the respective pathways.
- **Dispensing pressure**: U.S.: 6250 psi (430 bar) dispensing pressure; EU 12800 psi (880 bar)

  ⇒ Slightly higher compression energy effort in the EU cases

Outline

- Methodology and scope of comparison
- Results: Costs
- Results: Energy use
- Results: GHG emissions
- Uncertainty analysis
- Conclusions

Uncertainty Analysis

Effects and ranges of results may affect decisions

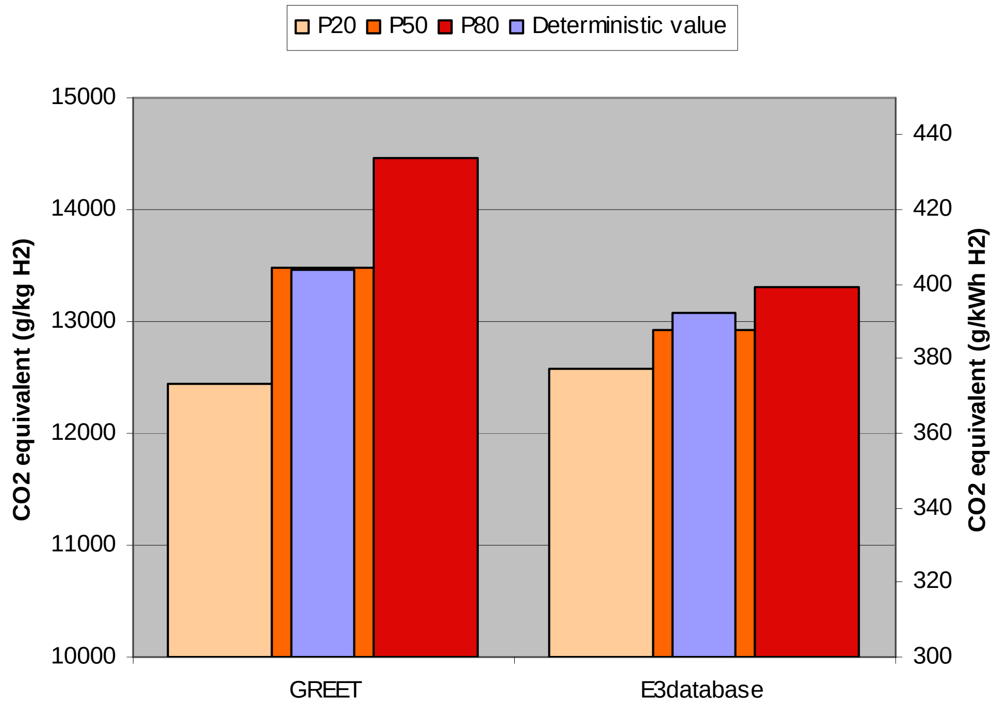
- May help define optimistic and pessimistic scenarios
- Ranges may overlap indicating that one result is not as much better than another as single deterministic values indicate.
- Some stochastic analyses have been completed in both the US and Europe; however results have not yet been included into the roadmaps

Comparison

- Uncertainty analysis of US and EU tools is very similar for GHG emissions

Hydrogen energy pathways example: Onsite SMR (near term): Uncertainty

- Higher uncertainty for SMR in GREET (± 5.2% vs. ± 1.4% in E3database)
- Uncertainty for carbon content of NG in GREET



Outline

- Methodology and scope of comparison
- Results: Costs
- Results: Energy use
- Results: GHG emissions
- Uncertainty analysis
- Conclusions

General lessons learned from pathway comparison I

HyWays - IPHE
Benchmarking of Hydrogen Energy Roadmaps

- Tools used by HyWays & US are consistent
- Modeling philosophies affect conclusions
  - US focuses on business cases, EU on policy support
  - Estimated vehicle fuel economy lower in the US than the EU
  - Cost reductions through time (EU: learning by doing, US: learning by technology development)
  - Design of delivery scenarios
  - Method of accounting for losses and emissions
- Developing a common understanding and language is challenging
  - Terms often have different meanings to different people (e.g., WTT: Process fuel / feedstock)

General lessons learned from pathway comparison II

HyWays - IPHE
Benchmarking of Hydrogen Energy Roadmaps

- Financial parameters may be different from nation to nation
- There may also be significant differences in technical assumptions:
  - Energy price projections (higher on EU side)
  - Vehicle efficiency (higher on EU side)
  - Biomass gasification efficiency (higher on EU side)
  - Coal gasification efficiency (higher on US side)
  - Process and pathway configurations (e.g. pipeline delivery, compressor station, geologic storage)
  - Dispensing pressure (higher on EU side)
  - Emissions for coal production
  - Liquid hydrogen losses
  - Estimating the effects of co-products is difficult

Thanks for your attention!