# **Decarbonising a Country:** H<sub>2</sub> and Electricity UK Scenarios & Considerations

Sustainability = Environment + Economy

Observations Current Energy Use Some Replacement Scenarios

> Prof. Pericles Pilidis - presenting a team effort Cranfield University - Thermal Power & Propulsion





1

# Zero Carbon to Protect

# **Economic Growth & the Environment**



Technology to protect socioeconomic benefits of many industries!

UK cost £1.3 trillion gross £400b nett (OBR) 2% or 0.7% of GDP over 30 years

# Via heat, electrification and H<sub>2</sub>



#### **Cutting out carbs**

Britain, net cost of reaching net zero\*, by sector Forecast, relative to current path, 2019 prices, £bn



The Economist

		Energy TJ
Coal - electr		78300
Coal - Ind		78300
Other		51300
Total Coal		207900
		0
Petrol		578100
Diesel - Cars		699200
Diesel-GoodsV		469200
JetFuel		565800
Other (Marine 12% Rail 4%)		777000
Total Lig Fuels		3089300
		0
		0
Gas-electr		972000
Gas-Domestic		1094400
Gas-Other		1087200
Total Gas		3153600
		0
	Capacity GW	0
Wind-land	13.99	115920
Wind-sea	9.89	114840
Hydro	1.61	21600
Solar PV	13.22	45720
BioEnergy	7.84	131760
Total Renewables	46.55	429840
Coal Electricity	6.82	24840
Gas Electricity	34.58	477000
Nuclear Electricity	9.26	202320
Other electricity	0.00	31320
Total Electricity Gen Capacity	97.21	1165320
Av gen Capacity	36.95	0
Total Primary E		7114280

Demand: Heat + Electricity + Transport

### 2019 Energy Demand & Supply

Source = DUKES (UK govt) + researcher's estimates

		Energy TJ
Coal - electr		78300
Coal - Ind		78300
Other		51300
Total Coal		207900
		0
Petrol		578100
Diesel - Cars		699200
Diesel-GoodsV		469200
JetFuel		565800
Other (Marine 12%, Rail 4%)		777000
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		0
		0
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		0
	Capacity	
	GW	0
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Demand: Heat + Electricity + Transport

First Iteration !

Decarbonise avoiding socio-economic damage same demand scenario

ource = DUKES (UK govt) + researcher's estimates

2019 Ener

		Energy TJ
Coal - electr		78300
Coal - Ind		78300
Other		51300
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		0
Petrol		578100
Diesel - Cars		699200
Diesel-GoodsV		469200
JetFuel		565800
Other (Merine 129/ Reil 49()		777000
Total Lig Eucle		2080200
		3089300
		0
Gas-electr		972000
Gas-Domestic		1094400
Gas-Other		1087200
Total Gas		3153600
		0
	Capacity	
	GW/	0
Wind lond	12.00	115020
Wind coo	0.90	11/920
Willu-Sea Hydro	9.09	21600
Solar PV	13.22	45720
BioEnergy	7 84	131760
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Demand: Heat + Electricity + Transport

Decarbonise avoiding socio-economic damage same demand scenario

Replace all items with supply of Heat + Electricity + Haration

2019 Ener/

ource = DUKES (UK govt) + researcher's estimates

		Energy TJ
Coal - electr		78300
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		0
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Diesel - Cars		699200
Diesel-GoodsV		469200
JetFuel		565800
		-0
Other (Marine 12%, Rail 4%)	; ati	777000
Total Liq Fuels	AVIO	3089300
-ople		0
ryanip		0
Gas-electr Ene		972000
Gas-Domestic		1094400
Gas-Other		1087200
Total Gas		3153600
		0
	Capacity	
	GŴ	0
Wind-land	13.99	115920
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### Demand: Heat + Electricity + Transport

Decarbonise avoiding socio-economic damage same demand scenario

Replace all items with supply of Heat + Electricity + Haration

2019 Ener

ource = DUKES (UK govt) + researcher's estimates



# Example: Jet Fuel Replacement In Zero Carbon World Carry Out Air Traffic Analysis

## 85% H<sub>2</sub> 15% Electricity 0% Heat

					Decarbonised Demand Calculation				
	2019 Energy demand in TJ	Replace	Need to	Replace			Hydrogen	H2 000 tonnes	
ltem	from pg 1	Factors	Replace	with	Gas TJ	Electr - TJ	TJ	p.a	Heat TJ
JetFuel	565800	0.15	84870	Electr	. 0	36373			
			480930	Hydrogen	. 0	961860	529023	4408.5	

Repeat & integrate for other energy sectors to obtain zero carbon UK energy demand **6** Replacement Scenarios examined - combinations of:

Expand RES (primarily wind) Decommission coal Convert & Expand Gas to CCS or Semiclosed CO<sub>2</sub> Oxyfuel CCGT Expand Nuclear Use District Heat + Cogeneration + Solar Heat

# **Semiclosed Cycle**

From Ulizar,I; Pilidis' P;

A Semiclosed-Cycle Gas Turbine with Carbon Dioxide–Argon as Working Fluid; J. Eng. Gas Turbines Power. Jul 1997, 119(3): 612-616 <u>https://doi.org/10.1115/1.2817028</u>

 $\eta_{th} - 0.45 \text{ (inc ASP)}$  $\eta_{th} - 0.55 \text{ (exc ASP)}$ Capture Ready CO<sub>2</sub> Zero NOX



#### **Replacement Scenario 1 – Focus on RES:**

Expand only RES (primarily wind) to cover new energy demand
Decommission coal
Convert Gas to CCS or Semiclosed CO<sub>2</sub> CCGT
Retain Nuclear + Hydro + Bio
Peak Estimate: 110 MW (Cold, dark and calm day)
Use District Heat + Cogeneration + Solar Heat

					Decarbonised Demand Calculation					
ltem	2019 Energy demand in TJ from pg 1	Replace Factors	Need to Replace	Replace with	Gas TJ	Electr - TJ	Hydrogen TJ	H2 000 tonnes p.a	Heat <sup>-</sup>	TJ
Total Electric	1165320		1165320		1143529	5081789	1174958	9791.32		666510
										679320
					Primary					
Total E	7114280	7114280			Energy	6414828	5748318			

Checks: Enough Heat? Peak Supply?



Needs 90 GW H2 CCGT: needs additional H2

Sources of Electricity Supply	Factor	Electr - TJ	AvGen GW	InstGW	Utilisation
Wind-land	15	1738800	55.137	110.27	0.5
Wind-sea	17	1952280	61.906	123.81	0.5
Hydro	1	21600	0.685	0.86	0.8
Solar PV	5.5	251460	7.974	31.89	0.25
BioEnergy	1	131760	4.178	5.22	0.8
	0		0.000		
Coal Electricity	0	0	0.000		
Gas Electricity	1	477000	15.126	18.91	0.8
Nuclear Electricity	1	202320	6.416	8.02	0.8
Other electric	1	31320	0.993	1.32	0.75
Peak LoppingH2GTCC		286998	9.101	91.01	0.1
Total		5093538		391.32	

### **Replacement Scenario 1 – Focus on RES:**

### Expand only RES (primarily wind) to cover new energy demand

					Decarboni	ised Demar	nd Calculati	on		
	2019 Energy							H2 000		
	demand in TJ	Replace	Need to	Replace			Hvdrogen	tonnes		
ltem	from pg 1	Factors	Replace	with	Gas TJ	Electr - TJ	ТĴ	p.a	Heat TJ	H2 %
Coal - electr	78300	) 1	78300		0	)				
Coal - Ind	78300	0.7	54810	Electr	0	54810				
			23490	Heat	0	0			23490	
Other- Coal	51300	) 1	51300	Heat	0	0			51300	
Total Coal	207900	)	207900		0	Ì				
					0					
Petrol	578100	0.8	462480	Electr	0	99102.86				
			115620	Hydrogen	0	86715	57810	481.8		4.92017
Diesel - Cars	699200	0.8	559360	Electr	. 0	199771.4				
			139840	Hydrogen	. 0	174800	116533.3	971.1		9.91808
Diesel-GoodsV	469200	0.8	375360	Electr	. 0	160868.6				
			93840	Hydrogen	0	140760	93840	782.0		7.98667
JetFuel	565800	0.15	84870	Electr	0	36373				
			480930	Hydrogen	0	961860	529023	4408.5		45.02483
Other Liquid Hydrocarbor	777000	0.7	543900	Electr	0	233100				
		0.2	155400	Heat	0	Ì			155400	
			77700	Hydrogen	0	116550	77700	647.5		6.61300
Total - Lig Fuel	3089300	)	3089300		0	)				
·					0	)				
					0	)				
Gas-electr	972000	)	972000	Electr	1143529	)				
Gas-Domestic	1094400	0.8	875520	Electr	0	875520				
			218880	Heat					218880	
Gas-Other	1087200	0.7	761040	Electr	0	326160	)			
		0.2	217440	Heat	0	)			217440	
			108720	Hvdrogen	0	163080	108720	906.0		9.25309
Total Gas	3153600	)		1.1.1	0	)				
Total Fossil Fuel	6450800	)			0	)				
					0					
Other electric										
Wind-land	115020		115020	Electr		115020	1			
Wind-see	11/18/0		11/18/10	Electr		11/8/0				
Hvdro	21600		21600	Electr		21600	· ·			
Solar PV	45720		45720	Electr		45720				
BioEnergy	131760		131760	Electr		131760				
Total Renewables	/208/0		/208/0	Electr		131700				
Coal Electricity	2/8/0		24840	Electr	0	24840				
Gas Electricity	477000		477000	Electr	0	477000				
Nuclear Electricity	202220		202220	Electr		202220				
	202320		212020	Electr		212020				
	31320		31320			20000 0	101000 4	1504 424		16 00/16
	1165000		1165200		1142520	£00330.2	1174050	0701 00	666540	10.20416
	1165320	, 	1105320		1143529	2001/89	11/4958	9/91.32	670000	
					Drimon				679320	
					Primary					
I OTALE	7114280	/114280			⊫nergy	6414828	5748318			

Sources of Electricity Supply	Factor	Electr - TJ	AvGen GW	InstGW
Wind-land	15	1738800	55.137	110.27
Wind-sea	17	1952280	61.906	123.81
Hydro	1	21600	0.685	0.86
Solar PV	5.5	251460	7.974	31.89
BioEnergy	1	131760	4.178	5.22
	0		0.000	
Coal Electricity	0	0	0.000	
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# **Greening a Country**

### extreme scenarios



Time of Day

Time of Day

### **Decarbonising the UK – H2 & Electricity**

Hydrogen:

35-40 % of electricity supply (use seawater electrolysis) Aviation > 50% of Hydrogen supply International trade

Mainly CCGT and/or Nuclear offer nearly constant power grid scenario Benefits of thermal plant and better heat use in colder countries (like UK) Scenario 4 (Short Term) and progress to 1 (LT) with international grids? Cost ~ 2% of GDP-

		Electricity	Installed
Scenario		Supply	Capacity
2019 Baseline		1	1
S1 - Emphasis on Renewable		4.4	4.0
S2 - Emphasis on Nuclear		3.6	1.8
S3 - Emphasis on Nuclear and RES	S	3.6	2.2
S4 - Emphasis on Gas Turbines ar	nd RES	3.6	2.2
S5 - Similar to 4 low heat		4.1	2.4
S6 - Emphasis on Gas Turbines		3.6	1.8

# A Liquid Hydrogen Tanker



Length OA	375m	362m
Draft FL	10.11m	23m
Depth	35m	30m
DW (000 t)	20	402
Speed (knots)	15.8	15.4
Power (MW)	30	29

### IMO Restricting HFO opens door for GTs

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S3 - Emphasis on Nuclear and RES	3.6	2.2
S4 - Emphasis on Gas Turbines and RE	S 3.6	2.2
S5 - Similar to 4 low heat	4.1	2.4
S6 - Emphasis on Gas Turbines	3.6	1.8

# NEEDED!

20 years: details & implement

2% of GDP

1000s of talented Engineers & Scientists

Thank you for your attention



# **GAS TURBINES A CORE ACTIVITY AT CRANFIELD**

Two Sites 4000 + PG s Leading research & CPD university H<sub>2</sub> and Gas Turbines At Cranfield

1994 – Hydrogen for GTs

2000 Cryoplane

2010 – NASA Project

Now: ENABLEH2, HyPER Airbus/ATI + 3 x Fly Zero + EU

+ + + Cranfield Own Projects



1946 - Cranfield College of Aeronautics One of the 4 units was Aircraft Propulsion

- 1969 Cranfield Institute of Technology (University)
- 1993 Cranfield University (change of name)

## **Replacement - Aviation Example Innovation Waves – Hydrogen and Electric**



### **Replacement Scenario 2 – Focus on nuclear:**

### **Expand only nuclear to cover new energy demand**

					Decarboni	sed Demar	nd Calculati	ion			_				
4	2019 Energy demand in TJ	Replace	Need to	Replace	0 TI		Hydrogen	Hydrogen 000	Line T.						
Item	from pg 1	Factors	Replace	with	Gas IJ	Electr - I J	IJ	tonnes	Heat IJ	H2 %	_				
Coal - electr	78300		78300	) Electr		E 4040	\				_				
Coal - Ind	78300	0.7	00400			54610	) \		00.400						
Other Oral	54000		23490	Heat	0	0			23490	/	Sources of Electricity Supply	Factor	Electr - TJ	AvGen GW	InstGW
Uther- Coal	51300	· · · ·	007000			U	/		51300	·	Wind-land		1 11592	3.676	7.35
	207900	·	207900	,						·	Wind-sea		1 11484	3.642	7.28
Detrol	579400		460400	Lootr		00102.06					Hydro		1 2160	0.685	0.86
Felloi	578100	0.0	402400			99102.00	E7040	401.0	>	E 07700	Solar PV		1 4572	0 1.450	5.80
Dissel Care	600000		110020			400774 4	5/610	401.0	<b>)</b>	5.6/723	BioEnergy		1 13176	0 4.178	5.22
Diesei - Cars	699200	0.0				199771.4	446500.0	071.4		44.04700			0	0.000	
Disa al Os a da V	400000		139640			1/4000	110000.0	971.1		11.04/32	Coal Electricity		0	0.000 0	
Diesel-Goods v	409200	0.0	02040			140700	00040	700 (	<b>\</b>	0 54004	Gas Electricity		1 47700	0 15.126	18.91
letFuel	ECEDO	0.15	93640			140700	93040	/ /62.0	)	9.54021	Nuclear Electricity		16 323712	0 102.648	128.31
Jelfuei	00606	0.10	0 04070 400000			30372.00	E20022	4400 5		E0 70000	Other electric		1 3132	0.993	1.32
Oth an Linuid Lhudna a sha	777000	0.5	480930	Hydrogen		961860	529023	4408.5	)	53.78292	Peak LoppingH2GTCC			0.000 0	0.00
Other Liquid Hydrocarbo		0.5	388500	Electr		166500	) 		240000		Total		417528	0	175.05
	-	0.4	1 310800	Heat		110550	77700	647.6	310800	7 00024	1			-	
Total Liz Fuel	2020200		2000200				11100	047.5	)	7.09934	+				
I otal - Liq Fuel	3089300	, 	3089300	)	0										
	-				0										
0	070000		070000		1110500										
Gas-electr	972000		972000		1143529	000000	\ \								
Gas-Domestic	1094400	0.3	5 320320 766090		1 0	326320	/		70000		_				
Cap Other	1007000	0.7	700000			206460	\		700000		_				
Gas-Other	1087200	0.7	017440			320100	, 		017440		-				
	-	0.2	2 217440			462000	100700	0000	21/440	11.05000					
Total Cas	2452600		106720	nyarogen		103060	106720	906.0	)	11.05290	3				
Total Gas	6450900										-				
TULAI FUSSII FUEI	0450600				0										
Otherstein					0										
Other electric	11500		445000		0	445000					-				
wind-land	115920		115920	Electr	0	115920									
vvind-sea	114840		114840	Electr	0	114840	)								
Hydro	21600		21600	Electr	0	21600	)								
Solar PV	45720		45720	Electr	0	45720	)								
BIOEnergy	131760		131760	Electr	0	131760	)				-				
Total Renewables	429840		429840	Electr	0	0.40.40					-				
Coal Electricity	24840		24840	Electr	0	24840					-				
Gas Electricity	477000	(	4//000	Electr		4//000					-				
Nuclear Electricity	202320	2	202320	Electr	0	202320					-				
	31320	, 	31320	Electr	0	31320	-								
Peak LoppingH2GTCC					0	0	00	) (	)	0.00000					
Total Electric	1165320	)	1165320	)	1143529	4180991	983626.3	8196.886	1369110		_				
									3714120	2					
					Primary										
Total E	7114280	7114280	)		Energy	6216630	4847520								

#### **Replacement Scenario 3 – Focus on RES and nuclear:**

### Expand RES and nuclear to cover new energy demand and peak load

					Decarboni	sed Deman	d Calculati	on							
Item	2019 Energy	Replace	Need to	Replace	Gas TJ	Electr - TJ	Hydrogen	Hydrogen	Heat TJ	H2 %					
Coal - electr	78300	) 1	78300	)	0										
Coal - Ind	78300	0.7	54810	Electr	0	54810									
			23490	Heat	0	0			23490						
Other	51300	) 1	51300	Heat	0	0			51300						
Total Coal	207900	)	207900	)	0										
					0										
Petrol	578100	3.0	462480	Electr	. 0	99102.86									
			115620	Hydrogen	. 0	86715	57810	481.8	3	5.87723					
Diesel - Cars	699200	3.0	559360	Electr	. 0	199771.4									
			139840	Hydrogen	. 0	174800	116533.3	971.1		11.84732					
Diesel-GoodsV	469200	3.0	375360	Electr	. 0	160868.6					Sources of Electricity Supply	Factor	Electr - TJ	AvGen GW I	nstGW
			93840	Hydrogen	. 0	140760	93840	782.0	)	9.54021	Wind-land	7	<u></u>	25 721	51.46
JetFuel	565800	0.15	84870	Electr	. 0	36372.86					Wind cos	1	4000500	20.731	05.55
			480930	Hydrogen	. 0	961860	529023	4408.5	5	53.78292	wind-sea	9	1033560	32.774	65.55
Other	777000	0.5	388500	Electr	0	166500					Hydro	1	21600	0.685	0.86
		0.4	310800	Heat	0				310800		Solar PV	1.5	68580	2.175	8.70
			77700	Hydrogen	0	116550	77700	647.5	5	7.89934	BioEnergy	1	131760	4.178	5.22
Total - Lig Fuel	3089300		3089300	)	0							0		0.000	
					0						Coal Electricity	0	0	0.000	
					0						Gas Electricity	1	477000	15 126	18 91
Gas-electr	972000		972000	Electr	1143529						Nuclear Electricity	8	1618560	51 324	64.16
Gas-Domestic	1094400	0.3	328320	Electr	. 0	328320					Other electric	1	21220	0.002	1 22
			766080	Heat					766080				31320	0.993	1.32
Gas-Other	1087200	0.7	761040	Electr	0	326160							0	0.000	0.00
		0.2	217440	) Heat	0				217440		Total		4193820		216.17
			108720	Hydrogen	0	163080	108720	906.0	)	11.05298					
Total Gas	3153600	)			0										
Total Fossil Fuel	6450800	)			0										
					0										
Other electric					0										
Wind-land	115920		115920	Electr	0	115920									
Wind-sea	114840	)	114840	Electr	0	114840									
Hydro	21600		21600	Electr	0	21600									
Solar PV	45720		45720	Electr	0	45720									
BioEnergy	131760		131760	Electr	0	131760									
Total Renewables	429840	)	429840	Electr	0										
Coal Electricity	24840		24840	Electr	0	24840									
Gas Electricity	477000		477000	Electr	0	477000									
Nuclear Electricity	202320		202320	Electr	0	202320									
Other electric	31320		31320	Electr	0	31320									
Peak LoppingH2GTCC					0	0	0	0	)						
Total Electric	1165320	)	1165320	)	1143529	4180991	983626.3	8196.886	1369110						
							200020.0	5.00.000	2095560						
					Primary										
Total F	711/280	7114280			Energy	6216630	4847520								
	7114200		1			0210000	10 11 020		1						

#### **Replacement Scenario 4 – Focus on RES and CCGT:**

### Expand RES and CCGT to cover new energy demand and peak load

					Decarboni	sed Demar	nd Calculati	ion			
	2019 Energy demand in TJ	Replace	Need to	Replace			Hydrogen	Hydrogen 000			
ltem	from pg 1	Factors	Replace	with	Gas TJ	Electr - TJ	TJ	tonnes	Heat TJ	H2 %	
Coal - electr	78300	1	78300		0						
Coal - Ind	78300	0.7	54810	Electr	0	54810					
	_		23490	Heat	0	0			23490		
Other	51300	1	51300	Heat	0	0		-	51300		
I otal Coal	207900		207900		0						
Potrol	578100	0.8	462480	Electr	0	00102.86					
relio	578100	0.0	402400	Hydrogen		99102.00	57810	/81.8	1	5 87723	
Diesel - Cars	699200	0.8	559360	Flectr		199771 4	57010			5.07725	
	000200	0.0	139840	Hydrogen		174800	116533.3	971.1		11 84732	
Diesel-GoodsV	469200	0.8	375360	Electr	0	160868.6		0			
			93840	Hydrogen	0	140760	93840	782.0	)	9.54021	Sources of Electricity Supp
JetFuel	565800	0.15	84870	Electr	. 0	36372.86					Wind-land
			480930	Hydrogen	. 0	961860	529023	4408.5		53.78292	Wind-see
Other	777000	0.5	388500	Electr	0	166500					Willu-Sea
		0.4	310800	Heat	0				310800		Folor DV
			77700	Hydrogen	0	116550	77700	647.5		7.89934	Solar PV
I otal - Liq Fuel	3089300		3089300		0						BIOEnergy
	-				0						
Gas-plactr	072000		072000	Floctr	4574119						Coal Electricity
Gas-Domestic	1094400	03	328320	Electr	4374110	328320					Gas Electricity
Cas Domestic	1034400	0.0	766080	Heat	ĺ	020020			766080		Nuclear Electricity
Gas-Other	1087200	0.7	761040	Electr	0	326160					Other electric
		0.2	217440	Heat	0				217440		Peak LoppingH2GTCC
			108720	Hydrogen	0	163080	108720	906.0		11.05298	Total
Total Gas	3153600				0						
Total Fossil Fuel	6450800				0						
					0						
Other electric	-				0						
Wind-land	115920		115920	Electr	0	115920					
Wind-sea	114840		114840	Electr	0	114840					
Hydro Solar D\/	21600		21600	Electr	0	21600					
Solar PV BioEporav	45720		45720	Electr	0	45720					
Total Renewables	429840		429840	Electr	0	131700					
Coal Electricity	24840		24840	Electr	0	24840					
Gas Electricity	477000		477000	Electr	0	477000					
Nuclear Electricity	202320		202320	Electr	0	202320					
Other electric	31320		31320	Electr	0	31320					
Peak LoppingH2GTCC					0	0	0	00			
Total Electric	1165320		1165320		4574118	4180991	983626.3	8196.886	1369110		
									2110320		
					Primary						
Total E	7114280	7114280			Energy	9647218	8278108	3			

Sources of Electricity Supply	Factor	Electr - TJ	AvGen GW	InstGW
Wind-land	7	811440	25.731	51.46
Wind-sea	9	1033560	32.774	65.55
Hydro	1	21600	0.685	0.86
Solar PV	1	45720	1.450	5.80
BioEnergy	1	131760	4.178	5.22
	0		0.000	
Coal Electricity	0	0	0.000	
Gas Electricity	4	1908000	60.502	75.63
Nuclear Electricity	1	202320	6.416	8.02
Other electric	1	31320	0.993	1.32
Peak LoppingH2GTCC		0	0.000	0.00
Total		4185720		213.86

### **Replacement Scenario 5 – Focus on RES and CCGT but less heat:**

### Expand RES and CCGT to cover new energy demand and peak load

					Decarbonis	sed Demar	nd Calculat	ion						
	2019 Energy							Hydrogen						
	demand in TJ	Replace	Need to	Replace			Hydrogen	000						
ltem	from pg 1	Factors	Replace	with	Gas TJ	Electr - TJ	TJ	tonnes	Heat TJ					
Coal - electr	78300	<mark>)</mark> 1	78300	l	0									
Coal - Ind	78300	0.7	54810	Electr	0	54810								
			23490	Heat	0	0			23490					
Other	51300	<mark>)</mark> 1	51300	Heat	0	0			51300					
Total Coal	207900	D	207900		0									
					0									
Petrol	578100	0.8	3 462480	Electr	0	99102.86								
			115620	Hydrogen	0	86715	57810	481.8	; 					
Diesel - Cars	699200	0.8	3 559360	Electr	0	199771.4								
			139840	Hydrogen	0	174800	116533.3	3 971.1						
Diesel-GoodsV	469200	0.8	375360	Electr	0	160868.6	000.40							
			93840	Hydrogen	0	140760	93840	) 782.0		Sources of Electricity Supply	Factor	Electr - TJ	AvGen GW	nstGW
Jet⊦uel	565800	0.15	84870	Electr	0	36372.86	500000	4400 5		Wind-land	7	81144(	25 731	51 (
0.1			480930	Hydrogen	0	961860	529023	4408.5		Wind-sea	8	918720	0 29 132	58 (
Other	777000	0.5	388500	Electr	0	166500			0.40000	Hydro	1	21600	0 0.685	0
		0.4	310800	Heat	0	440550		0.47.5	310800	Solar D\/	1	45720	0 1.450	
Tatal I in Frank	000000		///00	Hydrogen	0	116550	77700	) 647.5			1	40720	0 4.179	5.
I otal - Liq Fuel	3089300	J	3089300		0					biochergy	1	131700	J 4.170	5.
					0						0		0.000	
0	070000		070000	El	0						0	(	0.000	400
Gas-electr	972000		972000	Electr	6289412	075500				Gas Electricity	5.5	2623500	J 83.191	103.9
Gas-Domestic	1094400	0.8	8/5520	Electr	0	875520			040000	Nuclear Electricity	1	202320	) 6.416	8.
Cap Other	1097000	0.7	Z18880	Fleat		206460			218880	Other electric	1	31320	) 0.993	1.:
Gas-Other	1067200	0.7	217440	Liect	0	320100			217440	Peak LoppingH2GTCC		(	) 0.000	0.
		0.2	109720	Hudrogon	0	162000	100700	006.0	217440	Total		4786380	)	234.
Total Can	2152600		100720	nyulugen	0	103000	100720	900.0						
Total Gas	6450800				0									
	0430800				0									
Other electric					0									
Wind land	115020		115020	Electr	0	115020								
Wind-soo	11/920		11/920	Electr	0	11/19/0								
Hydro	21600		21600	Electr	0	21600								
Solar P\/	45720		45720	Electr	0	45720								
BioEnergy	131760		131760	Electr	0	131760								
Total Renewables	429840		429840	Electr	0	131700								
Coal Electricity	24840		24840	Electr	0	24840								
Gas Electricity	477000		477000	Electr	0	477000								
Nuclear Electricity	202320		202320	Electr	0	202320								
Other electric	31320		31320	Electr	0	31320								
Peak LoppingH2GTCC	01020		01020		0	01020	ſ		)					
Total Electric	1165220		1165320		6280/12	4728101	083626 3	2 8106 886	821010					
	1103320	<u> </u>	1103320		0203412	7120131	303020.3	0130.000	2825820					
					Primony				2023020					
Total E	7114000	7114000			Enorgy	11000540	10540000							
IUIAIE	/ 114200	/ ///4200	,		LIICIY	11302312	10040602	-						

51.46 58.26 0.86 5.80 5.22

103.99 8.02 1.32 0.00 234.94

### **Replacement Scenario 6 – Focus on gas turbines:**

### Expand CCGTs to cover new energy demand

					Decarbonised Demand Calculation										
	2019 Energy							Hydrogen							
	demand in TJ	Replace	Need to	Replace			Hydrogen	000							
ltem	from pg 1	Factors	Replace	with	Gas TJ	Electr - TJ	TJ	tonnes	Heat TJ	H2 %					
Coal - electr	78300	1	78300	)	0										
Coal - Ind	78300	0.7	54810	Electr	0	54810									
			23490	Heat	0	0			23490						
Other	51300	1	51300	Heat	0	0			51300						
Total Coal	207900		207900	)	0										
					0										
Petrol	578100	0.8	462480	Electr	. 0	99102.86									
			115620	Hydrogen	. 0	86715	57810	481.8	3	5.87723	5				
Diesel - Cars	699200	0.8	559360	Electr	. 0	199771.4									
			139840	Hydrogen	0	174800	116533.3	971.1	1	11.84732	2				
Diesel-GoodsV	469200	0.8	375360	Electr	. 0	160868.6									
			93840	Hydrogen	. 0	140760	93840	782.0	)	9.54021					
JetFuel	565800	0.15	5 84870	Electr	. 0	36372.86									
			480930	Hydrogen	. 0	961860	529023	4408.5	5	53.78292	Sources of Electricity Supply	Factor	Electr - TJ	AvGen GW	InstGW
Other	777000	0.5	388500	Electr	0	166500					Wind-land	1	115920	3.676	7.35
		0.4	310800	Heat	0				310800		Wind-sea	1	114840	3.642	7.28
			77700	Hydrogen	0	116550	77700	647.5	5	7.89934	Hydro	1	21600	0.685	0.86
Total - Liq Fuel	3089300		3089300	)	0						Solar PV	1	45720	1.450	5.80
					0						BioEnergy	1	131760	4.178	5.22
					0							0		0.000	
Gas-electr	972000		972000	Electr	8462118						Coal Electricity	0	0	0.000	
Gas-Domestic	1094400	0.3	328320	Electr	0	328320					Gas Electricity	7.4	3529800	111.929	139.91
			766080	Heat					766080		Nuclear Electricity	1	202320	6.416	8.02
Gas-Other	1087200	0.7	761040	Electr	0	326160					Other electric	1	31320	0.993	1.32
		0.2	2 217440	Heat	0				217440		Peak LoppingH2GTCC		0	0.000	0.00
			108720	Hvdrogen	0	163080	108720	906.0	)	11.05298	Total		4193280		175.77
Total Gas	3153600			1	0										
Total Fossil Fuel	6450800				0						-				
					0						1				
Other electric					0						1				
Wind-land	115920		115920	Electr	0	115920									
Wind-sea	114840		114840	Flectr	0	114840					1				
Hydro	21600		21600	Flectr	0	21600					1				
Solar PV	45720		45720	Flectr	0	45720					1				
BioEnerav	131760		131760	Electr	0	131760					1				
Total Renewables	429840		429840	Electr	0						1				
Coal Electricity	24840		24840	Electr	0	24840					1				
Gas Electricity	477000		477000	Electr	0	477000					1				
Nuclear Electricity	202320		202320	Electr	0 0	202320					1				
Other electric	31320		31320	Electr	0	31320					1				
Peak LoppingH2GTCC	01020		0.020		0	0.020	0	) (	)		1				
Total Electric	1165320		1165320		8462119	4180001	083626.3	8106 896	1360110		1				
	1103320		1103320		0402110	+100391	303020.3	0130.000	3732120		1				
					Primory				0102120		-				
Total F	744,6000	7114000			Enorgy	40505040	40400400								
IUIAIE	7114280	/114280	J		Energy	13535218	12166108	5							





# Hydrogen Micromix Combustion Why Hydrogen?







# ENABLE H2

H<sub>2</sub> Micromix flames

- ~4M€, 20+ (partners + industry advisory board)
- Objectives
  - 1. Hydrogen combustion ultra low Nox
  - 2. Fuel system heat management
    - exploit LH<sub>2</sub> formidable heat sink potential
  - 3. TERA
  - 4. Challenges/scepticism economic & safety
  - 5. Introduce roadmaps for  $LH_2$





### ENABLEH2 – A World Class Team





### **Decarbonising the UK – H2 & Electricity**

Hydrogen:

35-40 % of electricity supply (use seawater electrolysis) Aviation > 50% of Hydrogen supply International trade

Mainly CCGT and/or Nuclear offer nearly constant power grid scenario Benefits of thermal plant and better heat use in colder countries (like UK) Scenario 4 (Short Term) and progress to 1 (LT) with international grids? Cost ~ 2% of GDP-

	Electricity	Installed
Scenario	Supply	Capacity
2019 Baseline	1	1
S1 - Emphasis on Renewable	4.4	4.0
S2 - Emphasis on Nuclear	3.6	1.8
S3 - Emphasis on Nuclear and RES	3.6	2.2
S4 - Emphasis on Gas Turbines and RES	3.6	2.2
S5 - Similar to 4 low heat	4.1	2.4
S6 - Emphasis on Gas Turbines	3.6	1.8

# NEEDED!

20 years: details & implement

2% of GDP

# 1000s of talented Engineers & Scientists