Soft-linking UK MARKAL to a GIS interface to investigate spatial aspects of new hydrogen infrastructures

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International Energy Workshop
IEA, Paris, 3rd July 2008

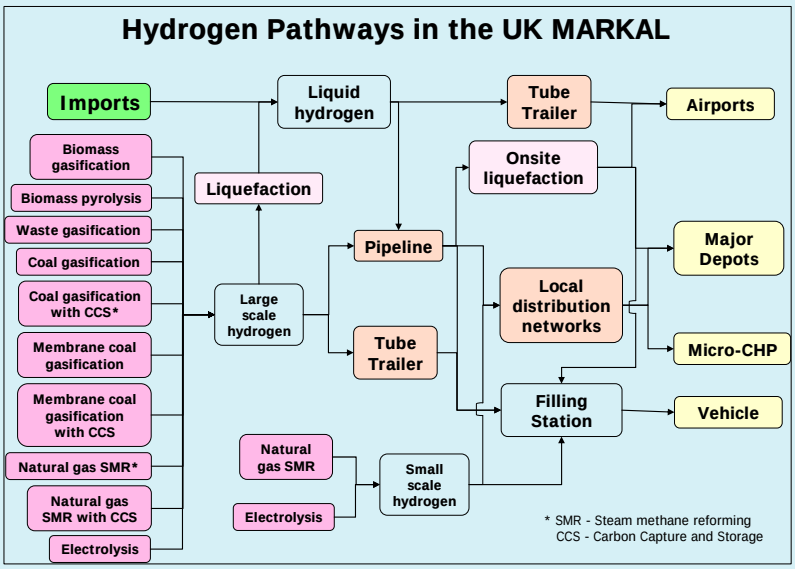
Outline

- Introduction
  - UK MARKAL energy systems modelling
    - Currently has detailed hydrogen pathways
    - BUT geography?, path dependency?
- Spatial MARKAL
  - Demand and resource disaggregation via GIS
  - H_2 infrastructure spatial detail via GIS model
- Scenario results
- Discussion

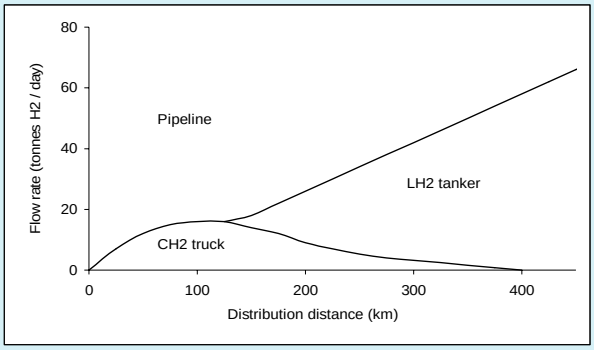
UK MARKAL modelling

- A **least cost optimization** model of competing technology pathways to meet **energy demand services**
- **Technology** rich bottom-up model
- An **integrated energy systems** model
  - Energy carriers, resources, processes, electricity/CHP, industry, services, residential, transport, agriculture
- Physical, economic and policy **constraints** to represent UK energy system and environment
- Model and data **validation**
- Emphasis on **sensitivity and uncertainty analysis**
- 2007 model substantially **rebuilt** – (ongoing 2008 improvements)
- **Extension** to MARKAL-Macro (M-M), Elastic Demand (MED), other variants
- **Peer review** (for example)
  - Strachan N. and R. Kannan (2008) *Hybrid Modelling of Long-Term Carbon Reduction Scenarios for the UK*, Energy Economics, doi:10.1016/j.eneco.2008.04.009

Non-spatial model H_2 pathways

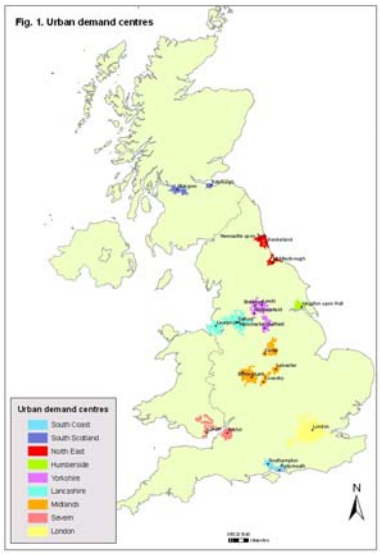


Non-spatial H_2 based on cost and distance



		Distribution Distance	
		Short (50 km)	**Long (300 km)**
Flow rate	**High (100 t/day)**	Air, rail, ship	Heavy goods vehicles (HGV)
	Low (15 t/day)	Bus, Two-wheeler	Car, light goods vehicles (LGV), micro-generation

Spatial demand disaggregation

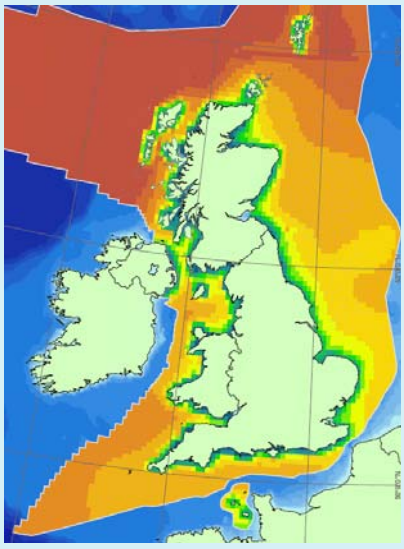


- 12 demand regions (A-L)
  - 9 urban
  - Other urban, rural, very rural
- Allocation of transport modal demands
  - Domestic air, international air, bus, car, HGV, LGV, rail freight, rail passenger,
  - Not 2 wheeler, domestic shipping
- Based on GIS mapping
  - population
  - additional demand drivers (e.g., public transport network)

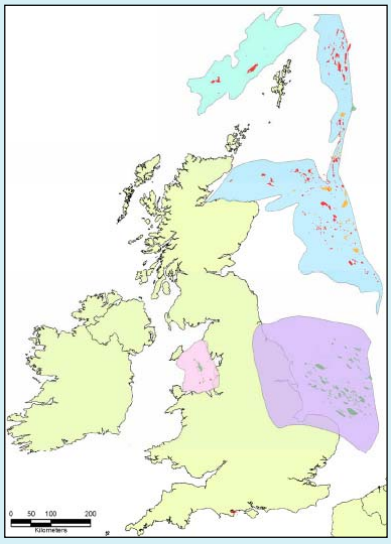
Transport demand shares

Region	Area	Population Share (%)	Adjusted Ratios by each transport mode							
			TA	TB	TC	TF	TH	TI	TL	TR
A	South Scotland	3.07	22.5	2.05	3.33	3.07	3.07	3.7	3.07	3.07
B	North East	2.88	3.3	1.92	3.12	2.88	2.88	1.8	2.88	2.88
C	Humberside	0.65	0.1	0.44	0.71	0.65	0.65	0.30	0.65	0.65
D	Yorkshire	4.90	1.3	3.28	5.32	4.90	4.90	0.8	4.90	4.90
E	Lancashire	7.15	10.1	4.78	7.76	7.15	7.15	11.8	7.15	7.15
F	Midlands	8.19	4.4	5.47	8.89	8.19	8.19	5.70	8.19	8.19
G	Severn	2.86	1.4	1.91	3.10	2.86	2.86	2.20	2.86	2.86
H	London	16.20	38.6	44.00	9.07	16.20	16.20	71.70	16.20	16.20
I	South Coast	1.62	1.8	1.09	1.76	1.62	1.62	0.40	1.62	1.62
J	Other Urban	28.73	16.5	19.20	31.17	28.73	28.73	1.60	28.73	28.73
K	Rural	20.07	0	13.41	21.78	20.07	20.07	0.00	20.07	20.07
L	Very rural	3.68	0	2.46	3.99	3.68	3.68	0.00	3.68	3.68
	TOTAL	100	100	100	100	100	100	100	100	100

Spatial resource disaggregation



UK Wind resource



UK CCS resource

H_2 supply points (1-6)

Supply point	Area	H_2 production	Carbon constrained H_2 production
1	Peterhead	Coal, natural gas, large scale electrolysis	CCS
2	Teesside	Coal, natural gas, large scale electrolysis, LH_2, LNG terminals	CCS, LH_2, LNG terminals
3	Humberside	Coal, natural gas, large scale electrolysis	CCS
4	Isle of Grain, Thames	LH_2, LNG terminals, natural gas, large scale electrolysis	LH_2, LNG terminals
5	Milford Haven, Wales	LH_2, LNG terminals, coal, large scale electrolysis	LH_2, LNG terminals
6	North West Scotland	Dedicated remote renewables resource	Dedicated remote renewables resource

Liquid H_2 distribution

- GIS cost-weighted shortest path function
  - Weighted in favour of travel via motorways
  - LH_2 delivery costs are only dependent on distance
  - Integer or 'lumpy' investment for liquefaction facilities
  - 'Regions' J-K have alternate approach based on increased rural delivery costs
- Air, rail, HGV modes must take LH_2
  - Airports have onsite liquefaction

Pipeline H_2 distribution

- Standard pipeline costs
  - Based on distance and scale (Yang and Ogden, 2006)
- Applicable to bus, car and LGV modes in urban regions (A-J)
- Sequential pipeline networks from nearer supply points to demand regions, then extended
  - Adhere to GIS least cost paths considering topology, existing infrastructures and buildings
  - Integer ('lumpy') investments, with 20-year planning horizon
- Finite set (~100) of pipelines

Small scale H_2 distribution

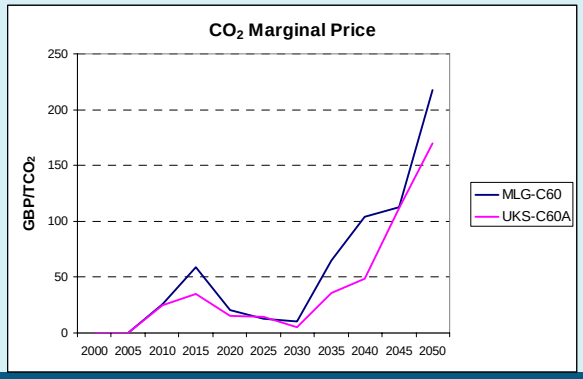
- Use of (expanded) electricity network and small-scale electrolysis
- Use of (expanded) natural gas network and small-scale steam methane reforming
- Waste gasification – based on population
- Biomass gasification – rural areas only (K-L)

Spatial Scenarios

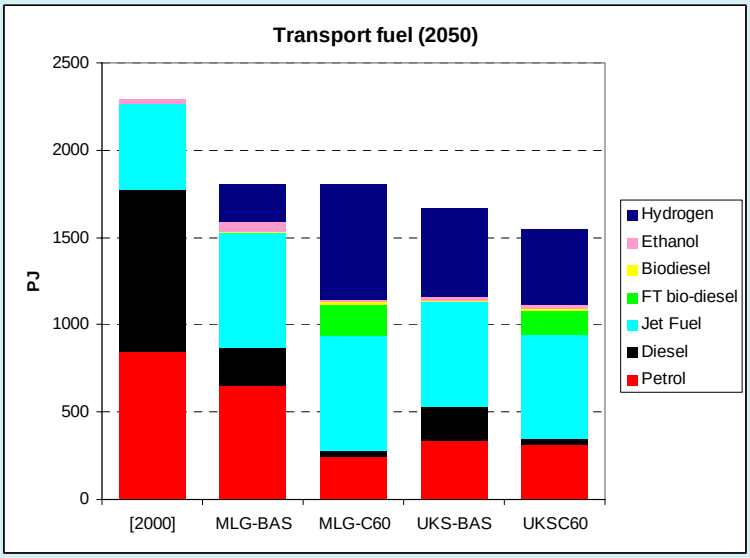
- Core runs
  - Non-spatial
    - **UKS-BASA** – base-case
    - **UKS-C60A** - 60% CO_2 reduction by 2050 (from 2010)
  - Spatial (all H_2 modes)
    - **MLG-BAS** – base-case
    - **MLG-C60** - 60% CO_2 reduction
- Sensitivity runs
  - Restricted H_2 modes
  - Alternate rural infrastructure costs
  - **MLG-C60I**: no imported hydrogen
  - Alternate constraints runs (CO_2 and H_2 share)

H_2 spatial vs. non spatial model

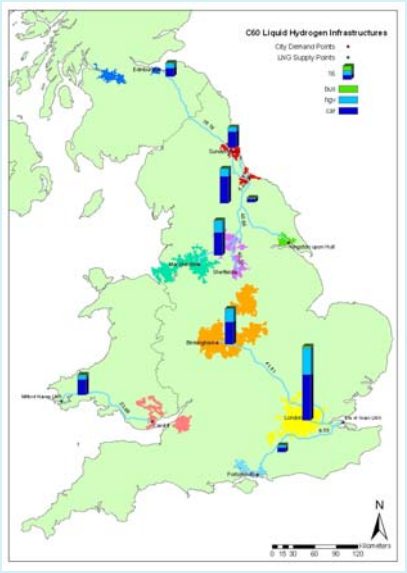
Cumulative system costs (£M)	Discount rate	3.5%	10.0%
	Spatial MLG-C60	41,497	5,405
	Non spatial UKS-C60A	35,056	5,112
	% additional cost from spatial model	18.4%	5.7%



Transport sector by fuel



Spatial MLG-C60 – liquid H_2 distribution



- Ordering of transport modes - HGVs, buses, cars
- Dominated by liquid H_2
  - Supplemented by small pipelines for urban buses
- Majority use of imported H_2 supply
  - Into Teesside, Thames and Milford Haven
- Clustering of demands to allow supply and delivery economies of scale

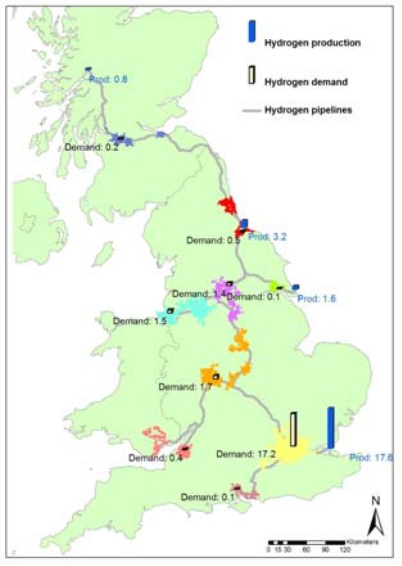
C60 and C60 no imports - H_2 by infrastructure

(PJ)		2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
MLG-C60	Pipeline	0	0	0	0	0	0	0	0	6.76	15.34	14.51
MLG-C60	Small scale	0	0	0	0	0.49	0.55	0.36	0.30	0.43	0	0
MLG-C60	Liquid	0	0	0	0	0	0	0	0	142.02	338.98	637.98
MLG-C60I	Pipeline	0	0	0	0	0	0	0	0	6.79	16.83	16.82
MLG-C60I	Small scale	0	0	0	0	0.49	0.55	0.36	0.230	4.17	10.6	10.6
MLG-C60I	Liquid	0	0	0	0	0	0	0	0	138.25	179.67	170.10

Spatial MLG-C60 (no imports) – Liquid H_2

- Only HGV (not car H_2 supply)
  - No contribution to bus pipeline network
- Majority of H_2 supply from Scottish renewables
  - Delivery extends down to Midlands
  - Again demand clustering for supply econ. of scale
- Supplemental supply points in Humberside and Thames

MLG-C60 (no imports) - pipelines



- Expanded to cover all major urban buses
  - Now small scale distribution for rural buses
- Still Eastern England supply points
  - with increased Scottish renewables
- Again, clustering of demand centres
- Again, extension of existing pipelines, with incremental capacity

Insights and Discussion

- **Overview**
  - Spatial (GIS) modelling for H_2 demand, resources and infrastructures
  - Anchored within energy systems model
- **Exploratory scenarios**
  - Back-casting scenarios not designed to explore niche markets issues
  - Simplification of resource and demand points
  - Finite set of pipeline infrastructures
- **Spatial model results**
  - Consistent ordering of H_2 transport modes and supply-demand centres
  - Nuanced supply-demand H_2 configurations
    - Higher cost H_2 transport infrastructures
    - But able to thrive in carbon constrained world
  - Clustering of demand centres for supply economies of scale
  - Liquid H_2 as preferred distribution carrier
  - Reliance on imported H_2
    - Switching to Scottish renewables under import constraints