Renewable synthetic fuels for transport

Is ammonia also a friend?

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Why renewable synthetic fuels for transport?

For technologies that:
- Cannot be connected with static networks (pipes, cables)
- Require large high energy density storage
- Require tight fuel specification

⇒ **Almost exclusively transport – the toughest nut to crack**

Prime candidates:
- **aircraft**– kerosene equivalent hydrocarbon because of high energy density specification for aviation (but note

- **ships** – hydrogen, **ammonia**, hydrocarbon for ICE/fuel cells

- **trucks** - hydrogen, **ammonia**, hydrocarbon for ICE/fuel cells

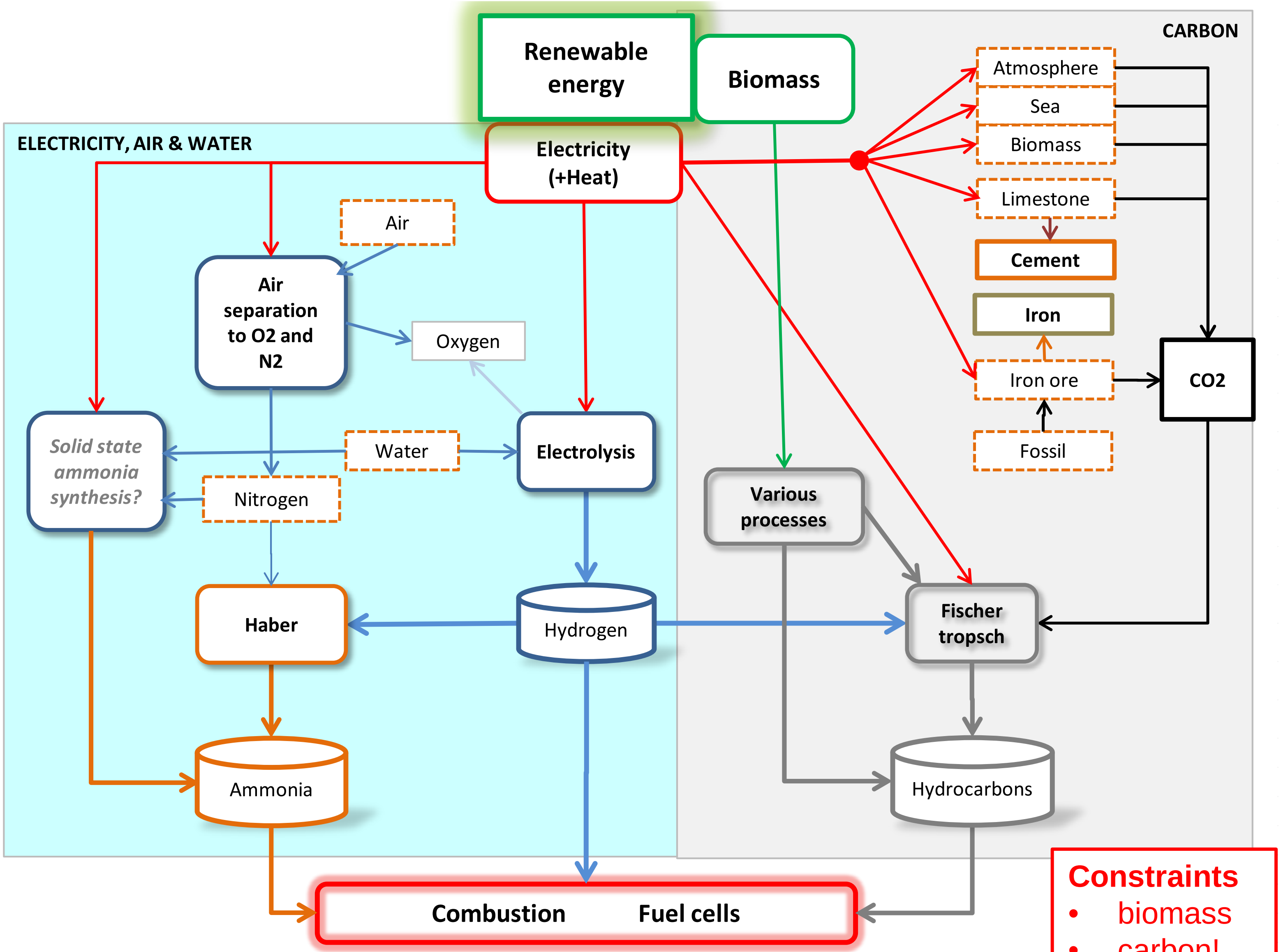
- Electric rail can cover much long distance freight and passenger transport
- Shorter distances can use EVs (cars, vans, buses) with batteries

Renewable fuel pathways

Energy input
- electricity
- biomass

- **Feedstocks**
- air
- water
- carbon

Products
- hydrogen
- ammonia
- hydrocarbons



Constraints
- biomass
- carbon!

Biofuels are best?

Biofuel production has complex interacting social, technical, environmental and economic factors that vary with location making it hard to analyse and regulate.

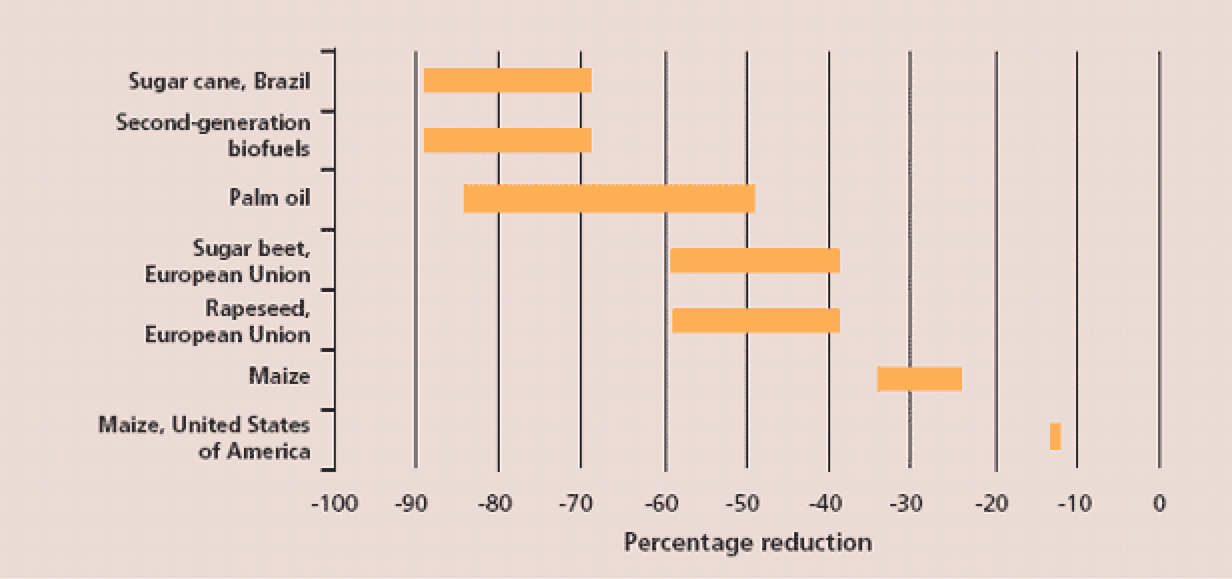
The good

- Oil-rich biomass (e.g. seeds) can be converted with reasonable efficiency to high specification biofuels for engines, but not other forms (e.g. wood).
- Biofuel production can increase farmers’ incomes

GHG emission relative to fossil

The bad

- Biofuels need large land areas
- Effect on food security and prices
- Land use change & ecosystems
- GHG emission (e.g. N2O)
- Inputs: fuels, water…



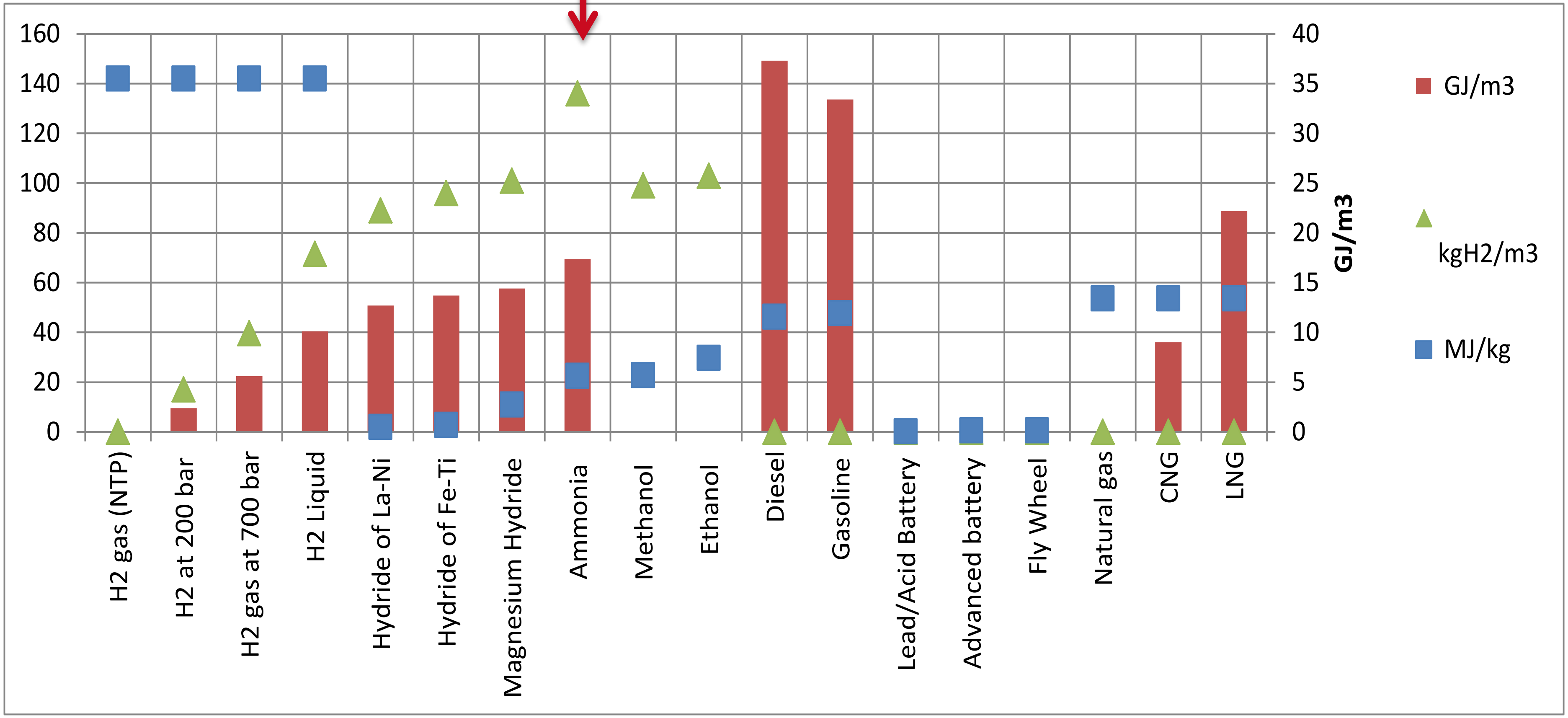
Note: Excludes the effects of land-use change.

Sources: IEA, 2006, and FAO, 2008d.

Fuel characteristics

Liquid Ammonia
Half energy density of fossil oil
Highest hydrogen volumetric density!

Excluding storage vessel size and efficiency



Ammonia: production from renewable electricity

Current global production ~180 Mt. Most for fertiliser and made from natural gas, some electrolysis.

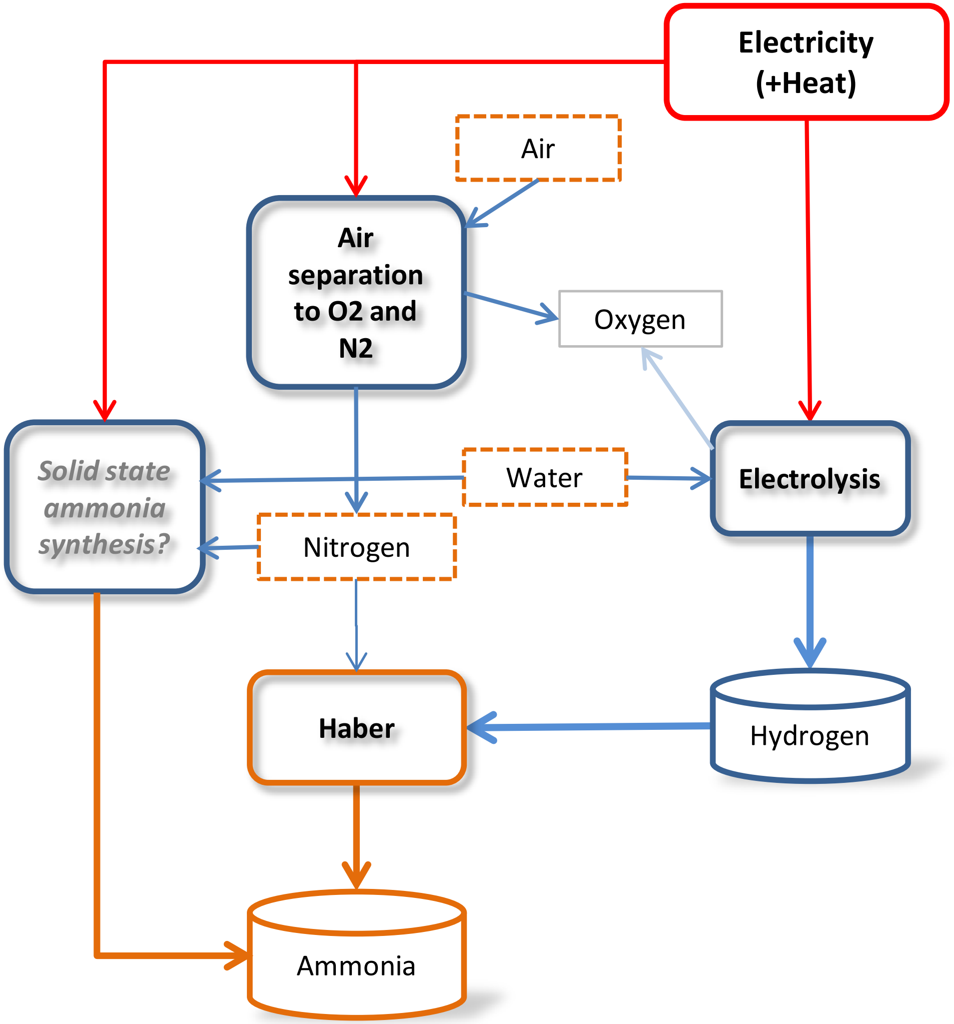
(About 50% of the nitrogen in humans originates in the Haber-Bosch process!!)

Ammonia can be made from air, water and renewable electricity.

Efficiency (electrical energy to ammonia energy) about 60%.

One 5 MW wind turbine:

- produces the same fuel energy (ammonia) as about 6 km2 of (European) biofuel,
- and about twice the GHG reduction.



Ammonia: safety, storage and transport

Safety
- Toxic at high concentrations but easily smelled at safe concentrations.
- Less flammable than diesel/gasoline

Storage as liquid at 250 psi pressure.

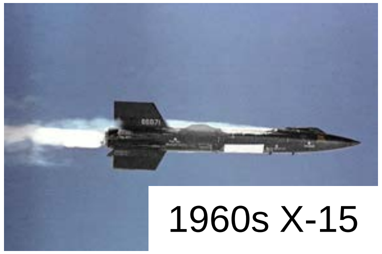
Transport:
- pipe (5000 km USA)
- ship
- road
- rail

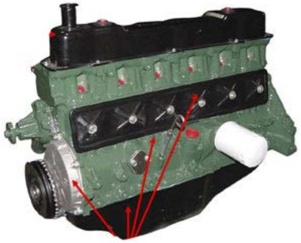
Ammonia: power production

Ammonia has been used in:
- internal combustion engines
- gas turbines
- fuel cells

Need more data on:
- Engine design and management
- NH3 and NOx emission (but negligible PM and SO2 emission)


1943 Ammonia bus in Belgium


1960s X-15


Hydrogen Engine Center (HEC) ammonia-powered engine meets California’s emissions standards.

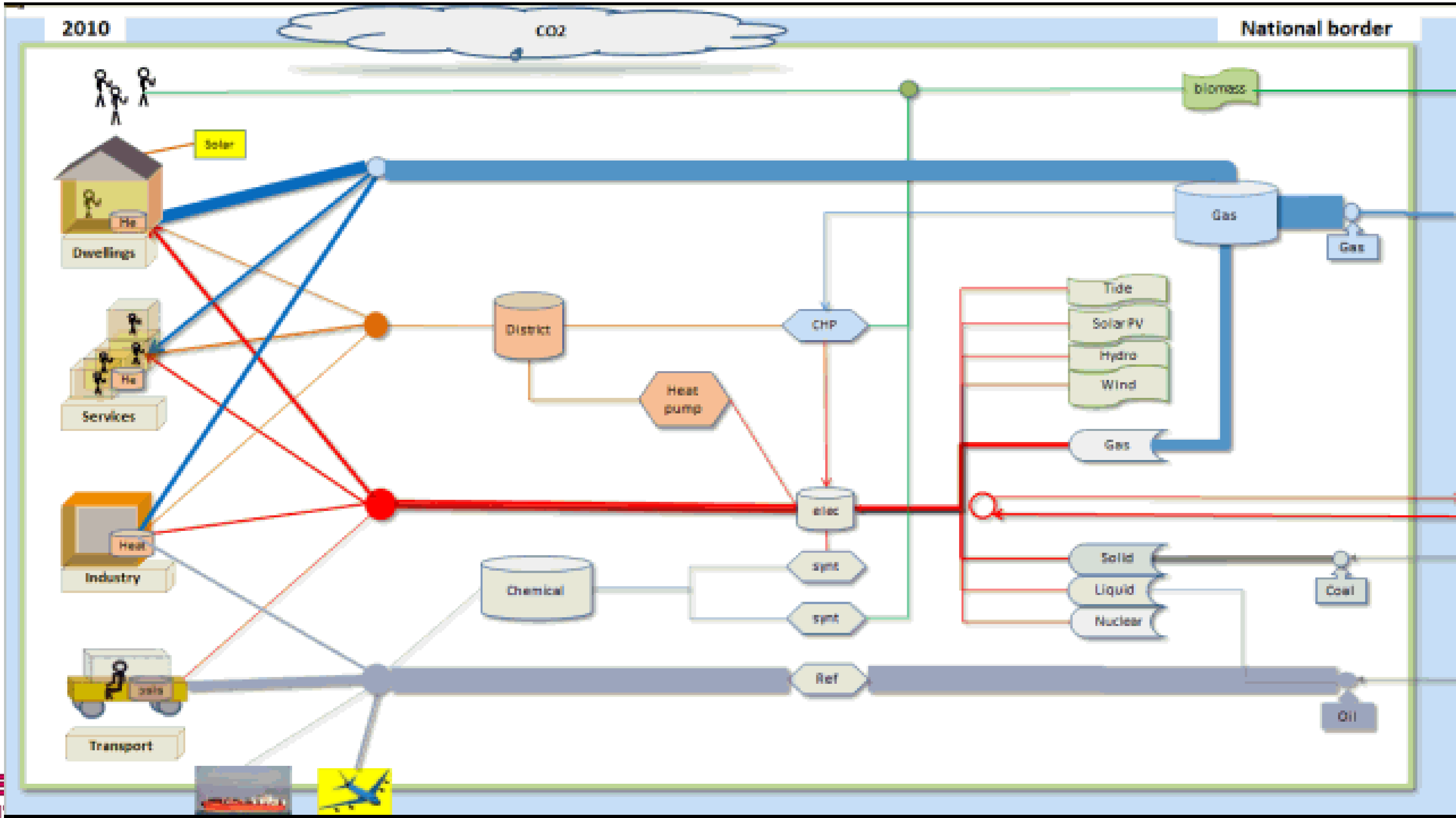

South Korean AmVeh car: mixture of ammonia and gasoline

2007 Detroit to San Francisco, a mix of ammonia and gasoline

Ammonia: ships

- Transport of bulk ammonia in ships well known
- Ammonia storage volume and weight not a big problem on ships; even dual fuelled with conventional fuel
- Ships engines slow revving and suitable for ammonia
- Current global oil use about 400 Mt.
- Current global ammonia production is about 200 Mt from methane, about a quarter of marine oil energy.
- As low carbon ammonia becomes available, it can be mixed in with fossil fuels in an increasing fraction.

Fuel synthesis integration in national energy system



Synthetic fuel production economics

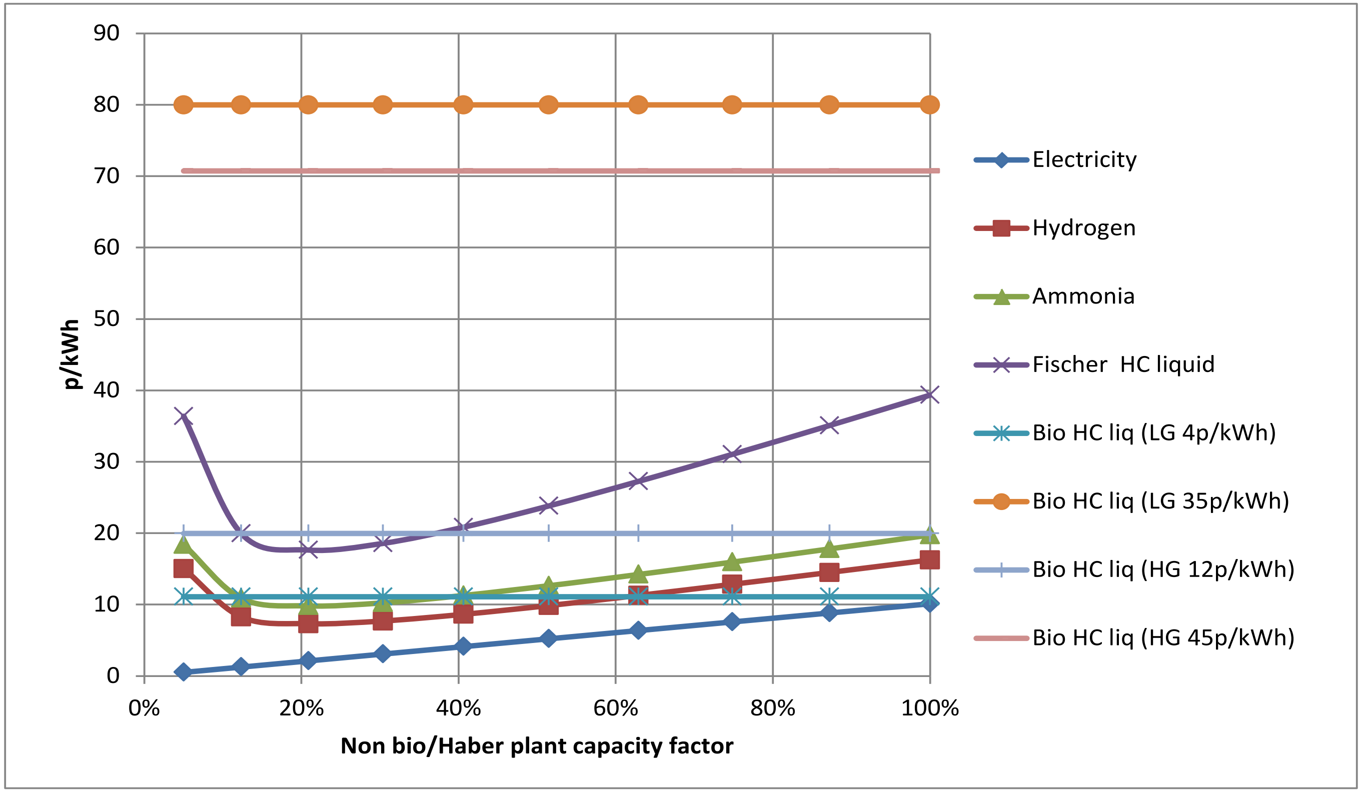
Costs depends on

- Feedstock costs
- Energy costs (time varying)
- Capital
- O&M

These depend on:

- synthesiser capacity factor:
- Unit capital costs
- Electricity costs

Electricity costs will vary with other demands and renewable output – i.e. a **national system dependency**



2012 fossil prices

	Marine diesel	Aviation kerosene
$/t	600	925
£/t	400	617
GJ/t	42	42
£/GJ	9.5	14.7
p/kWh	3.4	5.3

Pungent conclusions

- Ammonia can be a friend!
- Renewable electricity recycles air and water via a fuel that is a near zero greenhouse gas and air pollution emitter
- Relatively easy to quantify impacts and costs globally
- Perhaps 2-4 times more expensive than current fossil oil.

Further work

- Assessment of motors and fuel cells using ammonia
- Detailed technical, environmental & economic model of production, distribution and use pathways - partcularly ammonia leakage
- Analysis of technical/economic integration of synthesis into national system, including use of ammonia for energy storage

Thank you for listening. Questions?

http://www.cruisecritic.co.uk/news/news.cfm?ID=1641

In light of the ever-increasing prices for fuel, what *does* it cost to fill up Freedom's tank?

First we have to give the folks at CNBC a nod of thanks -- an assignment editor called us yesterday wanting to know how big Freedom's tank was, and so we set out to find out. The scoop? The tank itself, according to a Royal Caribbean spokesman, can hold 3,533 metric tons of fuel. That's actually not a record-setter even if the ship's overall tonnage is; Cunard's Queen Elizabeth 2, for instance, has a tank capacity of 4,381.

QE2 can run for 10 days on that fill-up, sailing at an average 32.5 knots -- and for a distance of some 7,800 nautical miles.

Conclusions

Conclusions

- Biomass and carbon feedstock constraints important

- Synthesis with renewable electricity a national system integration issue

- Synthetic H2/NH3 perhaps 2-4 times more expensive than current fossil oil; uses renewable electricity, air and water.

- Biofuels perhaps 4-10 more expensive than current fossil oil; possible severe social and environmental impacts.

Further work

- Assessment of motors and fuel cells using synthetic fuels
- Analysis of constraints
- Detailed technical, environmental & economic model of synthesis pathways
- Analysis of technical/economic integration of synthesis into national system

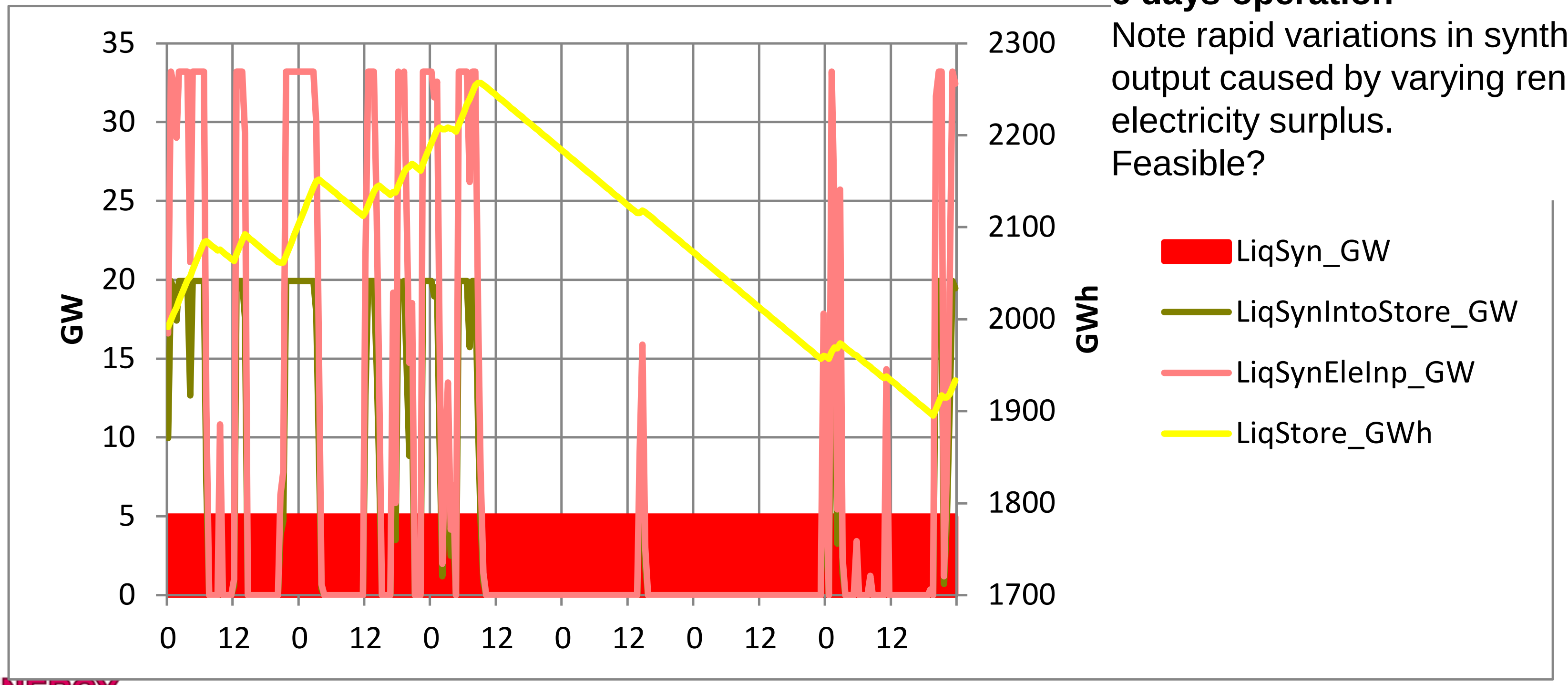
Some transport fuel pathways

Red italic most uncertain data		**Fossil**		**Biofuel**	**Renewable electricity**						**CHP (excl**
Primary		**Crude oil**	**Gas**	**Biomass**	**Renewable**	**Renewable**	**Renewable**	**Renewable**	**Renewable**	**Renewable**	**Biomass**
Refine		94%		***50%***							
Transform											CHP
											30%
Distribution		Crude oil	Gas	Biomass	Electricity	Electricity	Electricity	Electricity	Electricity	Electricity	Electricity
		99%	99%	99%	97%	97%	97%	97%	93%	93%	93%
Delivered			Gas		Electricity	Electricity	Electricity	Electricity			
	Transform		95%		***75%***	***75%***	***75%***	***75%***			
	Product		CNG		Hydrogen	Hydrogen	Hydrogen	Hydrogen			
Synthesis	Material input				Water		Water	Water			
					Nitrogen		Carbon	Carbon			
	Efficiency				***90%***		***70%***	***70%***			
	Output				Ammonia		Liquid	Gas			
Vehicle	**Input**	**Liquid**	**CNG**	**Liquid**	**Ammonia**	**Hydrogen**	**Liquid**	**Gas**	**Electricity**	**Electricity**	**Electricity**
							HC fuel	**HC fuel**			
	Input	100%	95%	100%	*99%*	*80%*	100%	90%	90%		90%
	Store	Tank	Tank	Tank	Tank	Tank	Tank	Tank	Battery		Battery
	Output	100%	100%	100%	100%	100%	100%	100%	90%		90%
	Engine type	ICE	ICE/FC	ICE	ICE/FC	ICE/FC	ICE	ICE/FC	EM (EV)	EM (train)	EM
	Conversion		CNG			Hydrogen					
			100%			40%					
		Liquid	Gas	Liquid	Ammonia	Electricity	Liquid	Gas	Electricity	Electricity	Electricity
	Engine to motive power	35%	35%	35%	32%	90%	35%	35%	85%	90%	90%
Overall	**Primary to power**	**33%**	**31%**	**17%**	**21%**	**21%**	**18%**	**16%**	**64%**	**84%**	**20%**
					32%	*33%*	*28%*	*25%*	*100%*	*131%*	
					Ratio overall efficiency to electric vehicle						

Electric synthesiser operation example

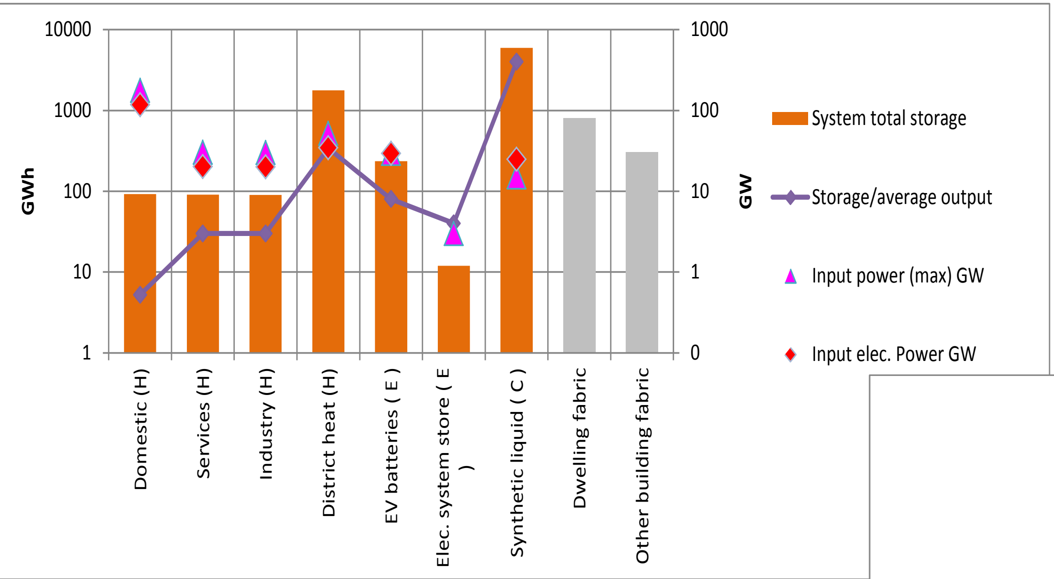
Balance between:

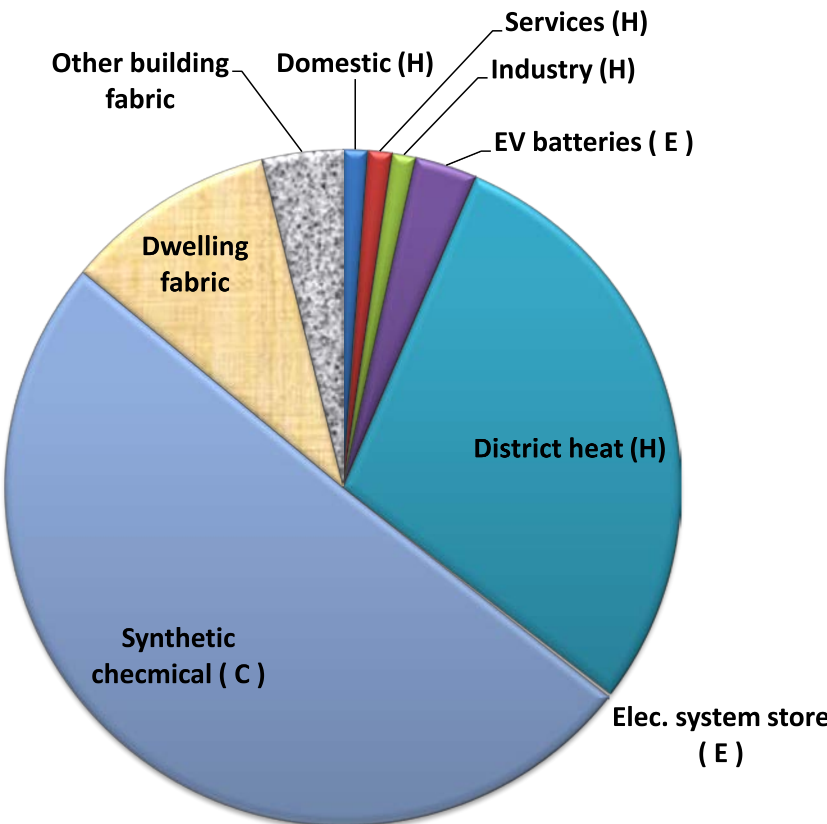
- Use of low cost/low carbon electricity
- Synthesiser capacity factor
- Variability of synthesiser operation



6 days operation
Note rapid variations in synthesiser output caused by varying renewable electricity surplus.
Feasible?

National – electrically connected storage





What matters most technically?

- **kW in**
- **kWh stored**
- **kW out**
- **Efficiency = Eout / Ein**

Why storage?

Storage costs money and consumes energy.

The only point of storage is if it reduces the total capital and operating costs of meeting energy and environment objectives.

It can:

- store renewable or other low marginal cost supply for when this supply is in deficit
- reduce the use of higher cost marginal supplies
- reduce peak flows and capital investment in generation, transmission etc.
- reduce the variability of demand which is costly, especially to electricity generation
- improve system reliabililty – e.g. if a power station fails

Transmission interconnection can produce most of the same benefits – how much storage, how much transmission?

SYSTEM CONTROL ALGORITHMS

Algorithms need to control whole system, including:

1. **Building heating and cooling, synthetic fuel production**
2. **Stores: thermal, EVs, chemical, pumped storage**
3. **Dispatchable generation**
4. **Multi-fuel switching – e.g. between heat pumps and CHP**
5. **International trade**

Algorithms should include forecast demand and supply

Complex non-linear system so biological, heuristic algorithms useful

STORAGE CONTROL ALGORITHMS

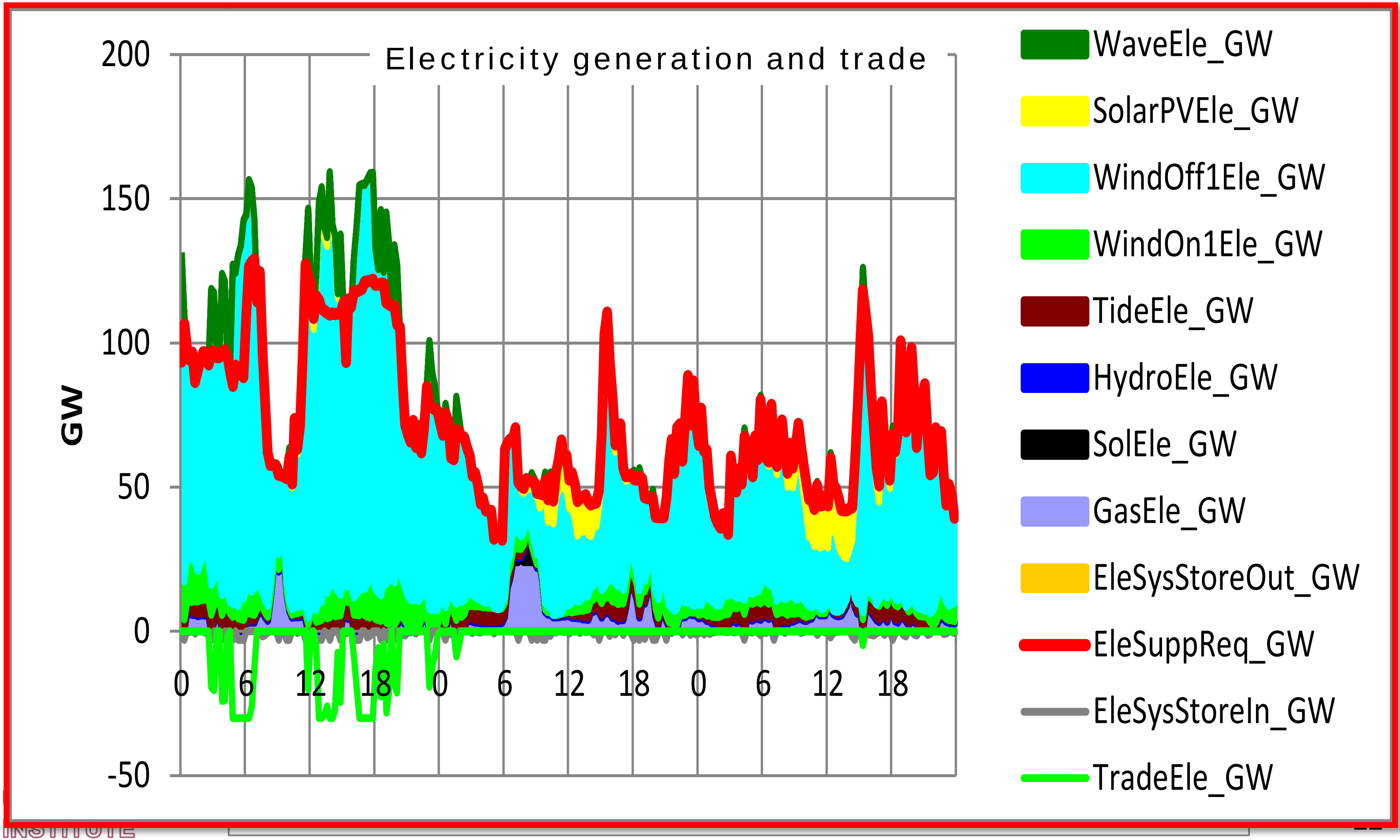
Example 1: Sequential surplus renewable electricity allocation to stores

The surplus to store control algorithm allocates any uncontrollable electricity surplus to flows with storage – heating, EVs, district heating, synthetic fuel production

1. The surplus is sequentially allocated according to proximity to service, energy store size and the availability of multi-fuelling:
    1. domestic (heat stores)
    2. electric vehicle (batteries)
    3. services (heat stores)
    4. industry (heat stores)
    5. district heating (heat stores)
    6. synthetic fuels (chemical stores)
    7. electricity system storage (e.g. pumped storage)

2. If all demands are met and stores or input capacities are full, any remaining surplus is exported or spilled

Matching demand to supply – DynEMo 1 day for months 1,4,7 ; modelled at 5 min intervals



Optimising storage configuration for whole system

What types and sizes of stores connected where in the energy system?

How do we optimise?

1. Accurately simulate whole energy system dynamics over short time steps.
Quite difficult if transmission included as spatial dimension then needed

2. Optimise dynamic system.
Very difficult– system is non-linear over perhaps 500-5000 time steps.

- **Transmission interconnection can produce most of the same benefits – how much storage, how much transmission?**
- **Should optimise whole system configuration and control at the same time**