GTSP

Global Energy Technology Strategy Program

End-use Energy and Its Role in Addressing Climate Change in the USA

Joint Global Change Research Institute
College Park, MD

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Pacific Northwest National Laboratory
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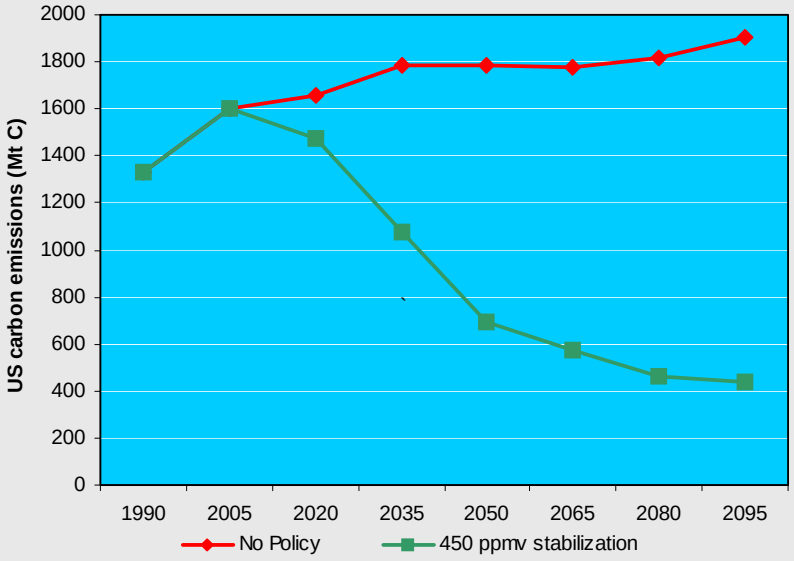
Introduction

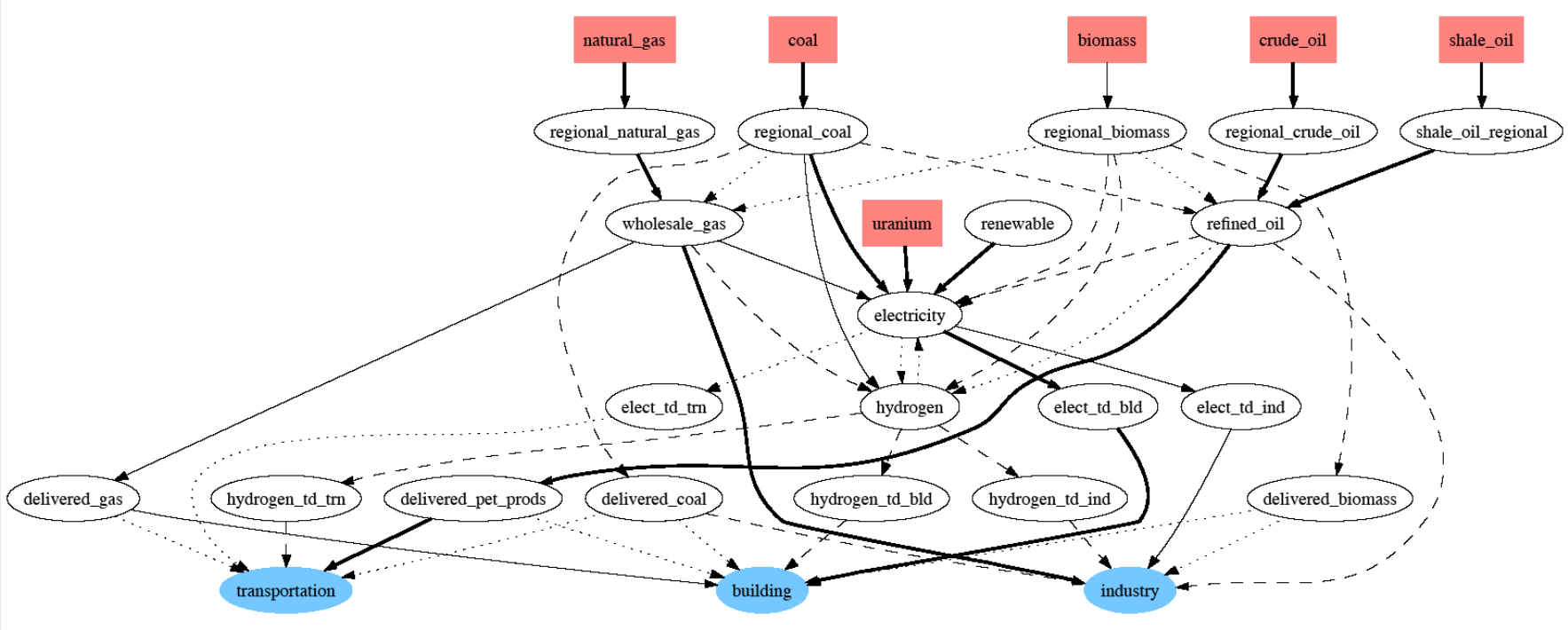
- Motivation: to quantify the value of deployment of advanced technologies
- Method
  - Detailed representations of United States buildings, industry, and transportation sectors
  - Reference technology: innovation as usual
  - Advanced technology: accelerated deployment of existing or emerging end-use technologies
  - Value of advanced technology calculated as reduced carbon abatement costs from reference scenario

Carbon policy emissions pathway

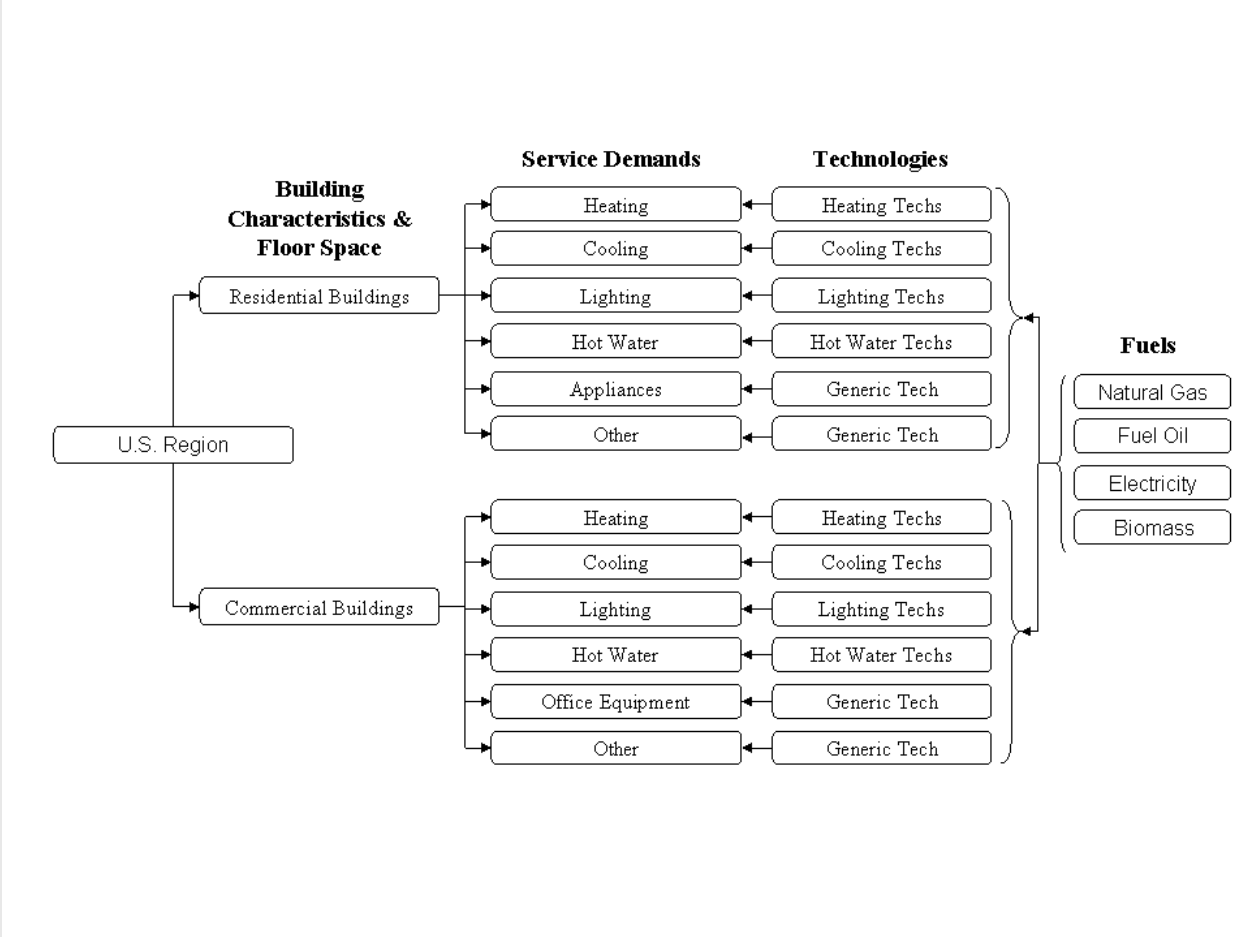


- U.S. fossil and industrial carbon emissions, without any emissions constraint, and with a policy to stabilize CO_2 at 450 ppmv
  - This emissions pathway will be used in all policy scenarios investigated in this study
- This policy is only a representative emissions pathway
  - Relative to 1990, emissions are 10% greater in 2020 and 50% lower in 2050

End-use sectors in MiniCAM



Buildings sector schematic

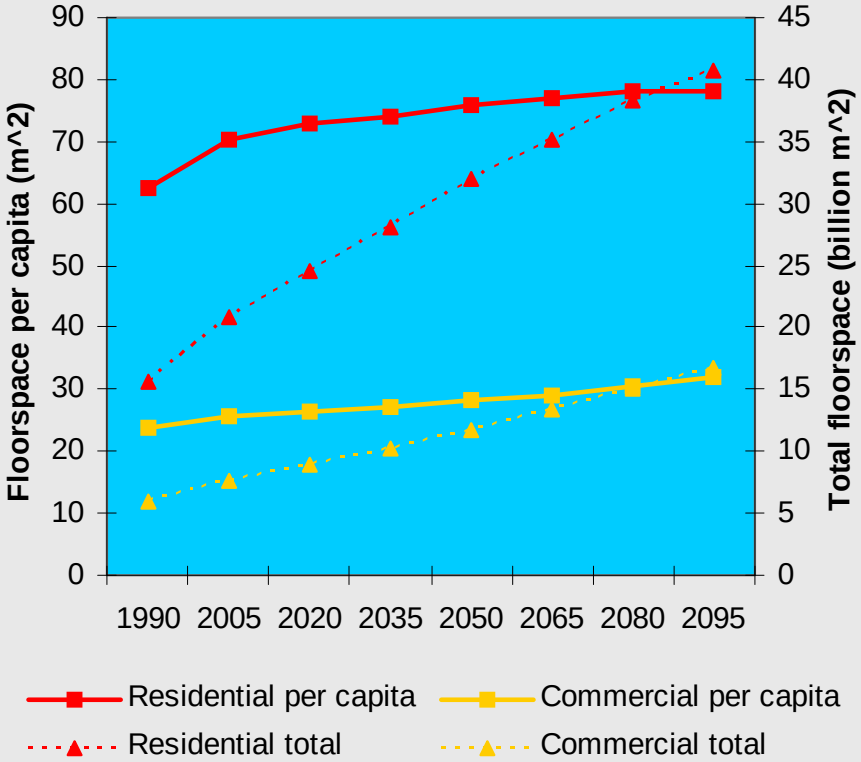


Residential sector technology assumptions

Technology	unit	2005	Reference 2050	Reference 2095	Advanced 2050	Advanced 2095
Building shell	W/m2	0.232	0.182	0.150	0.171	0.132
Gas furnace	AFUE	0.82	0.90	0.97	same as reference	
Gas heat pump	GCOP	na	na	na	1.75	2.45
Electric furnace	AFUE	0.98	0.99	0.99	same as reference	
Electric heat pump	HSPF	7.32	8.50	9.51	10.04	14.05
Oil furnace	AFUE	0.82	0.86	0.93	same as reference	
Wood furnace	AFUE equiv	0.40	0.42	0.44	same as reference	
Air conditioning	SEER	10.7	14.8	18.5	17.4	27.3
Gas water heater	EF	0.56	0.61	0.64	same as reference	
Gas HP water heater	EF	na	na	na	1.75	2.45
Electric water heater	EF	0.88	0.93	0.97	same as reference	
Electric HP water heater	EF	na	2.46	2.75	2.75	3.45
Oil water heater	EF	0.55	0.56	0.59	same as reference	
Incandescent lighting	lumens/W	14	15	16	same as reference	
Fluorescent lighting	lumens/W	60	75	94	same as reference	
Solidstate lighting	lumens/W	100	112	125	156	245
Gas appliances	indexed	1.00	1.12	1.26	1.12	1.26
Electric appliances	indexed	1.00	1.23	1.38	1.44	2.01
Other gas	indexed	1.00	1.12	1.25	same as reference	
Other electric	indexed	1.00	1.08	1.21	1.25	1.75
Other oil	indexed	1.00	1.12	1.25	same as reference	

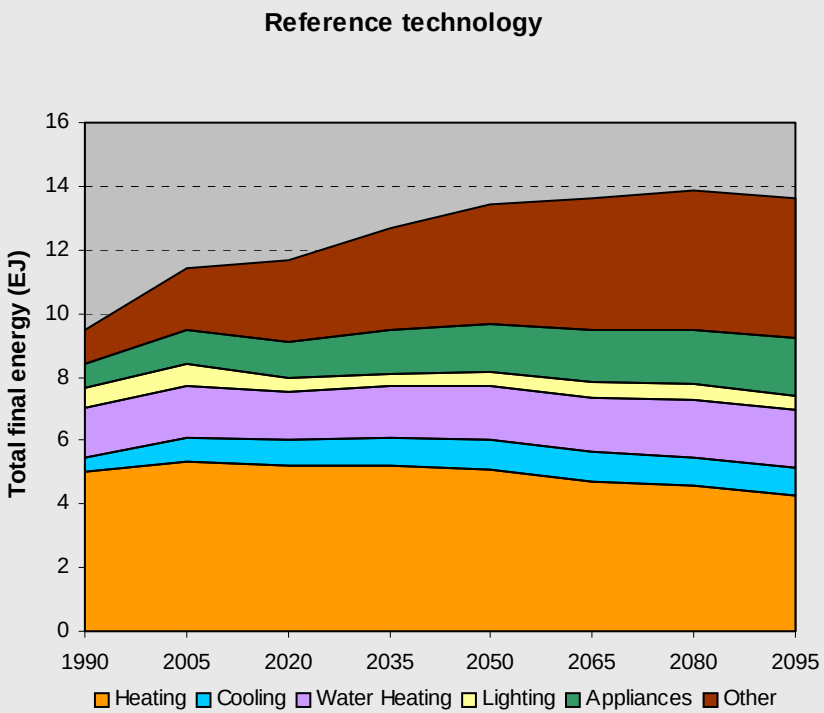
Floorspace per capita

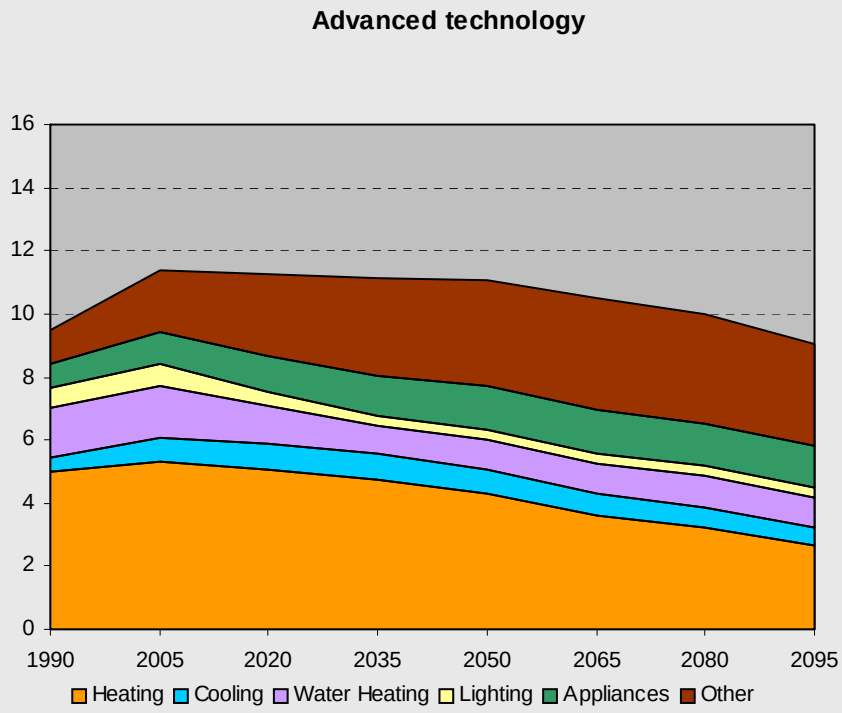
- Both residential and commercial sectors grow over time
- Attenuation in residential floorspace per capita.



Residential sector energy consumption by service, reference and advanced technology, 1990-2095

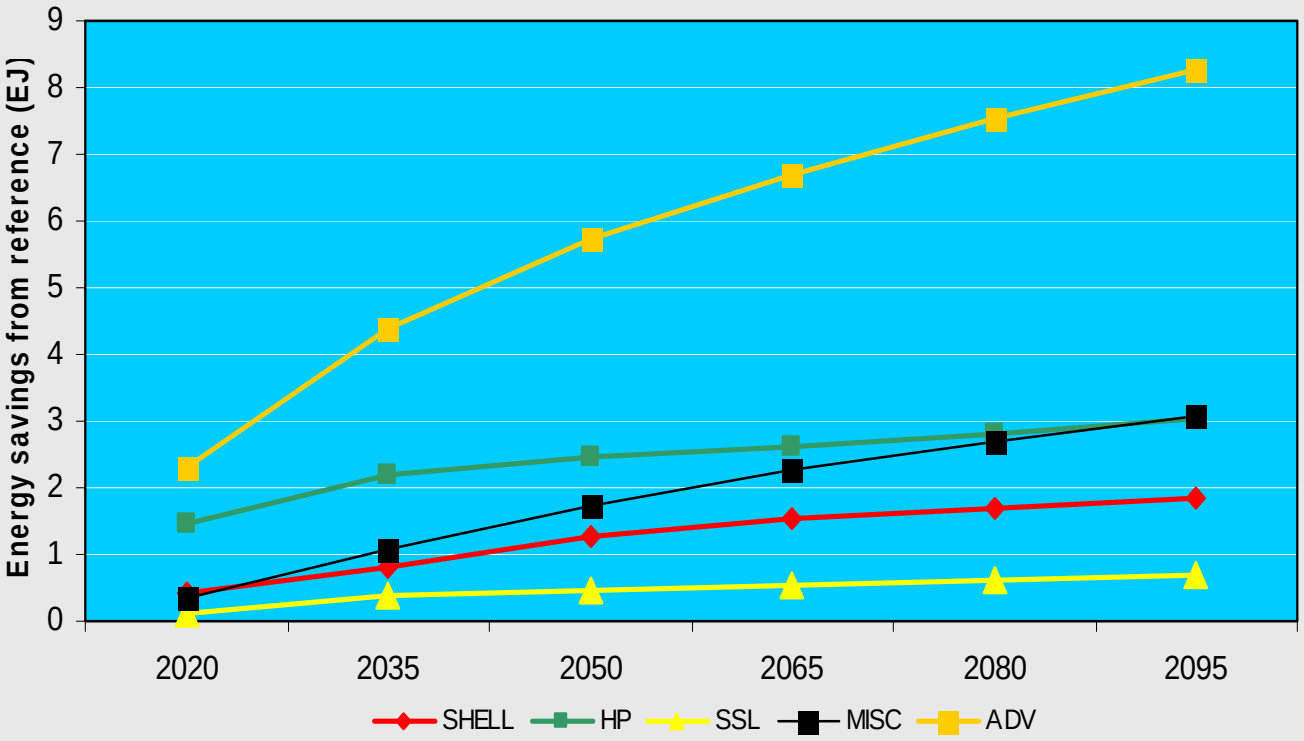
- Increasing share of “other” demands
- Heating service energy savings from reference to advanced





Secondary analysis: energy savings by technology area, residential and commercial sectors

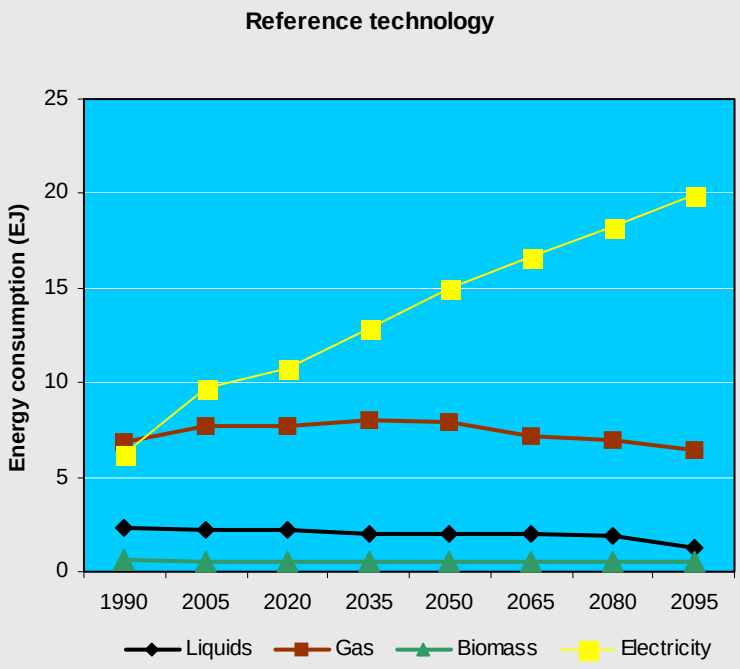
- Advanced heat pumps and miscellaneous techs account for the greatest energy savings from reference to advanced technology in these scenarios

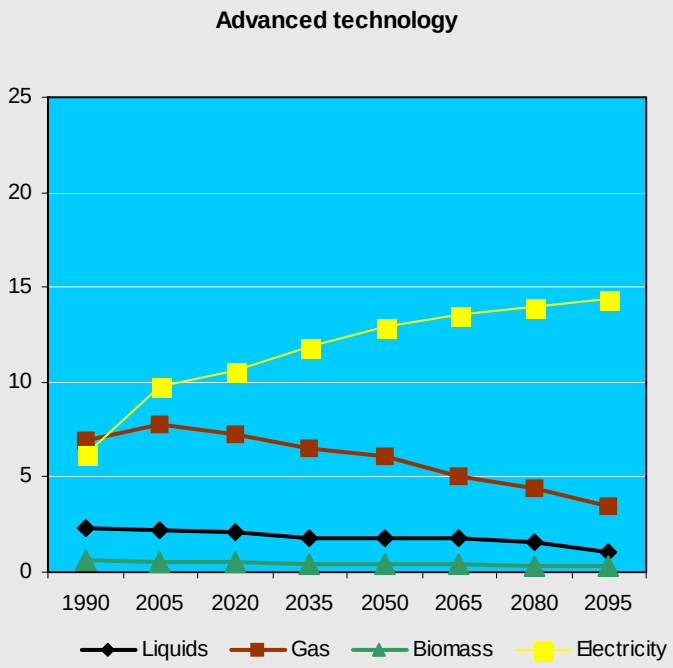


- SHELL = advanced building shells
- HP = advanced heat pumps (space and water heating)
- SSL = advanced solid-state lighting
- MISC = advanced miscellaneous technologies
- ADV = all techs advanced

US buildings sector total final energy by fuel

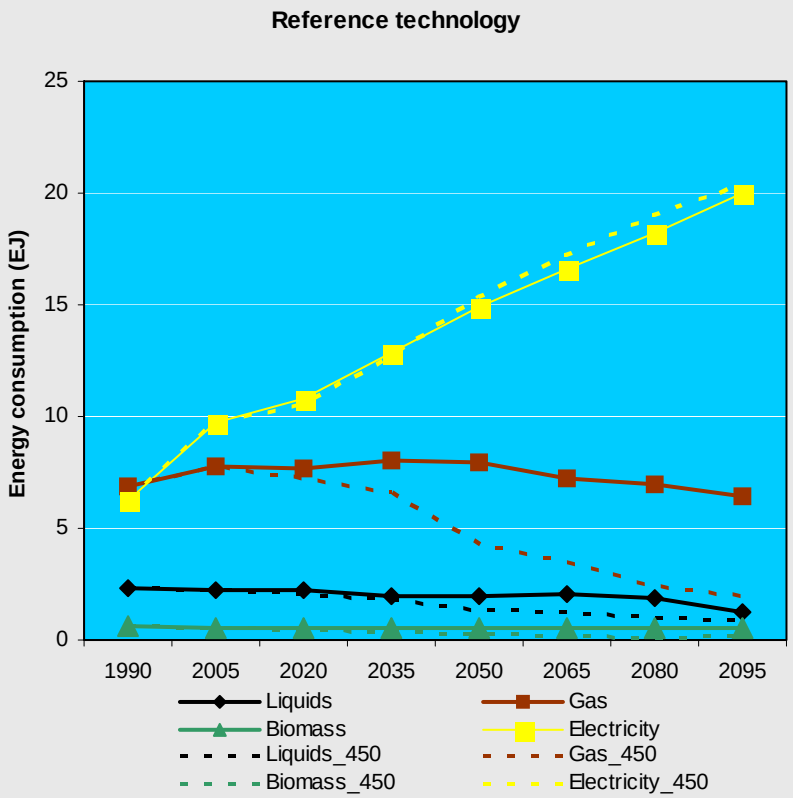
- Electricity is the dominant fuel of the future

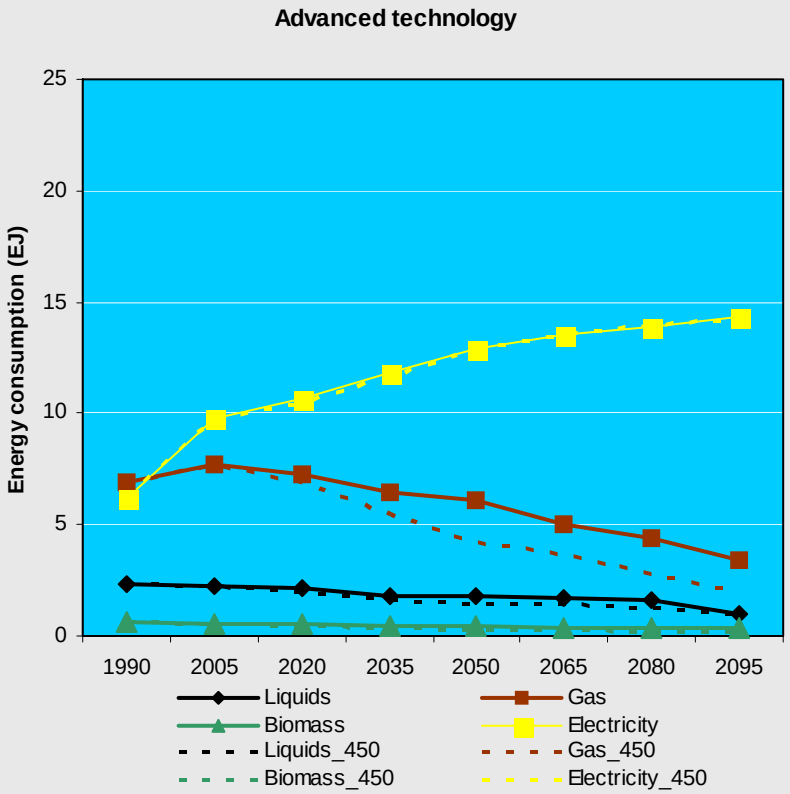




US buildings sector total final energy by fuel, with policy

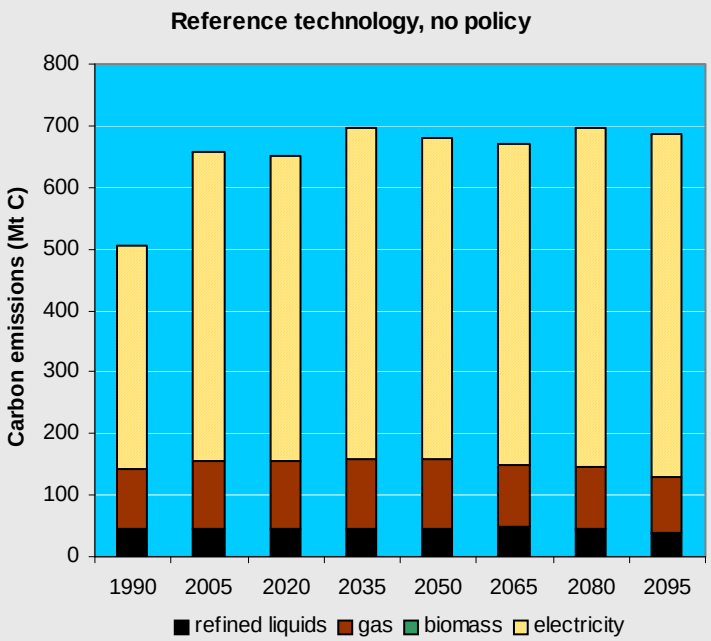
- Policy increases relative fuel share of electricity
- Advanced technology mitigates policy-induced service decline

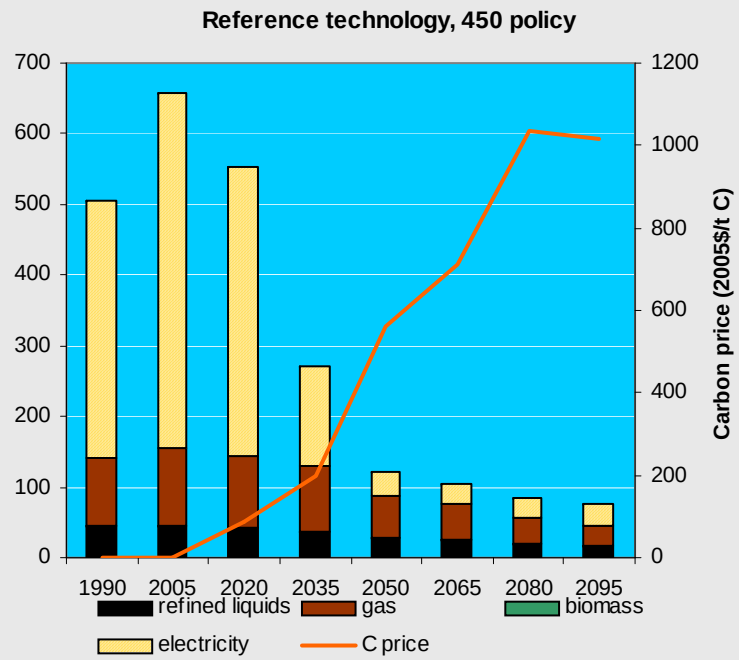




Buildings sector emissions with and without emissions constraints, reference technology

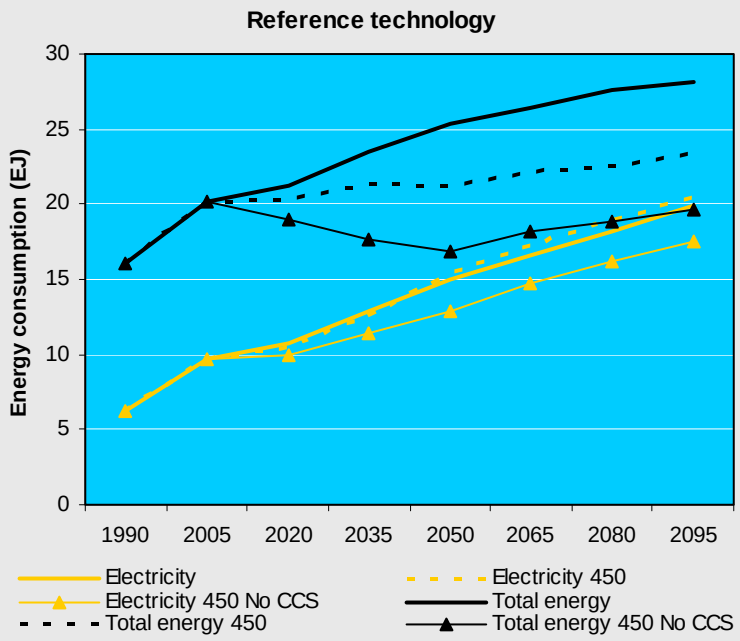
- Most of the carbon abatement from the buildings sector comes from changes in the electricity sector

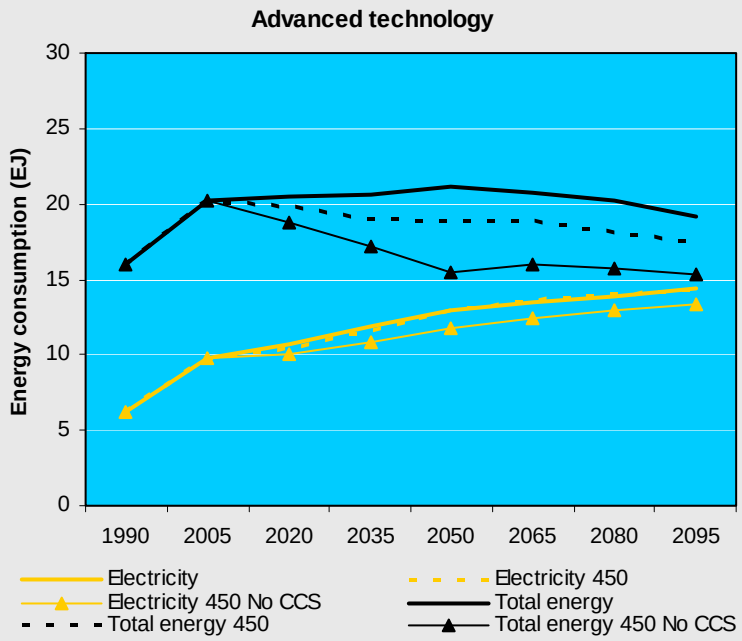




Secondary analysis: no CCS, no expansion of nuclear power

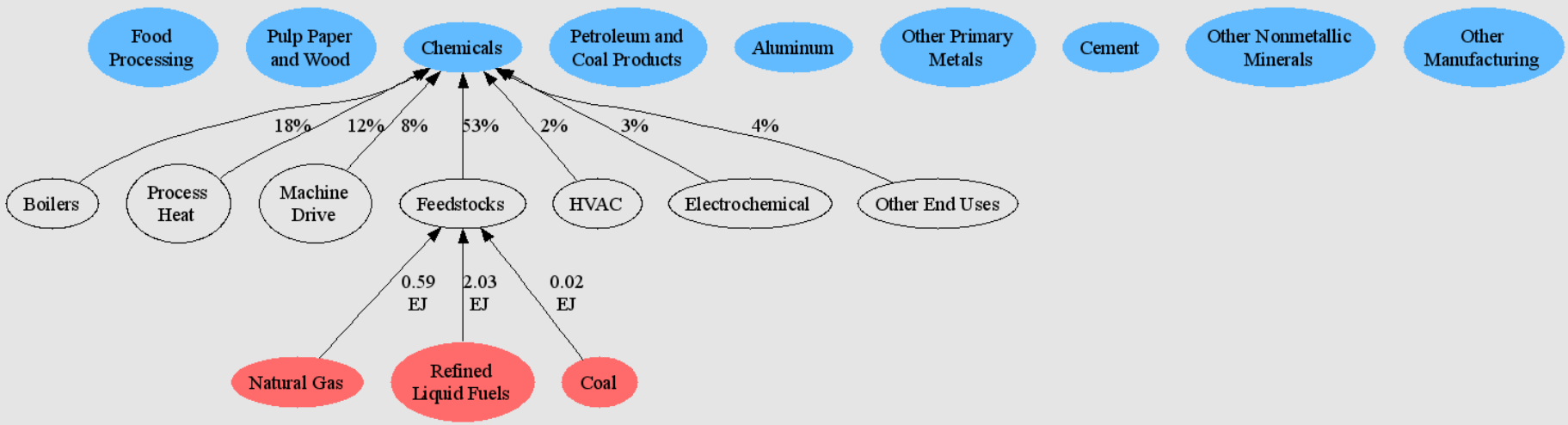
- Electricity consumption in a policy case is lower without CCS and expanded nuclear power
  - However it still remains the dominant fuel of the buildings sector
  - Relative fuel share increases with higher electricity prices



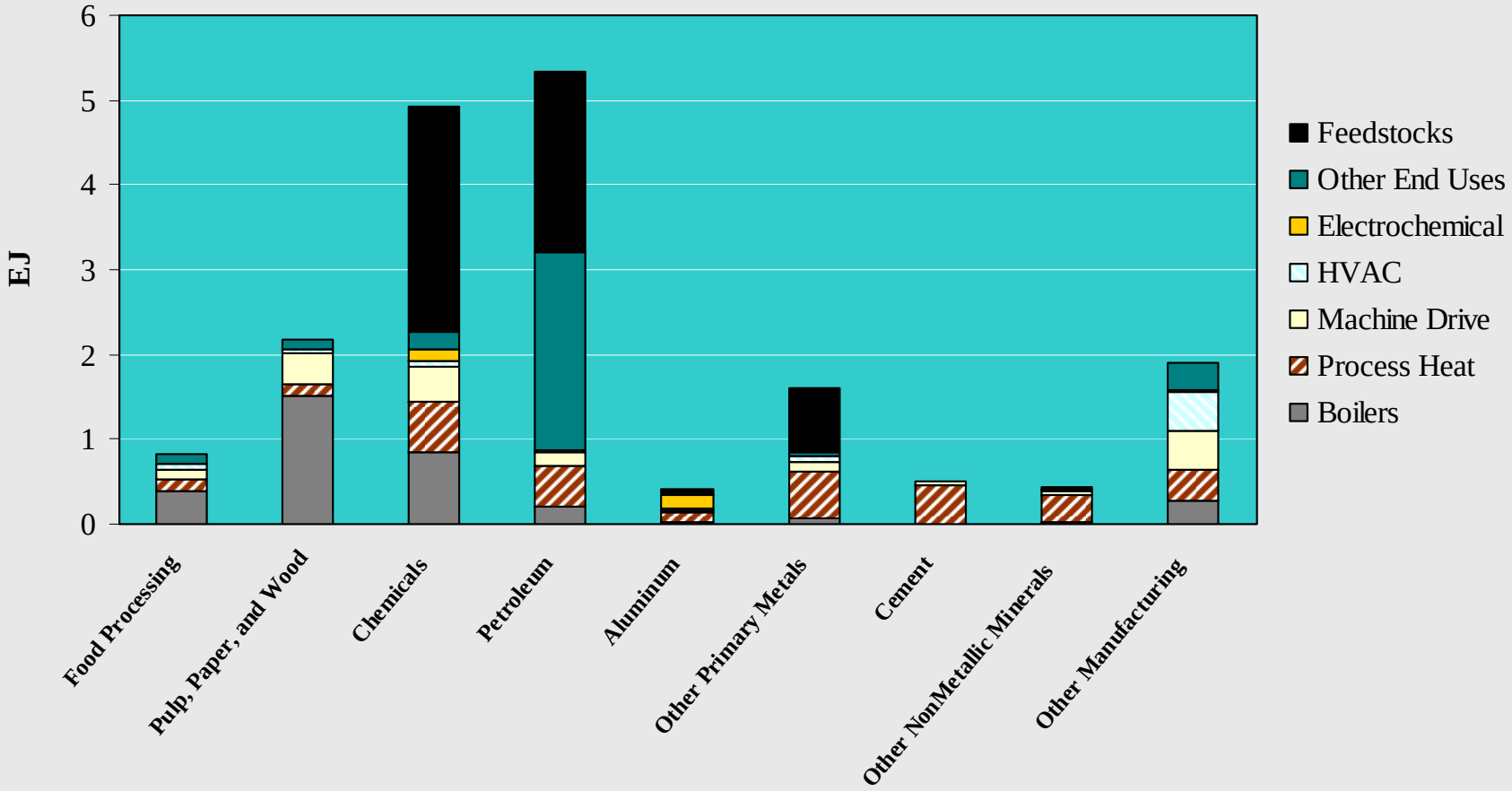


US Industrial sector schematic

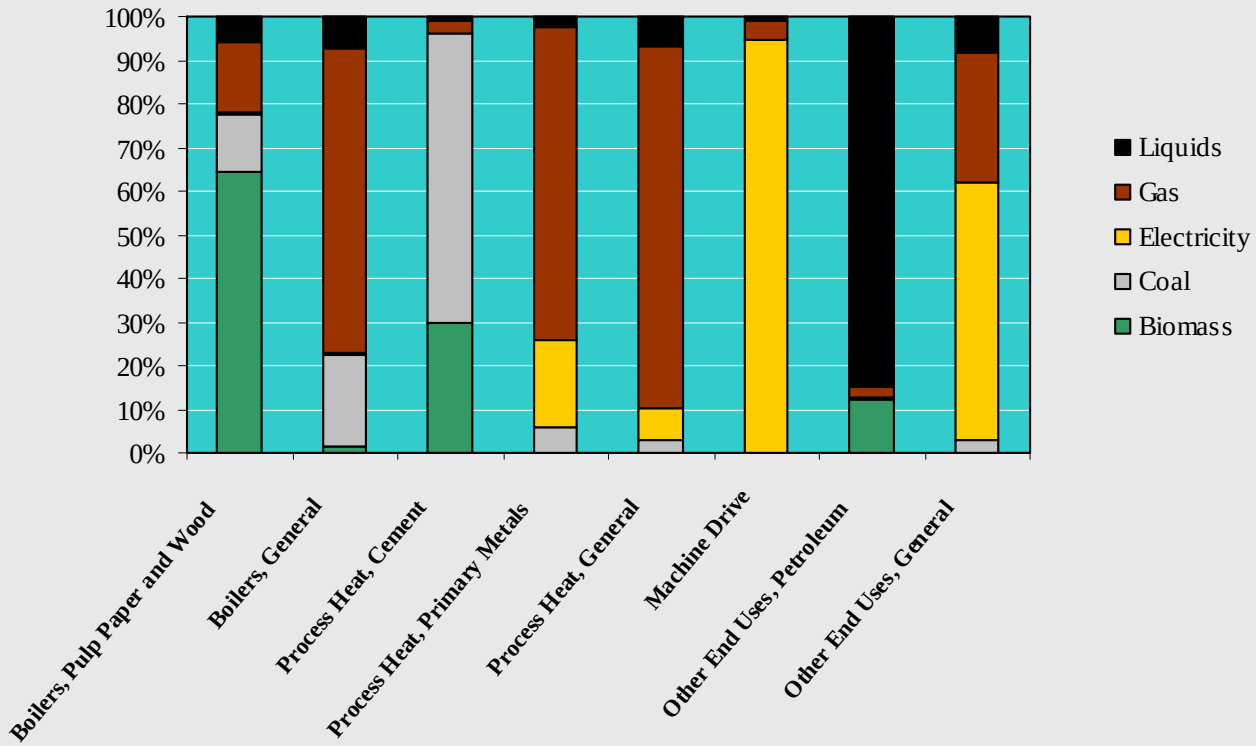
- Each industry group requires a range of services, in prescribed proportions
- Services are supplied by competing technologies
- Cogeneration is represented with feedbacks to electricity sector considered



Manufacturing energy consumption by industry group and service, 2005



Fuel preferences by service



- Some industries can use by-products of manufacturing processes as fuel (e.g. pulp and paper boilers, petroleum “other”)
- Some manufacturing processes require certain fuels (e.g. electric arc furnaces in iron and steel)

Efficiency and intensity assumptions, reference and advanced

- Advanced scenario assumes 10% improvement in boilers and 20% improvement in machine drive by 2035

Specific end-use technology improvement, relative to 2005

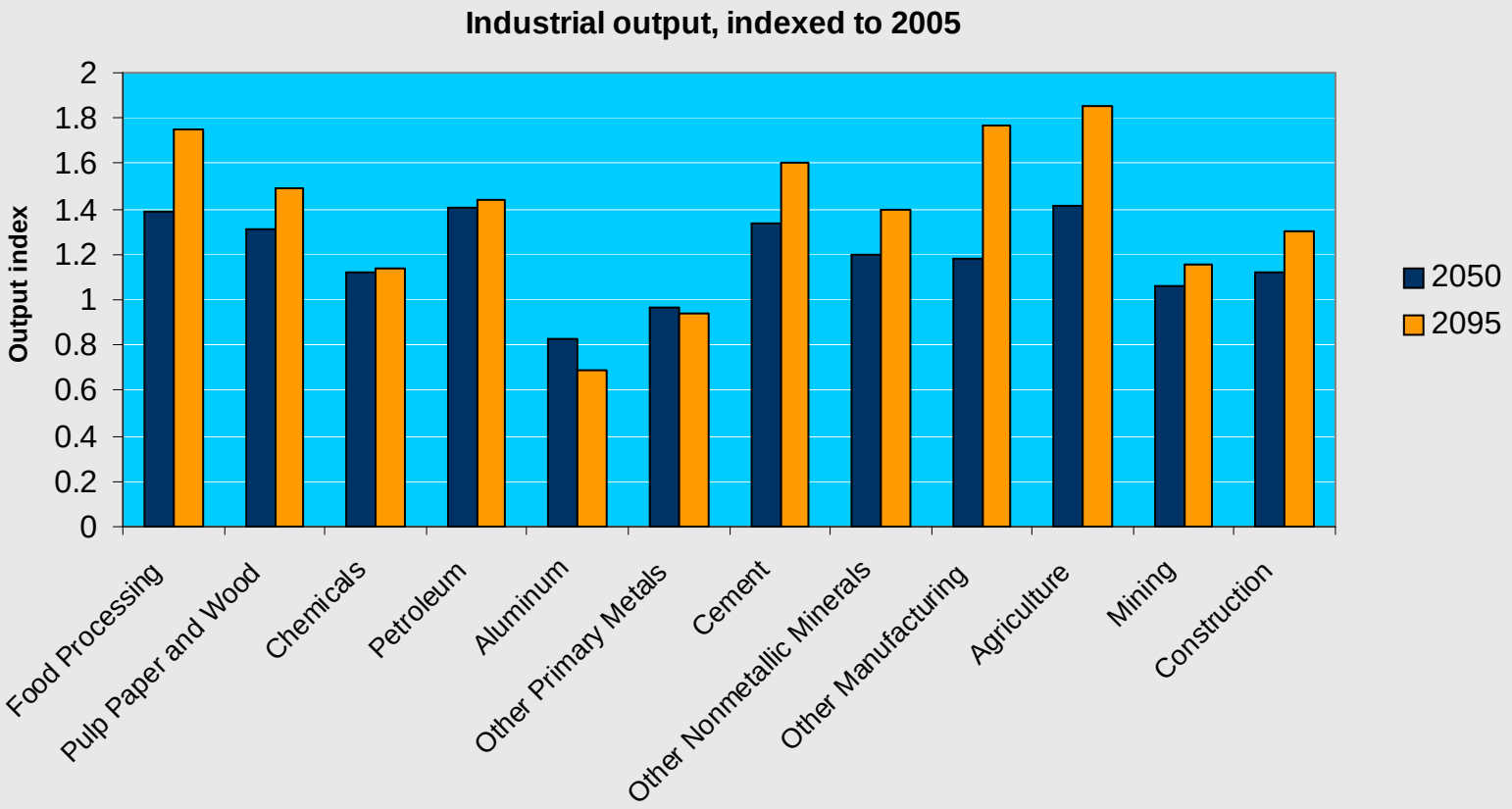
		Reference		Advanced	
	Fuel	**2050**	**2095**	**2050**	**2095**
Boilers	gas	5%	9%	12%	17%
Boilers	oil	5%	9%	12%	17%
Boilers	biomass	5%	9%	12%	17%
Boilers	coal	5%	9%	12%	17%
Boilers	electricity	0%	0%	0%	0%
Machine Drive	electricity	5%	9%	27%	33%

	Reference		Advanced	
	2050	**2095**	**2050**	**2095**
Food Processing	17%	37%	17%	37%
Pulp Paper and Wood	17%	37%	36%	86%
Chemicals	17%	37%	27%	60%
Petroleum	17%	37%	22%	48%
Aluminum	17%	37%	24%	53%
Other Primary Metals	17%	37%	24%	54%
Cement	10%	23%	49%	62%
Other Nonmetallic Minerals	17%	37%	17%	37%
Other Manufacturing	17%	37%	28%	64%
Agriculture	17%	37%	17%	37%
Mining	17%	37%	17%	37%
Construction	17%	37%	17%	37%

- Advanced production technologies deployed in pulp and paper, chemicals, primary metals, cement and "other" manufacturing
- Advanced scenario generally assumes convergence to global best available manufacturing practices

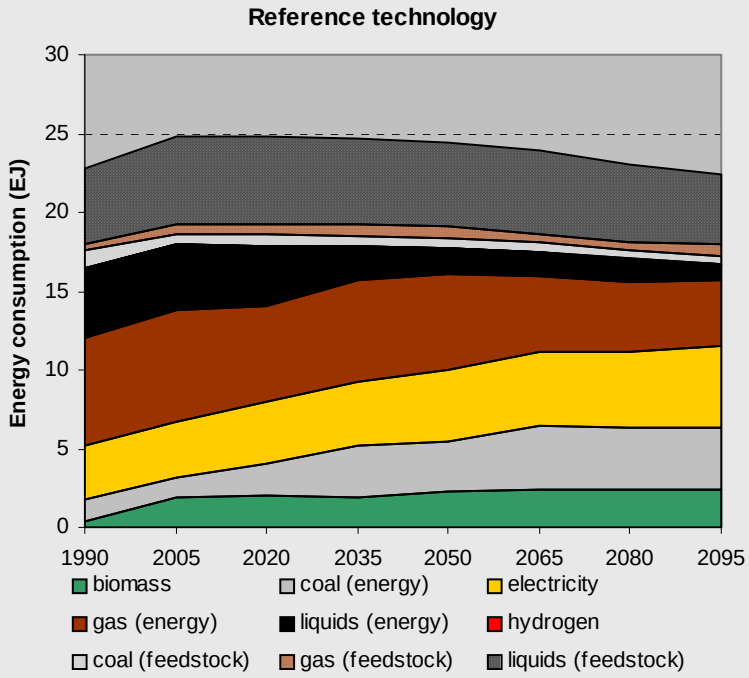
Output by industry, relative to 2005

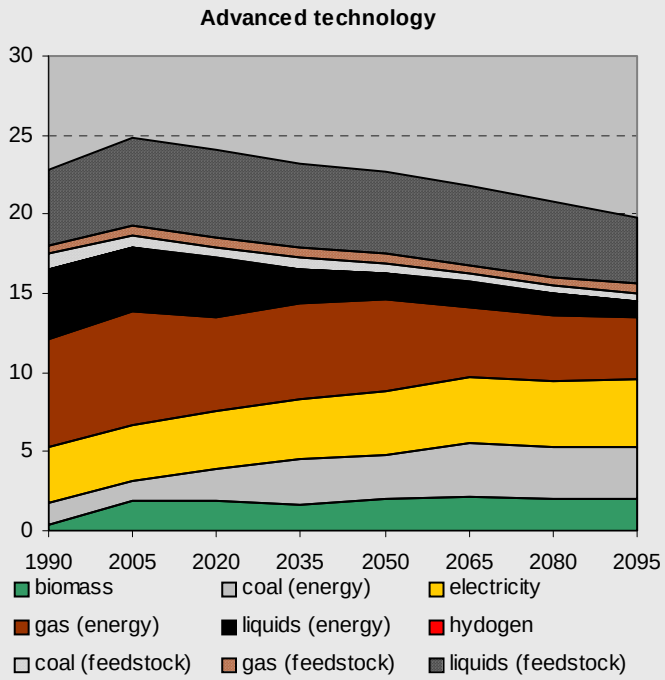
- Least growth in primary metals; most in agriculture and other manufacturing



US industry total final energy consumption by fuel

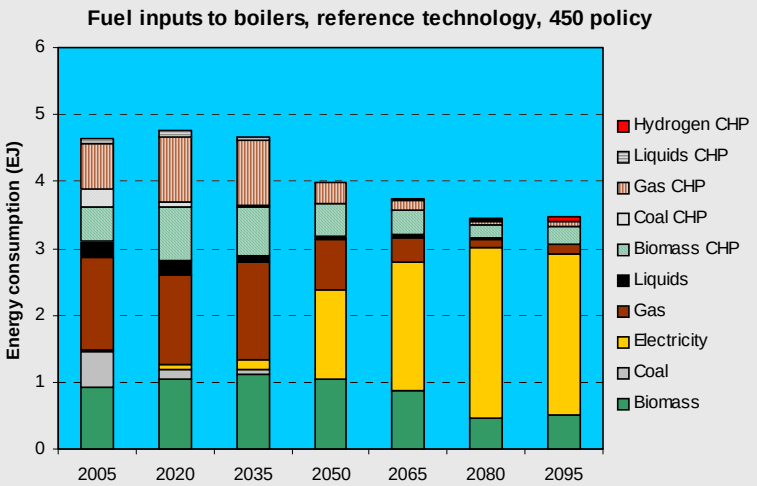
- Energy consumption stabilizes in reference technology
- Relative fuel shares are similar between scenarios

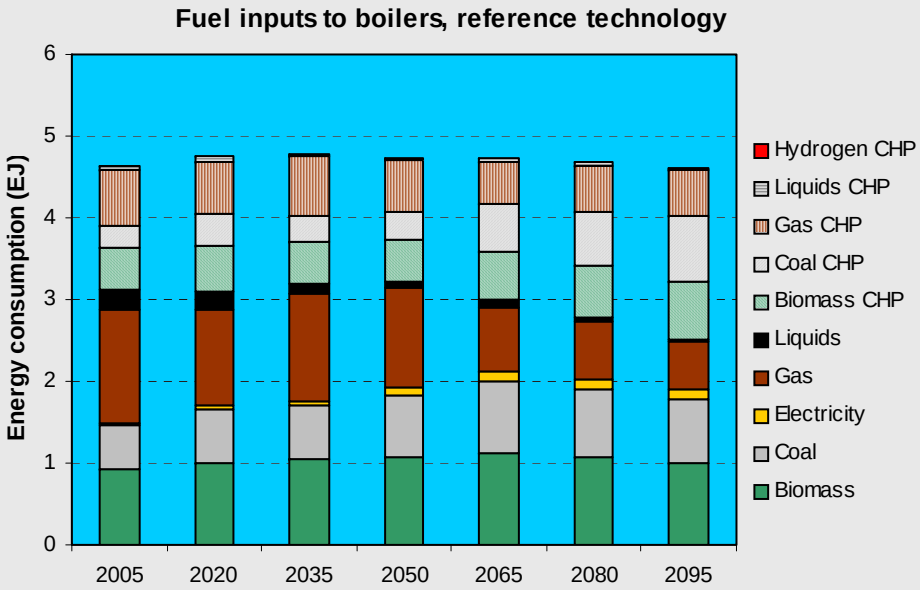


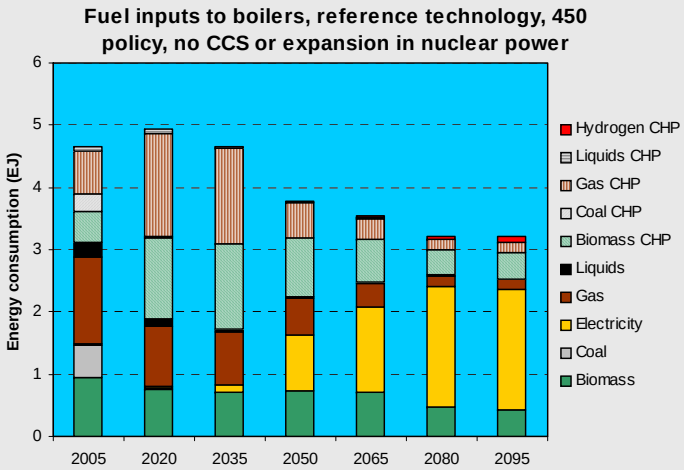


Energy consumption for steam generation (boilers)

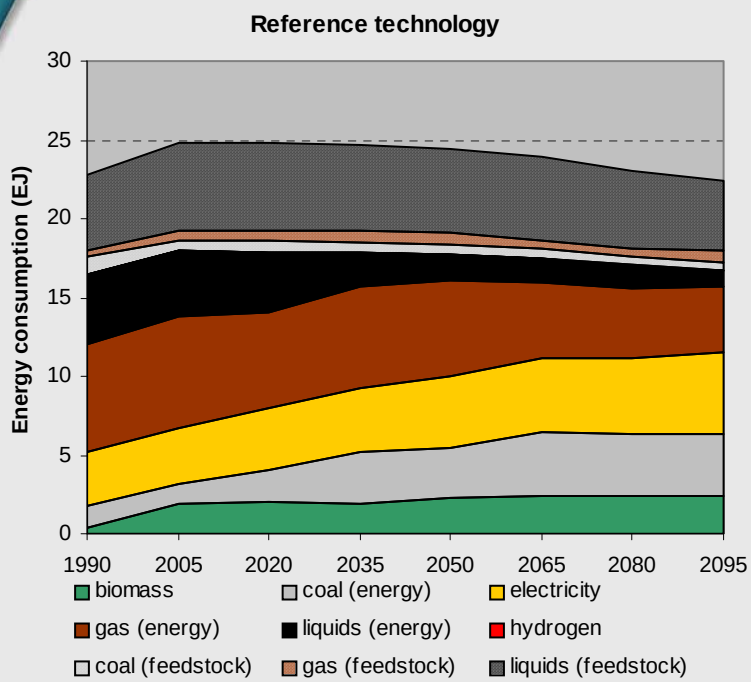
- Without an emissions constraint, cogeneration share increases
- With constraint, cogeneration increases at low carbon prices
- Driven out at high carbon prices: fuel switching towards electricity
- Without CCS and expanded nuclear, electricity is still the best option

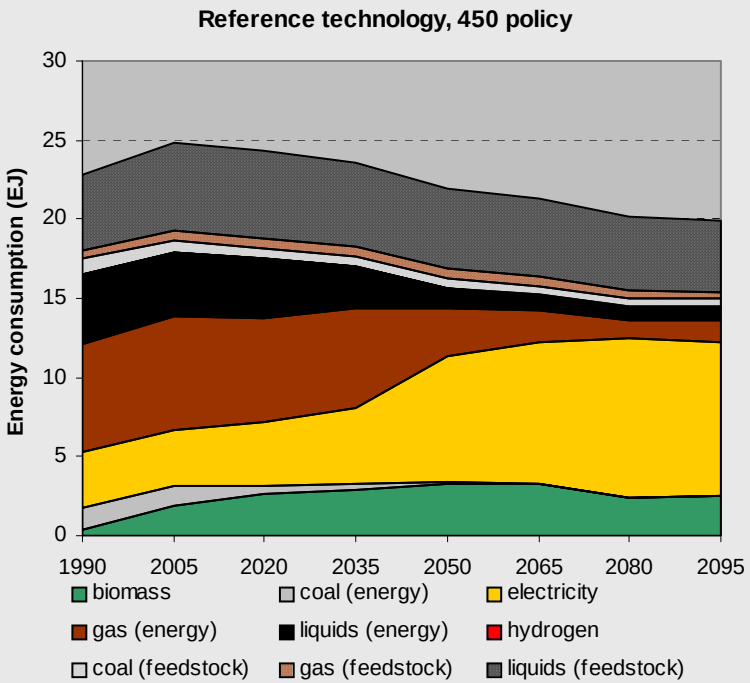






US industry total final energy consumption

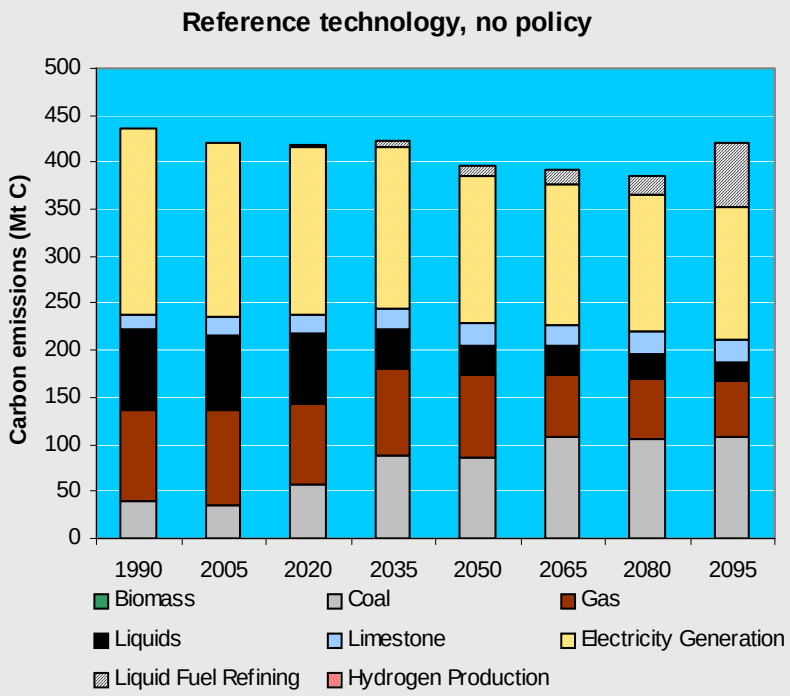


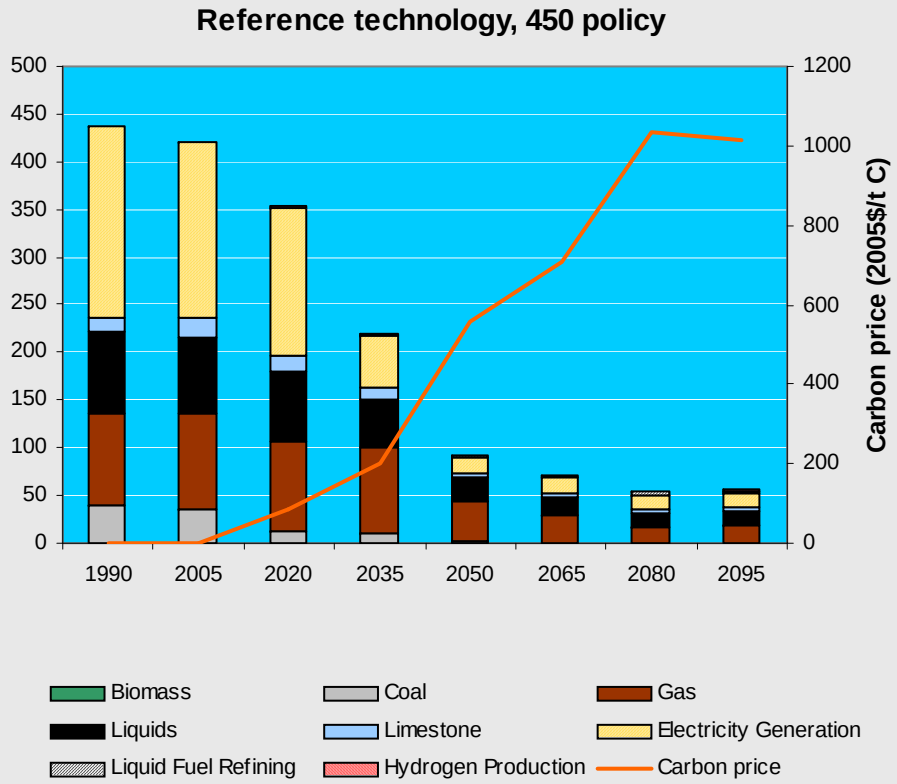


- Fuel switching: initially to gas and biomass, ultimately to electricity
- Feedstock energy use not affected by policy

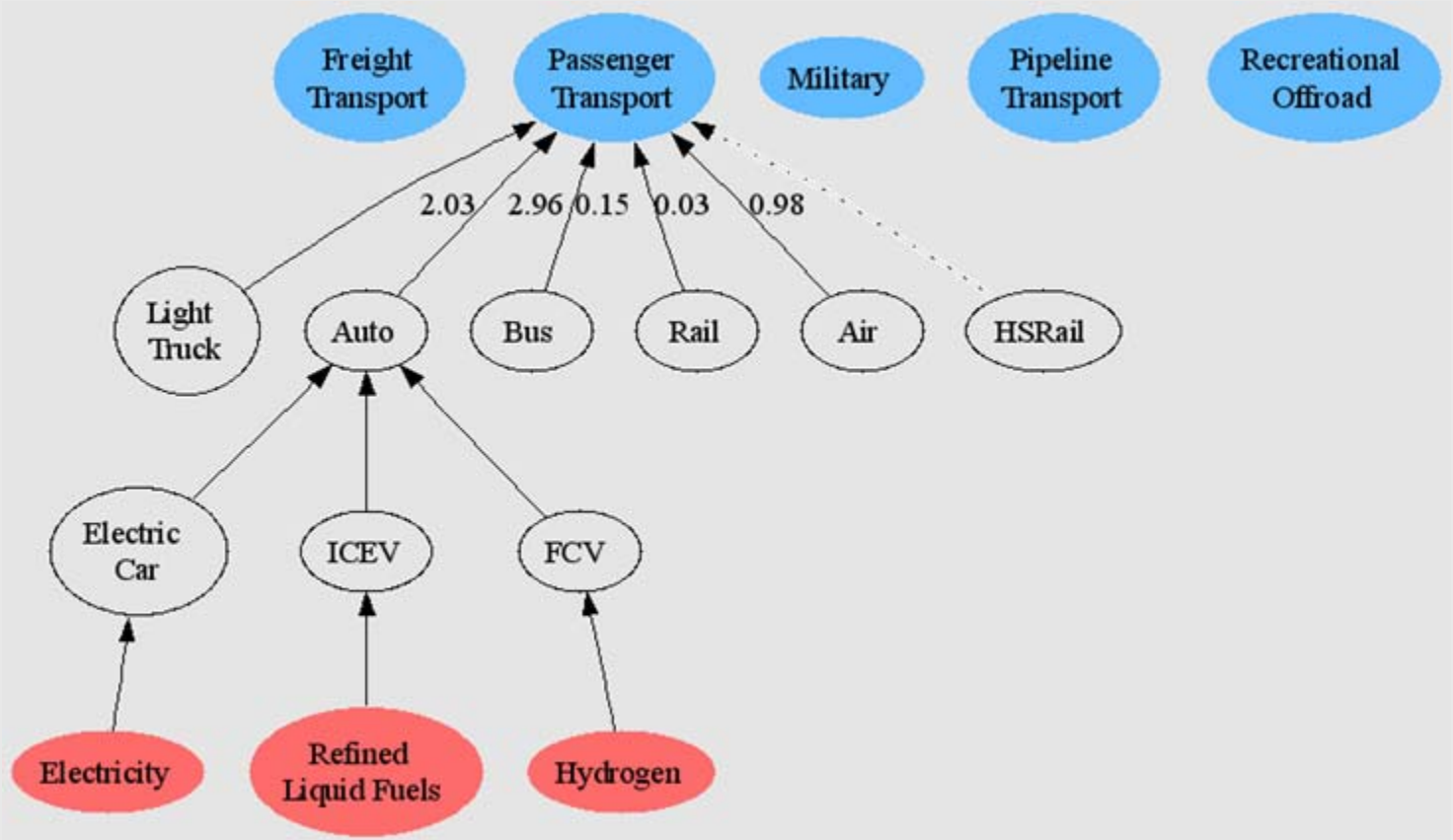
Total industrial sector emissions by fuel, reference technology

- Emissions reduced both at end-use level and "upstream" (electricity and refining)





US transportation sector schematic

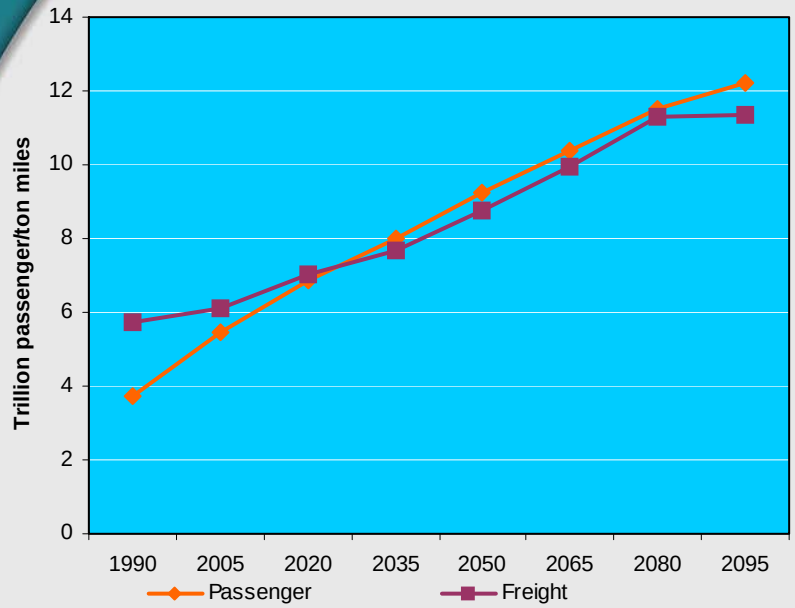


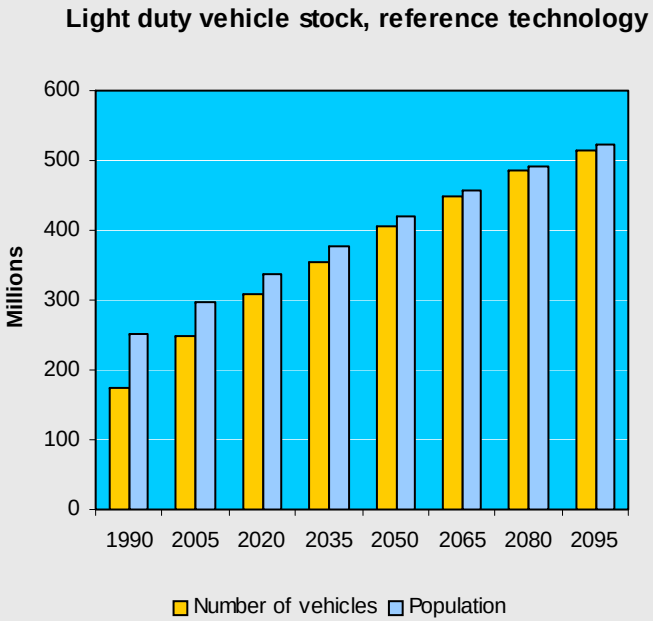
- Passenger sector modal competition considers time value of transportation (faster modes are less costly)

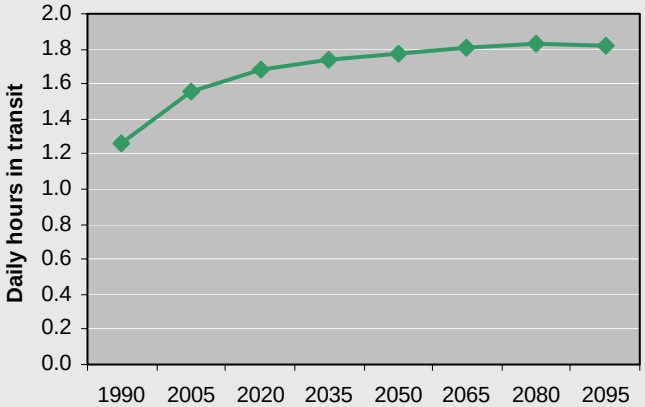
Transportation assumptions

			Reference		Advanced	
Technology	**unit**	**2005**	**2050**	**2095**	**2050**	**2095**
ICE auto	veh mpg	23	33	48	41	72
Electric auto	veh mpg-equiv	na	77	86	82	98
Fuel cell auto	veh mpg-equiv	na	52	75	64	113
ICE light truck	veh mpg	16	24	34	29	51
Electric light truck	veh mpg-equiv	na	54	61	58	69
Fuel cell light truck	veh mpg-equiv	na	37	53	45	80
ICE auto	1990$/veh mi	0.42	0.42	0.42	0.42	0.42
Electric auto	1990$/veh mi	na	0.44	0.44	0.42	0.42
Fuel cell auto	1990$/veh mi	na	0.44	0.44	0.42	0.42
ICE light truck	1990$/veh mi	0.47	0.47	0.47	0.47	0.47
Electric light truck	1990$/veh mi	na	0.50	0.50	0.47	0.47
Fuel cell light truck	1990$/veh mi	na	0.50	0.50	0.47	0.47

Transportation service output, reference technology

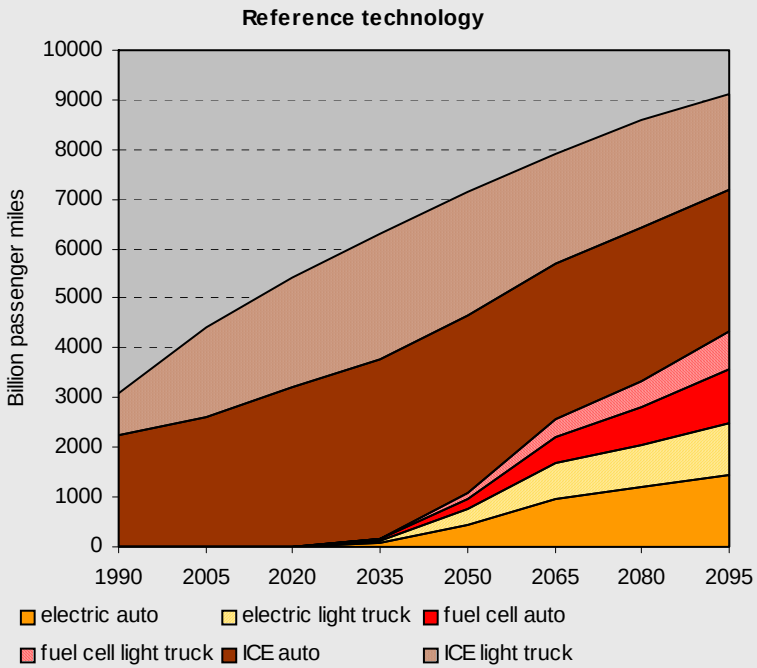


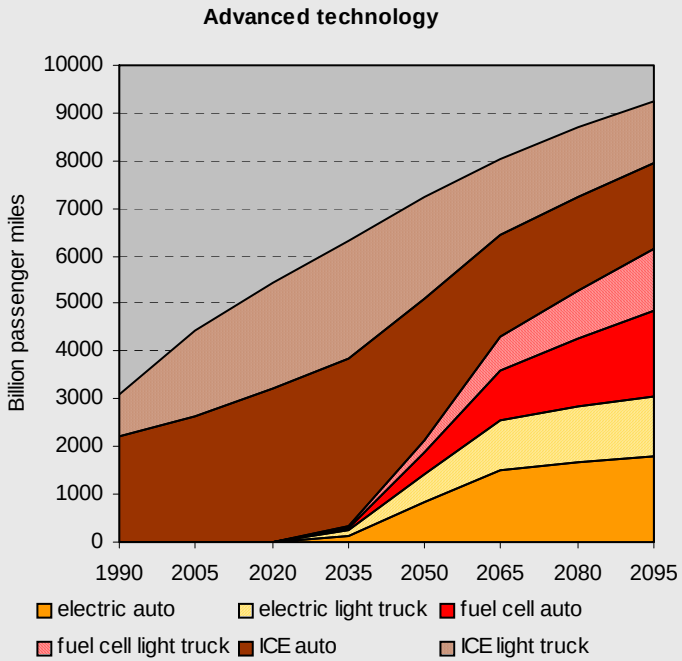




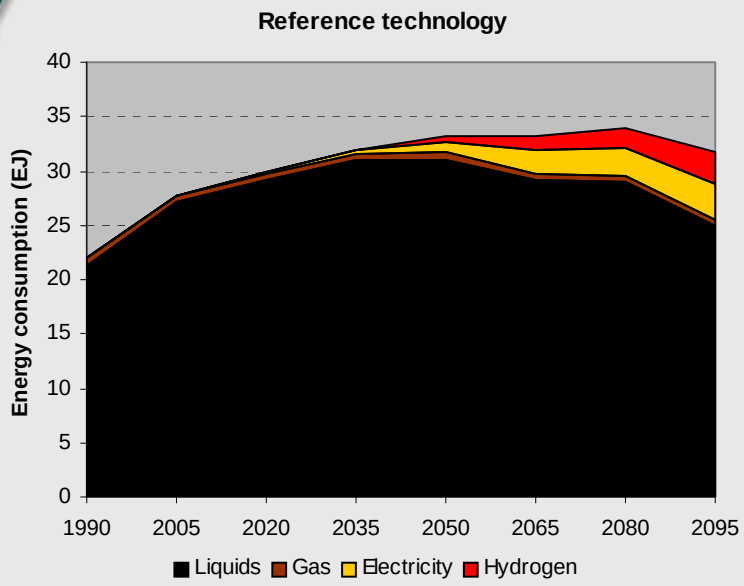
- Growth in passenger sector limited by time cost

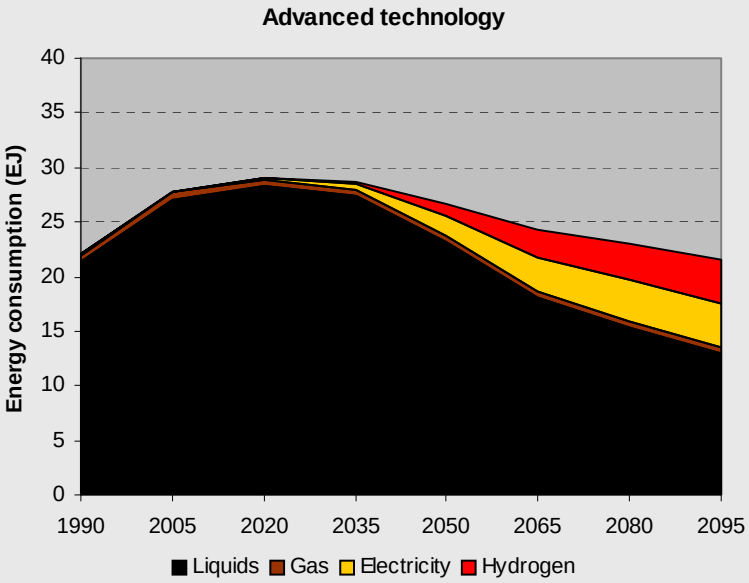
Transportation service by light duty vehicles





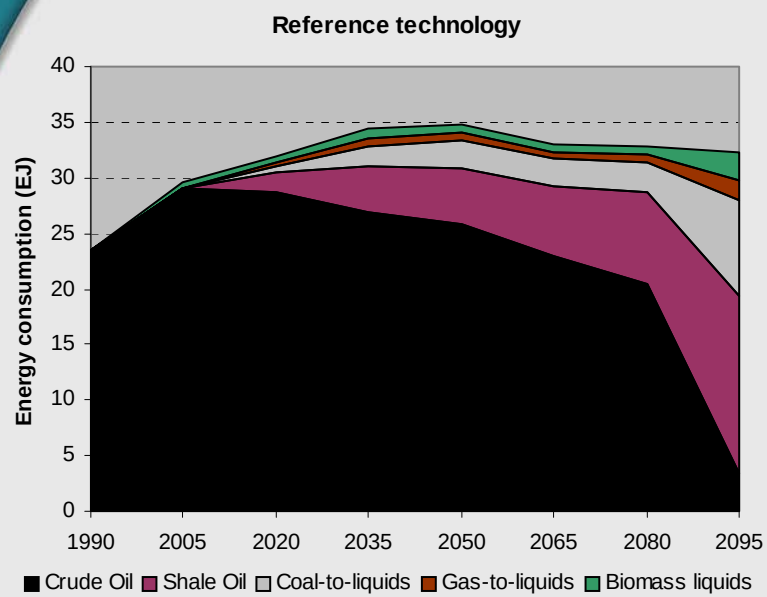
Transportation final energy

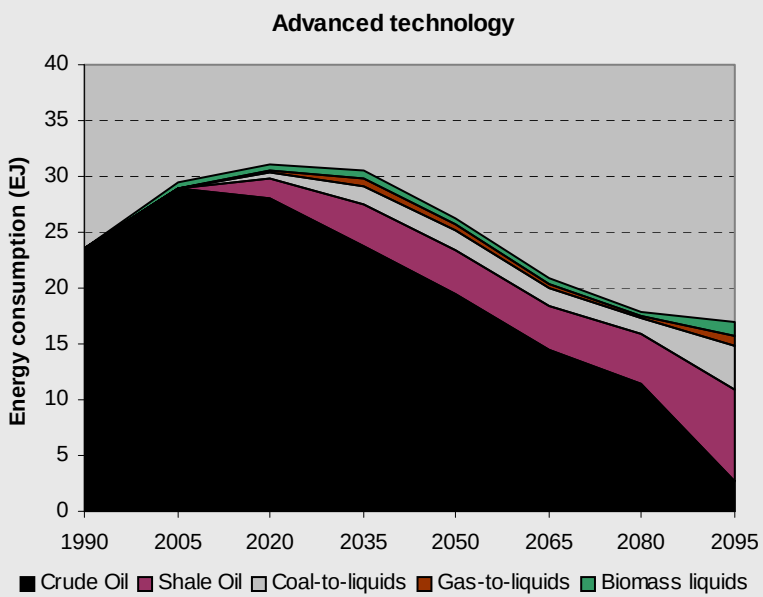




- Some fuel switching in transportation sector occurs as liquid fuel prices increase

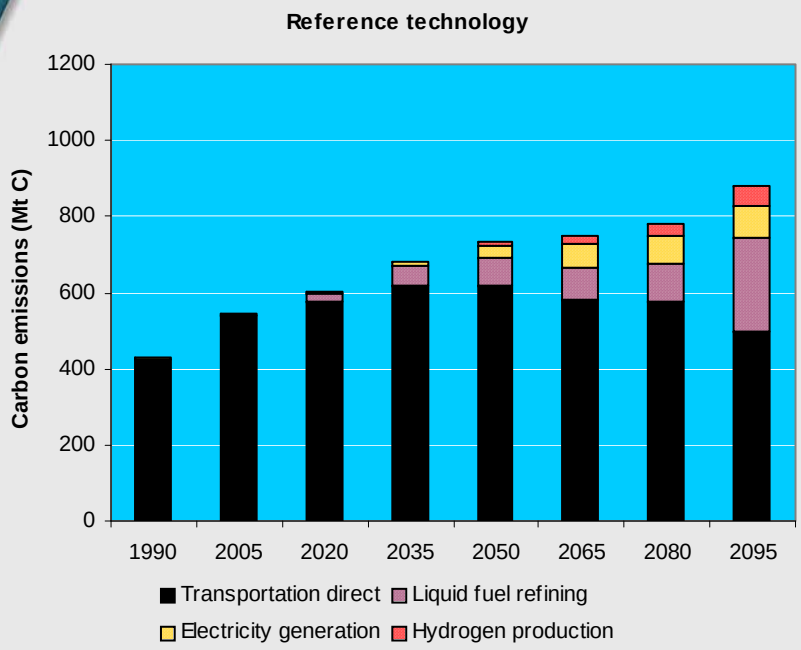
Energy inputs to liquid fuel production

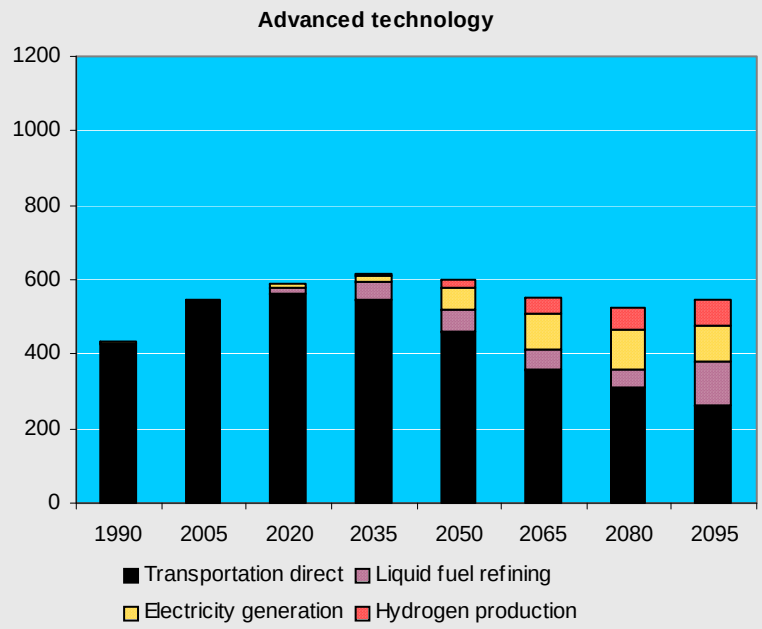




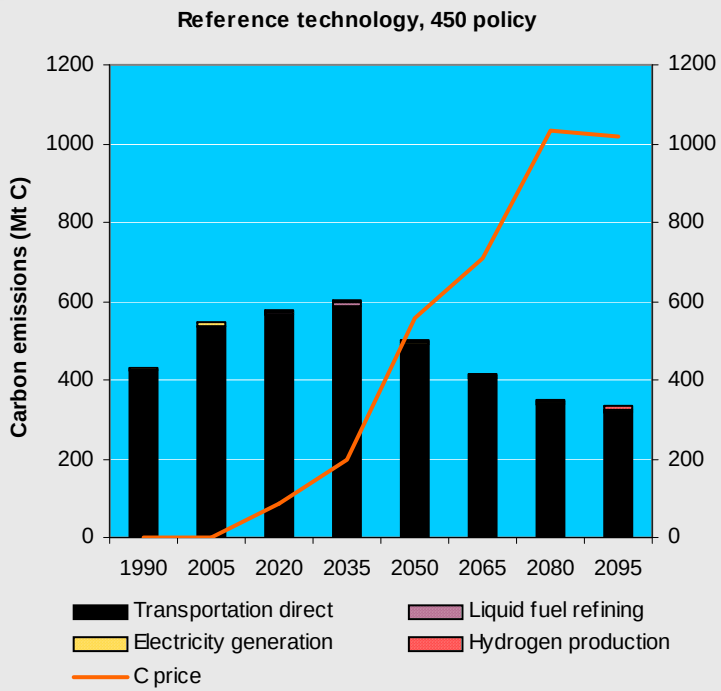
- By the end of the century, unconventional sources are supplying most liquid fuels
- Energy savings in advanced technology are important for minimizing these “upstream” emissions

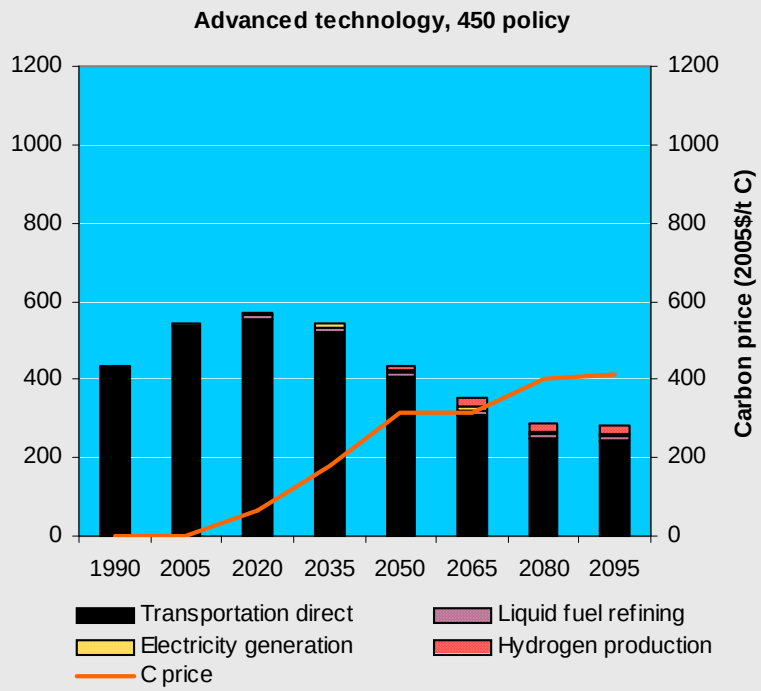
Total emissions from transportation, reference and advanced



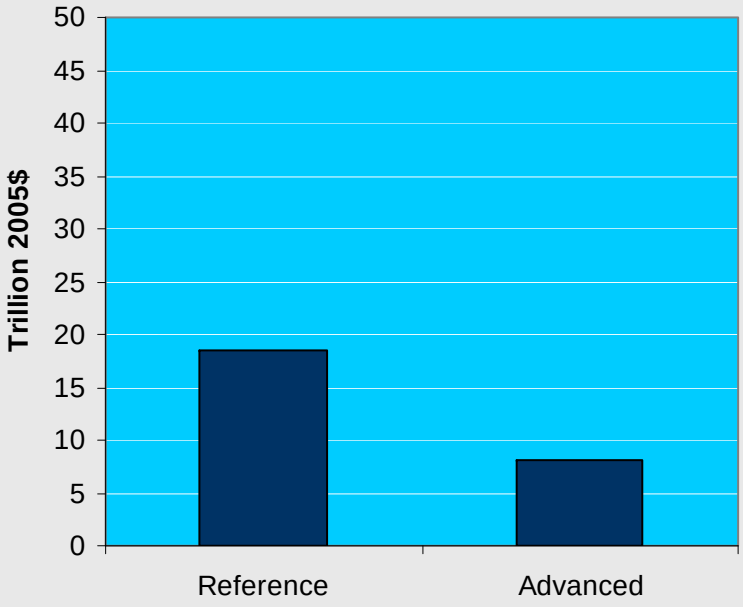


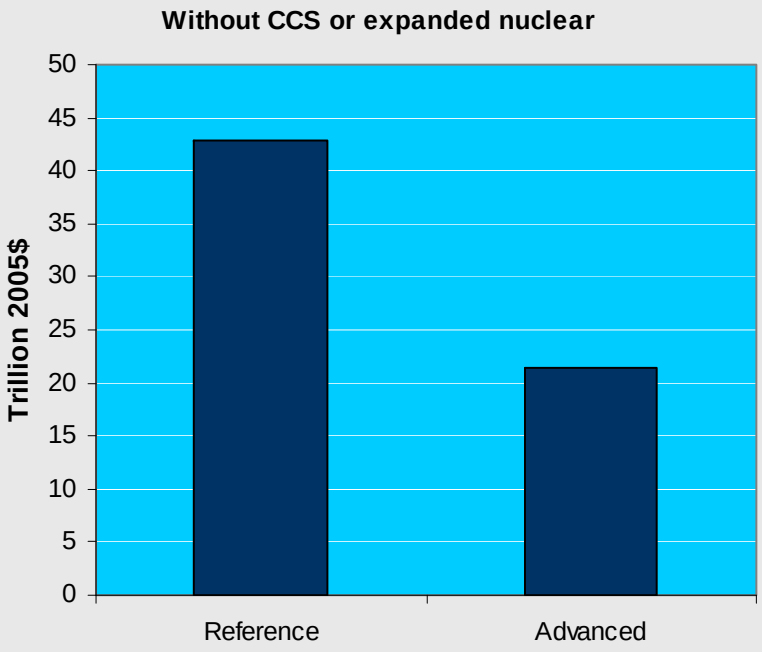
Total emissions from transportation, reference and advanced





Aggregate: value of technology across all sectors





Conclusions

- Buildings sector: technologies allowing switching to electricity are key
- Industrial sector: cogeneration at low carbon prices; forced out at high carbon prices
- Transportation sector: very large payoff from a more efficient fleet and flexible fuels in the future
- Future end-use efficiency is particularly important where “upstream” emissions are high
  - Savings from end-use energy efficiency are greatest when energy supply options are limited