High hydrogen gas turbine retrofit to enable a low carbon reliable electricity system

TU Delft

Thomassen Energy
a Hanwha company

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Alert me about Energy Transition

...ants 'will play ...rgy transition'

...of the power system will not be possible without ...H2 for elec... ...gy and Equinor tell R...

By Leigh Collins

The hydrogen gas turbine gets a lot of attention, mainly a hype or what will its role be in the energy transition ????

POWER

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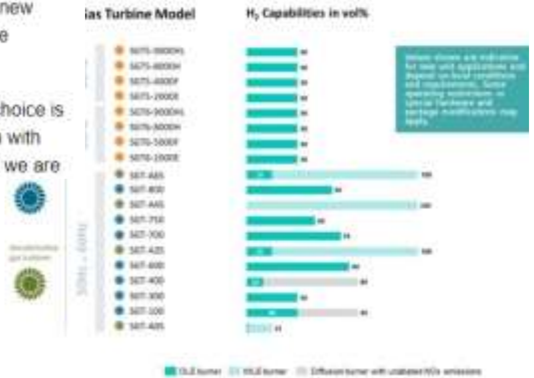
Hydrogen

Decarbonizi... Grid wi... A...

Mar... countries' energy supp... resources to their electricity mix, and de... other fossil-fueled power plants. Yet, these a... options. Research and development (R&D) efforts are also ... use of hydrogen and energy storage, and advance new technolog... as carbon capture and artificial intelligence, in an effort to reduce carbon emissions.

"I think there is a clear sign right now that the world has made the choice, and the choice is clearly the zero-CO_2 emission," Karim Amin, executive vice president of Generation with Siemens Energy, said as a guest on The POWER Podcast. "So, that's a given, and we are



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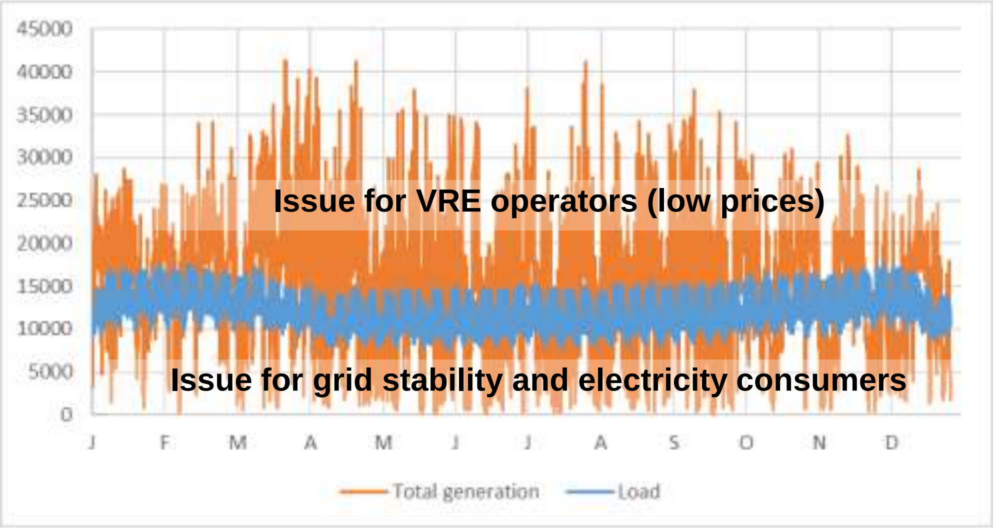
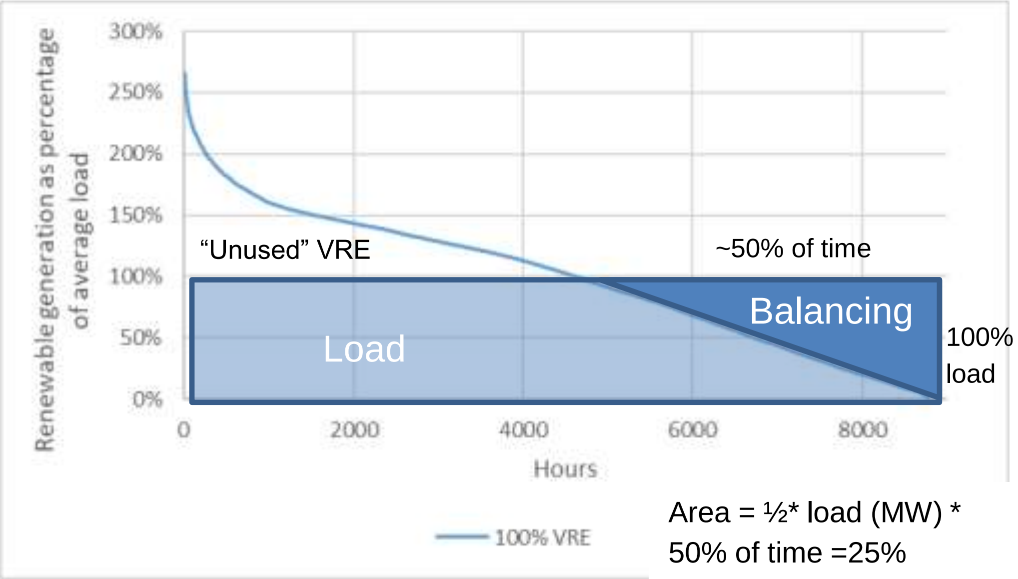
Future-proofing gas power

TU Delft

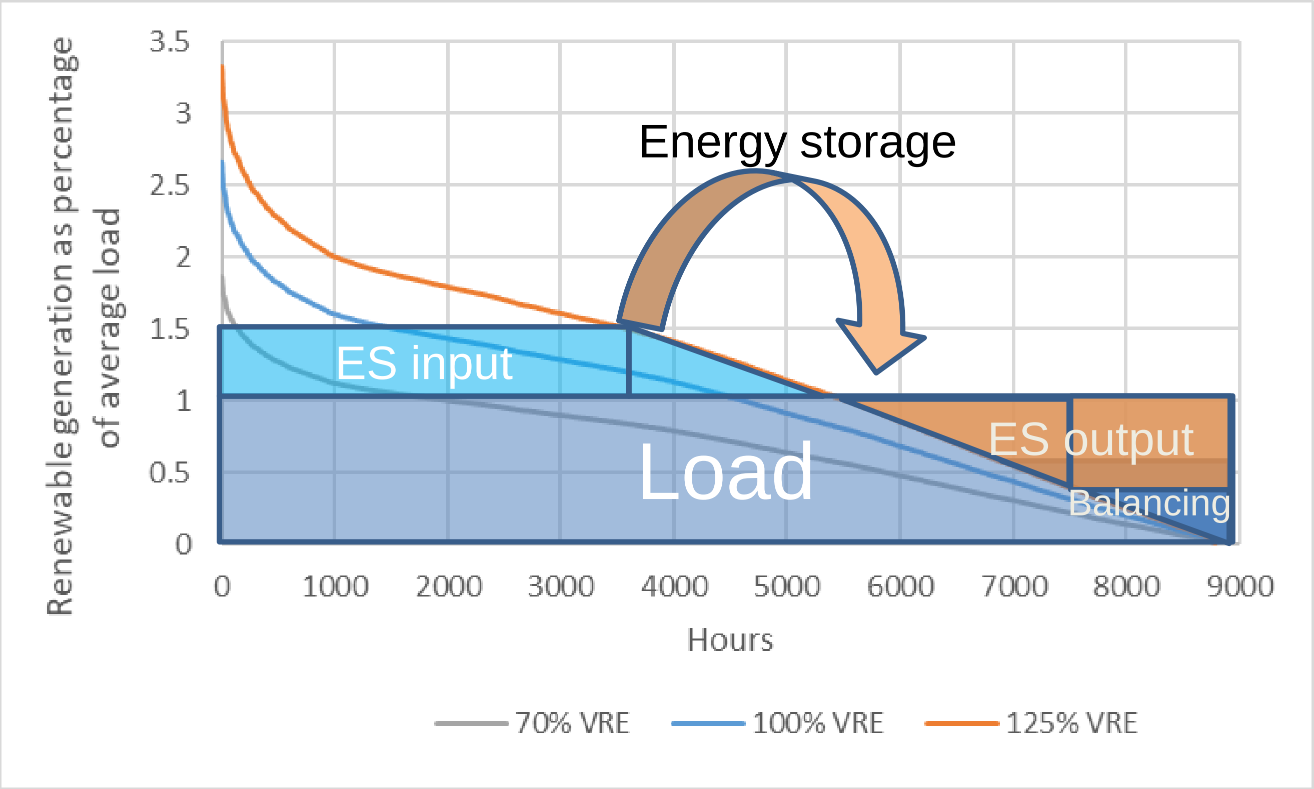
Electricity supply
Assume a fossil free electricity system ….

- Generation by Variable Renewable Energy (VRE): solar, wind on shore and wind off shore
- Balancing of supply and demand required: ~ 25% of (non flexible) load





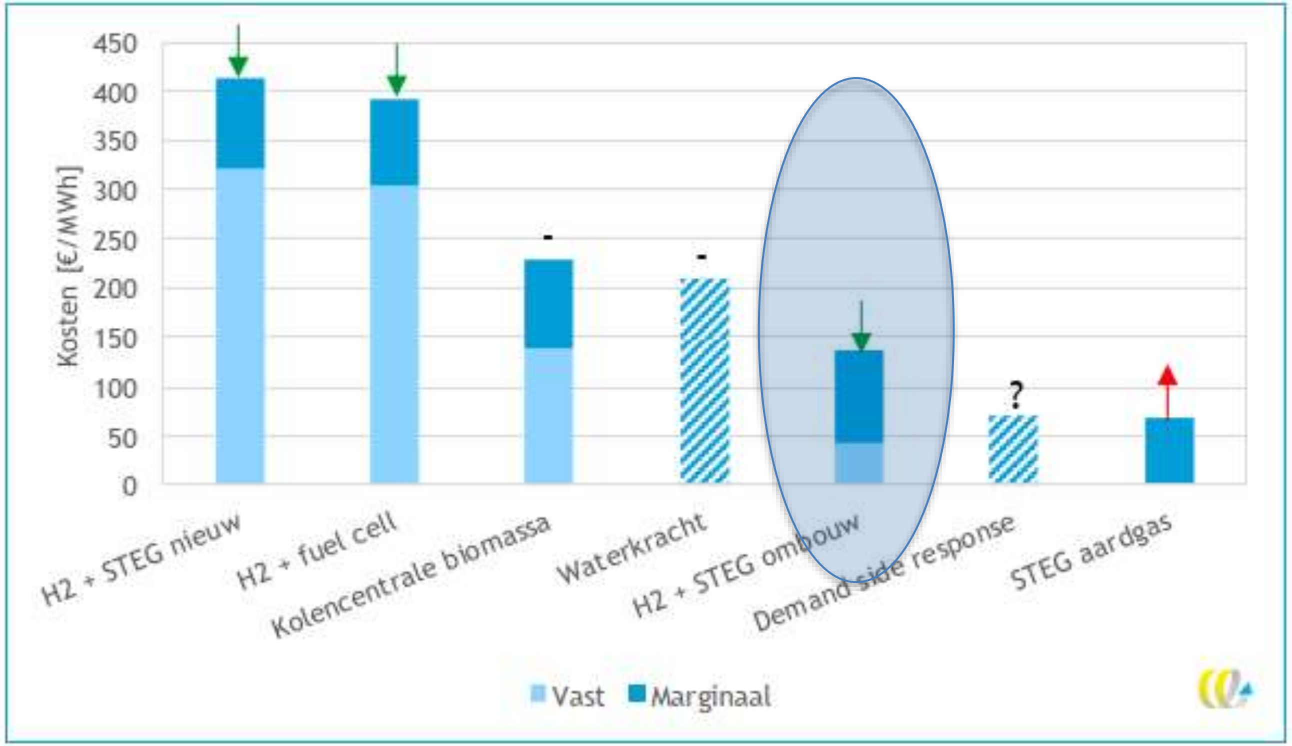
Utilization of excess Variable Renewable Energy for balancing



TUDelft

2020 CE Delft Study shows that H_2 in retrofit gas turbine power plant is attractive for balancing

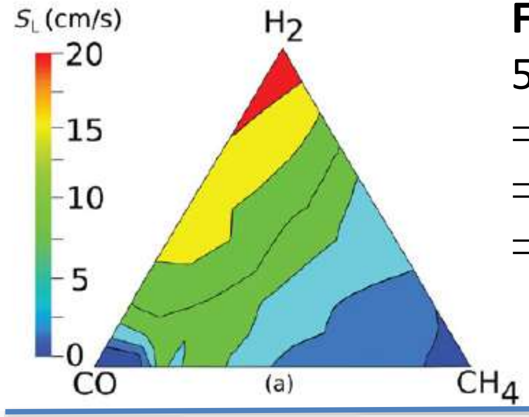
Figuur 5 - Marginale en vaste kosten in 2030 van technieken om tekorten aan te vullen



CE Delft, Verkenning ontwikkeling CO2-vrije flexibele energietechnieken, Publicatienummer: 20.190402.041 , 2020

Challenges for hydrogen in gas turbines: flash back, emissions (NOx), dynamics and leakages

Flashback



Flame speed

5-10x natural gas

⇒ Burner flash back

⇒ Stability

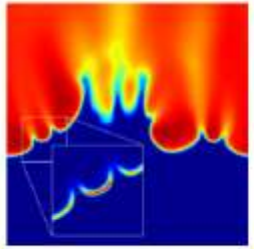
⇒ Dynamics

Lewis number << 1

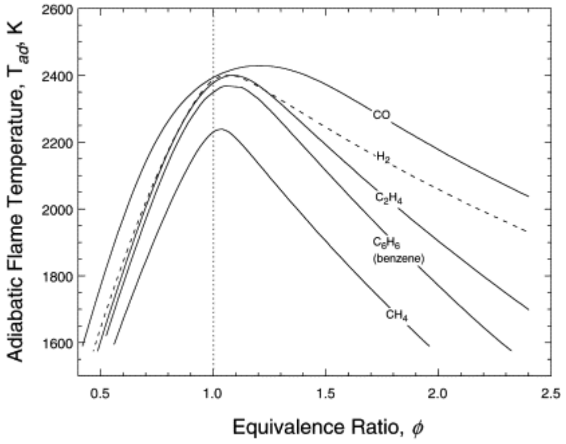
H_2 diffusivity >> thermal diffusivity

⇒ Increased flame speed at lean conditions

⇒ Stability, dynamics



NOx



Stoich. Flame temperature:

400K above natural gas

=> High NOx with non-premixed combustion

Diffusivity

3-4x higher than natural

⇒ Leakages valves and supply

⇒ Preferential diffusion

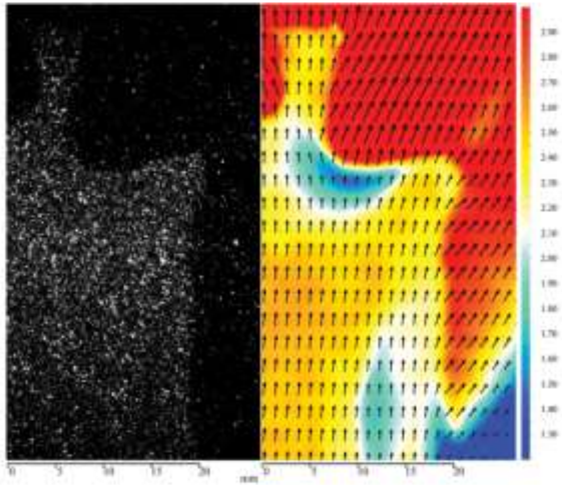
Substance	Symbol	Diffusivity (cm²/sec)
Flame gases (average effective value)	α	0.55
Oxygen	D_{O_2}	0.43
Methane	D_{CH_4}	0.47
Ethane	$D_{C_2H_6}$	0.30
Propane	$D_{C_3H_8}$	0.25
Butane	$D_{C_4H_{10}}$	0.22
Hexane	$D_{C_6H_{14}}$	0.18
Heptane	$D_{C_7H_{16}}$	0.17
Octane	$D_{C_8H_{18}}$	0.16
Decane	$D_{C_{10}H_{22}}$	0.15
C_nH_{2n+2} ($n \to \infty$)	$D_{M\to\infty}$	0
Hydrogen	D_{H_2}	1.86
Deuterium	D_{D_2}	1.32

TUDelft

TU Delft H2 Combustion & Flashback research

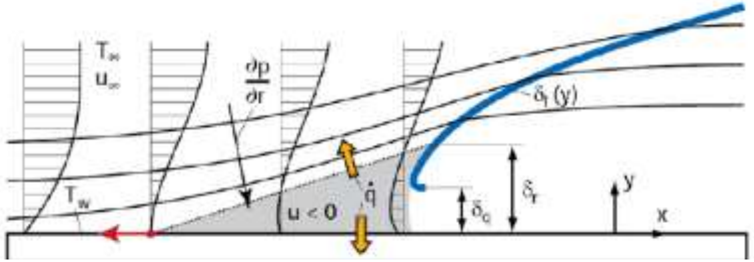
Experimental

GT combustor set up



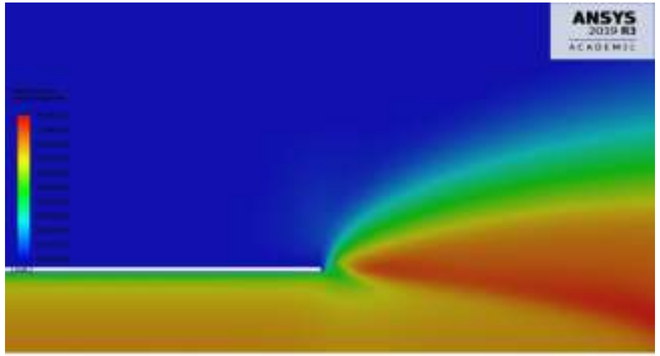
Advanced laser diagnostics

Theoretical/Modelling



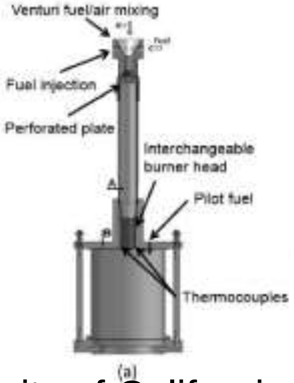
$$C_p^{\frac{1}{4}(n-2)}\left(\delta\frac{dC_p}{dx}\right)^{\frac{1}{2}} = \left(\frac{3(0.41\beta)^4}{(n+1)n^2}\right)^{\frac{1}{4}}\left(1-\frac{3}{n+1}\right)^{\frac{1}{4}(n-2)}$$

Boundary layer flashback model

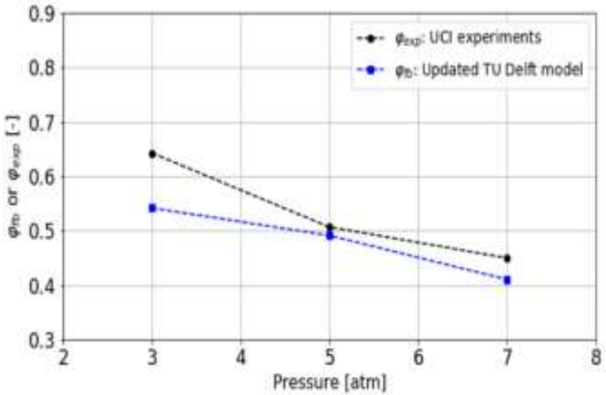


Transient CFD

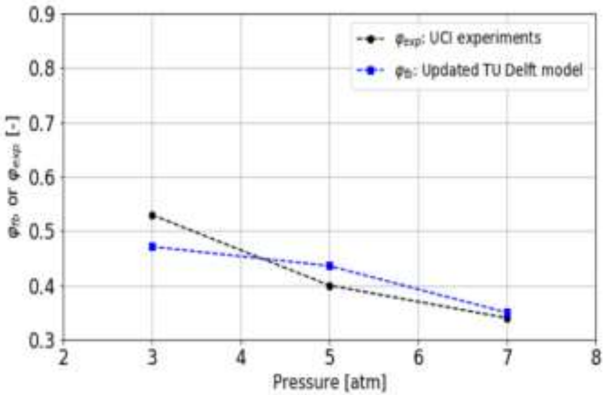
TU Delft BLF model performs well on gas turbine relevant geometries and configurations



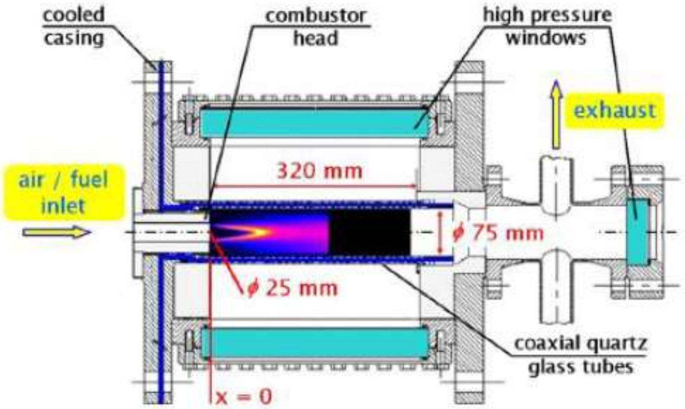
University of California, Irvine
Kalantari et al. (2016)



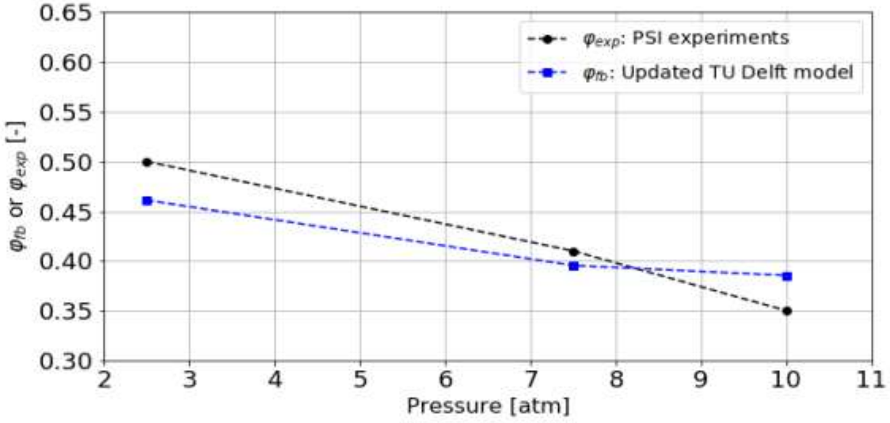
a)T=300 K, u_{bulk}=30 m/s



b)T=500 K, u_{bulk}=30 m/s



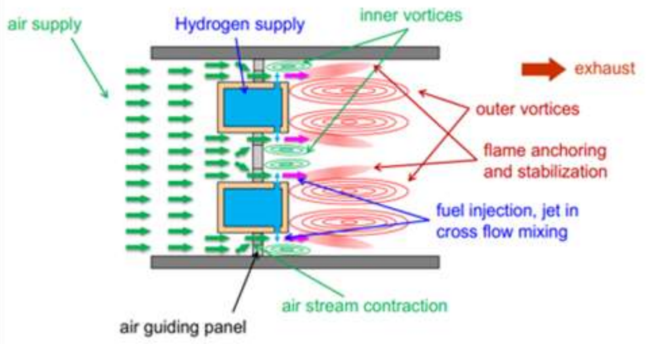
Paul Scheerer Institute
Lin, Daniele, Jahnson et al (2012)

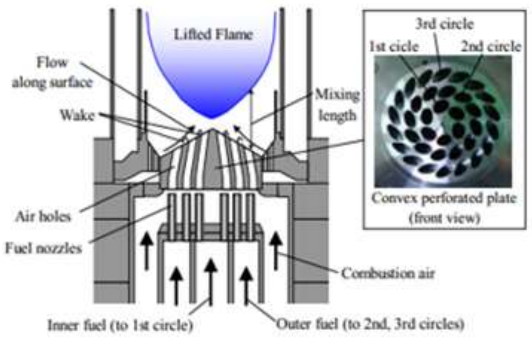


Combustor designs under development for high hydrogen in gas turbines

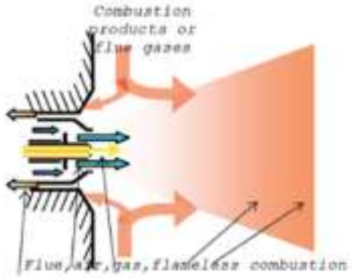
Non premixed combustion => high NOx

(reduction of NOx: flame temperature/residence time)

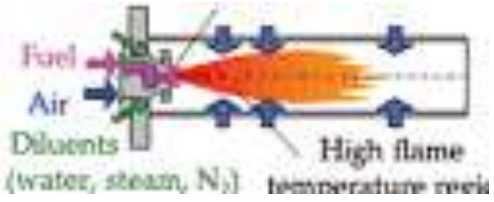




MicroMixing - Small diffusion flames



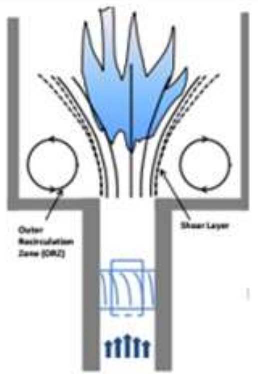
FLOX



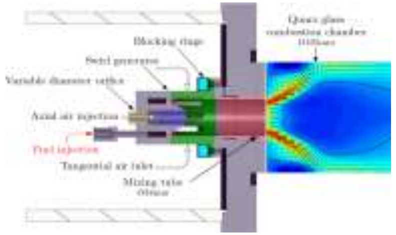
Steam injection

Premixed combustion => low NOx

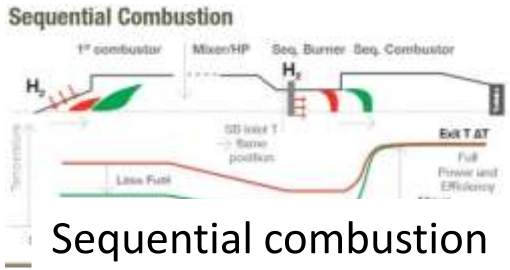
(flashback prevention)



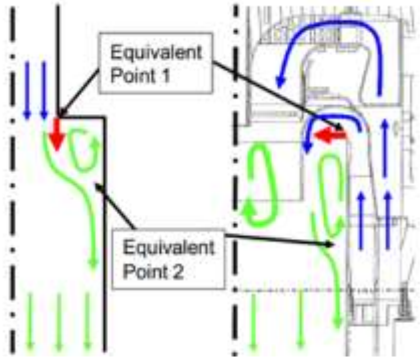
Low Swirl



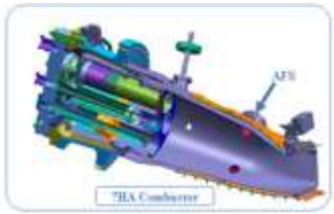
High swirl + axial injection



Sequential combustion



Trapped vortex



Axial staged combustion

Summary & TU Delft H_2 combustion research

Hydrogen in power plants

- Retrofit of existing power plants : zero carbon balancing
- Hydrogen combustion much more challenging than natural gas:
  - NOx, flame speed, diffusivity, ….
- 100% H_2 application in gas turbine not commercially available yet => demonstrations needed

TU Delft research

- TU Delft flash back model performs well for flash back prediction and is used in burner development
- Further research required on fundamentals, active instability control and applications

TUDelft

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October 2021

Gas Turbine Services – Thomassen Energy / PSM

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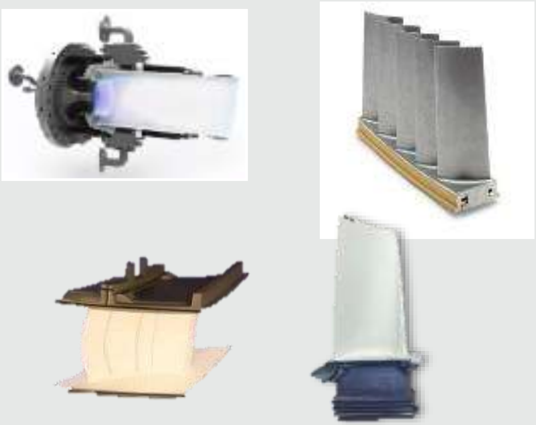
7F: 170 - 190 MW

501F: 175 - 200 MW

7E: 75 - 85 MW

Global M&D w/with Digital and Service Engineering

Upgraded Components



Repair

Field Service

9F: 230 - 245 MW

6B: 35 - 45 MW
Fr5: 20 - 28 MW

9E: 120 - 130 MW

Service with Innovation

Filling The Renewable Gap

- The Gas Turbine Advantage

- Flexible fast load coverage
- Cleanest of the fossil fuels
- Ability to run on wide range of fuels,
  including green fuels such as **hydrogen**

- Excess renewable energy can be harvested, stored and released in gas turbines

- Existing gas turbine power plants available for retrofit with cost effective carbon free upgrades

- Ability to follow the transition to renewable World at a pace which is flexible and dependent on local & regional market drivers

H_2 =

Gas Turbines can meet the flexibility need … and go green

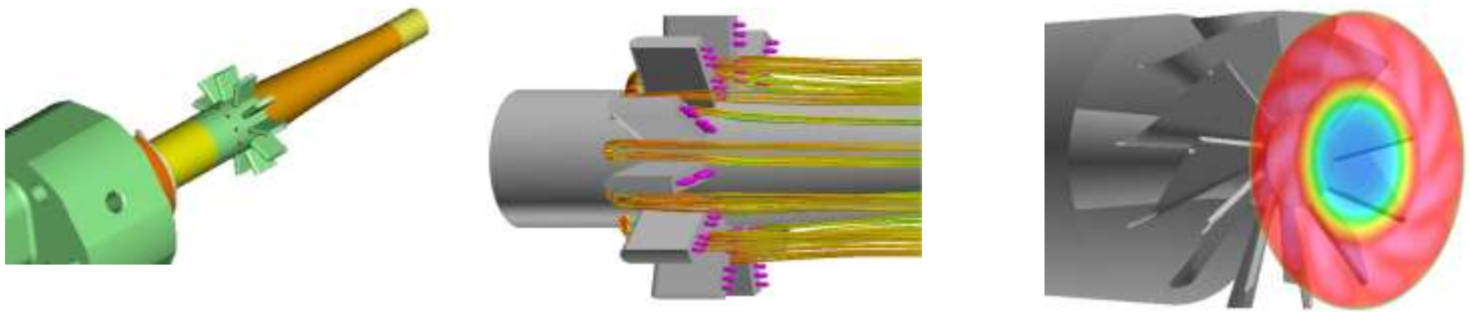
9E Hydrogen in Commercial Operation – Key Package Elements

1. Fuel skid

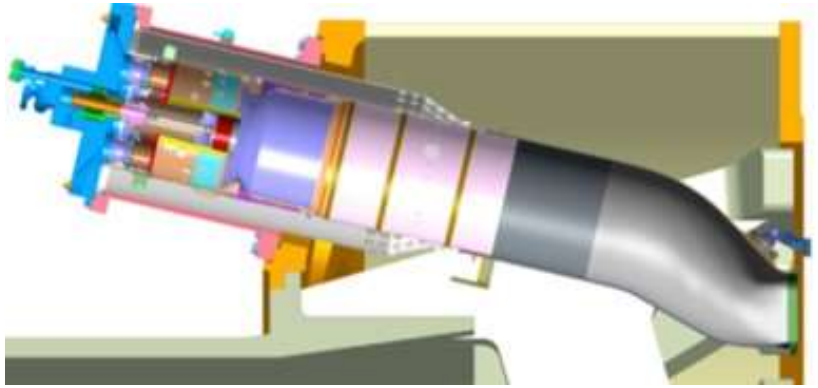
2. Control System / AutoTune

DOW Netherlands – 3 x 9E machines

3. Premix Combustion system (more than 100 natural gas E-class installations, 3 with H_2)



High hydrogen Secondary fuel nozzle upgrade



4 years stable and flexible sub-9ppm NOx Operation from 0% up to 35% Hydrogen

FlameSheet™ Commercial Machine Experience

Thomassen Energy
a Hanwha company

- **8** FlameSheet™ (7 FlameTOP) - enabled machines in operation, 6 years of experience
- Up to **20% additional load turndown** and **fuel flex** with **sub 9ppm NOx and CO**
- Hardware in excellent condition after 28,000 hours and 400 starts
- Up to **60% by vol H_2** F-class firing condition in test rig; up to 40% C2+'s*







FlameSheet™ Retrofit Enhances Operational and Fuel Flexibility

Thomassen Leading a Consortium for Hydrogen Retrofits

Thomassen Energy
a Hanwha company

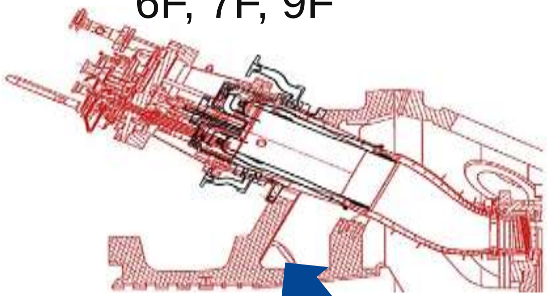
Objective:

- **Develop a low emission gas turbine combustor retrofit for fuel flexible operation from 100% Natural Gas to 100% Hydrogen and any mixture thereof**
- **Flexible fast load balancing capability**

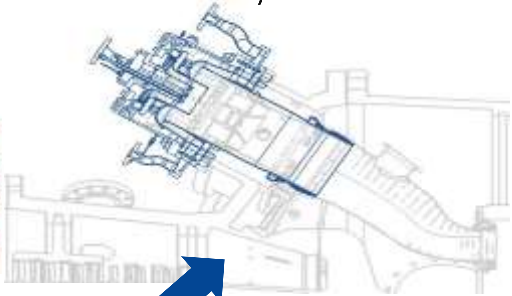
Dutch subsidy awards won:

- Phase 1 awarded April 2019
- Phase 2 awarded March 2021

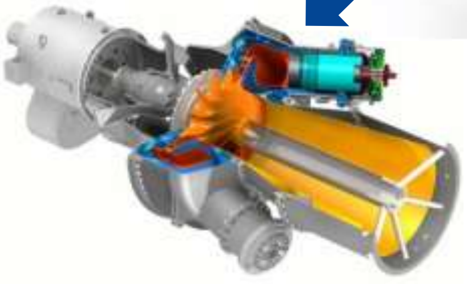
General Electric
6F, 7F, 9F



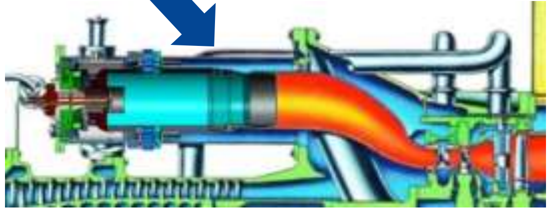
Siemens / Mitsubishi
501B/D/F/G, 701B/D/F/G



Common
FlameSheet™



OPRA OP16



General Electric
Fr3, Fr5, 6B, 7E, 9E

Thomassen Energy a Hanwha company · NOBIAN A Nouryon company · PSM · ELEKTROCIEPŁOWNIA NOWA SARZYNA · EMMTEC · Dow · VATTENFALL · OPRA TURBINES · TU Delft · HYGEAR · DLR · TU/e Eindhoven University of Technology

1MW to 300MW with 0% to 100% Hydrogen with 1 Scalable Combustor Platform

High Hydrogen – High pressure rig testing

Thomassen Energy
a Hanwha company

100% Natural Gas
OP16 Full Load
< 6 ppm NOx

100% Hydrogen
OP16 Full Load
< 10 ppm NOx

Operations from 100% natural gas to 100% hydrogen with dry low emissions

Scope for the Carbon Free Value Chain

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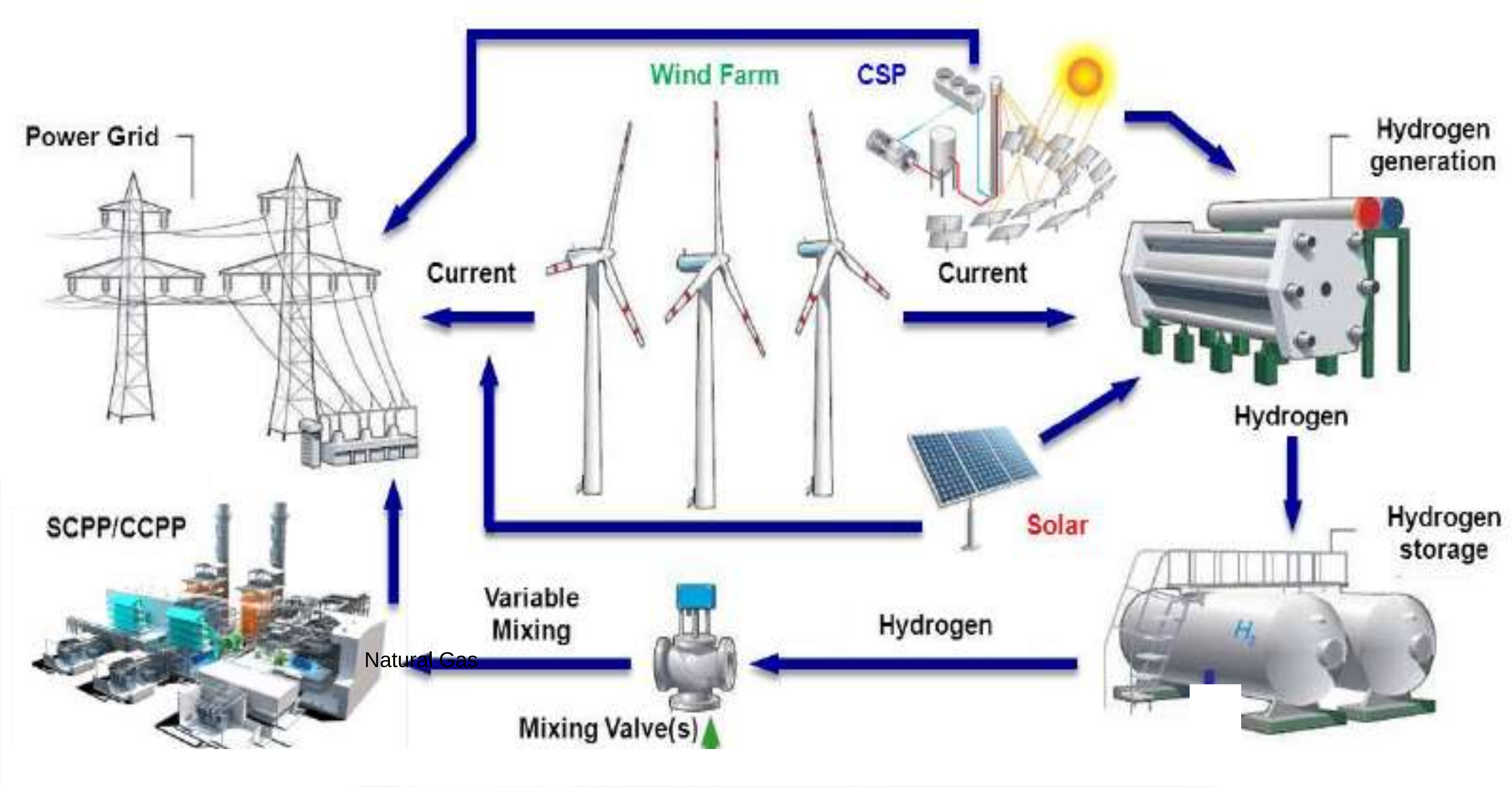

Complete solutions for reduced carbon operation

Solutions for the Energy Transition

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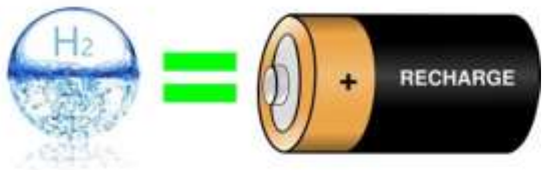
- The gas turbine advantage:
  - Rapid flexibility for power grid balancing
  - Opportunity for clean energy storage with hydrogen



- Partnership advantage:
  - Shared expertise
  - Shared risk
  - Cost effective and commercially applicable solutions

- Package solutions:
  - Hydrogen supply, storage and safety
  - Fuel mixing/handling, controls, combustion, hot end assessment

- Planned 100% hydrogen flexible engine demonstrations:
  - Small engine **2022/23 → 2MW**
  - Medium engine **2023/24 → 20 - 40MW**
  - Large engine **2024/25 → 100 - 300MW**

High hydrogen retrofits/partnerships for carbon free power generation and energy storage

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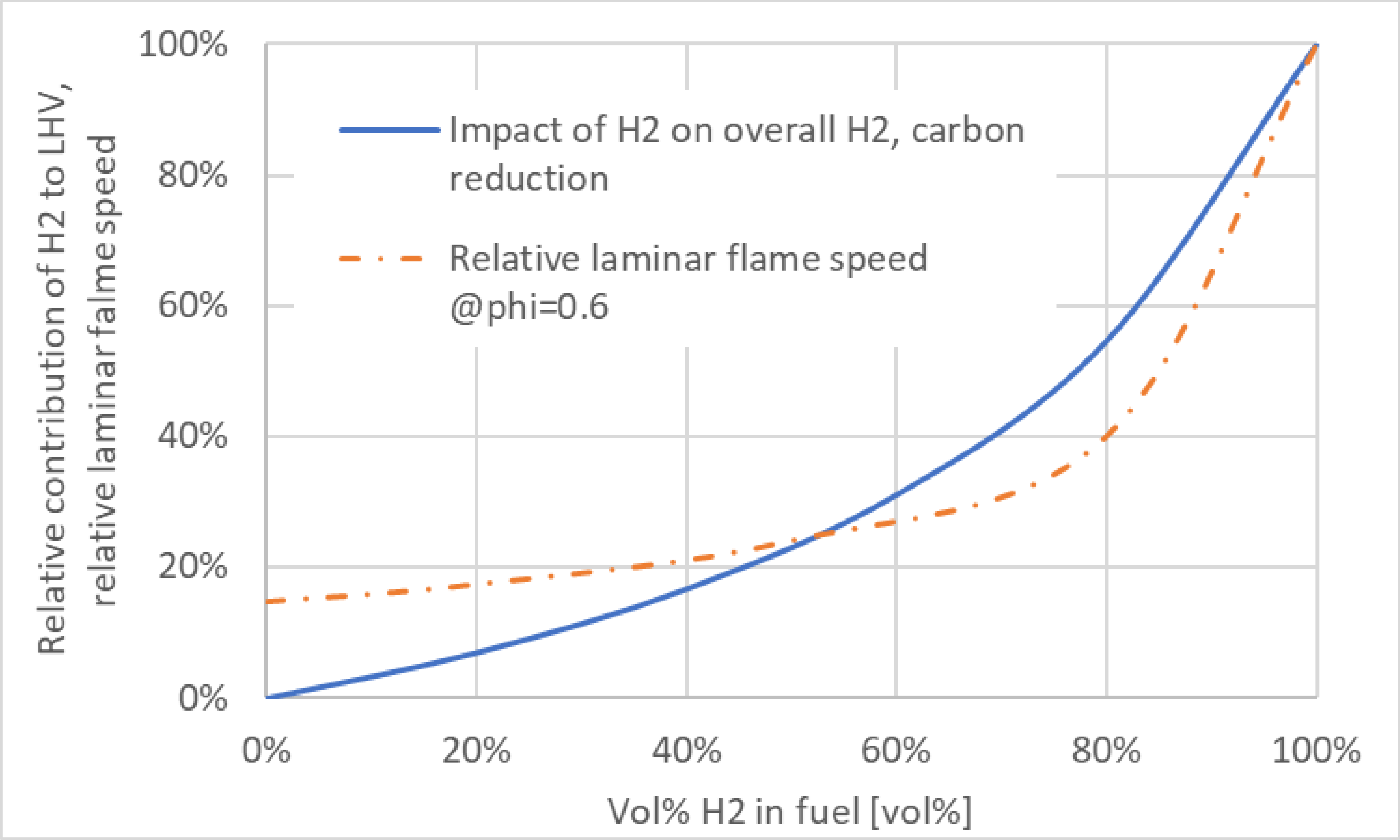
THANK YOU

DANK U WEL

BACK UP

Main advantages & challenges for hydrogen at higher volume percentages



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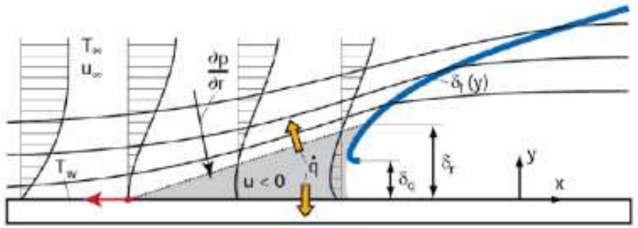
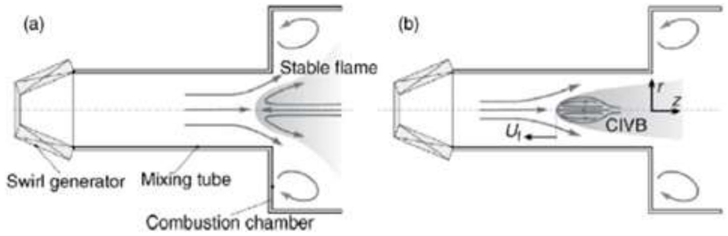
Flash back types for premixed H2 flames relevant for gas turbine applications

Confined



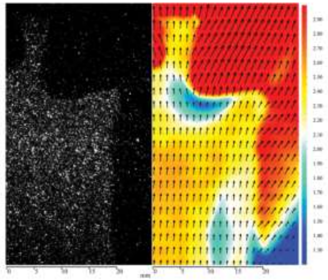
- Boundary layer instability by flame adverse pressure

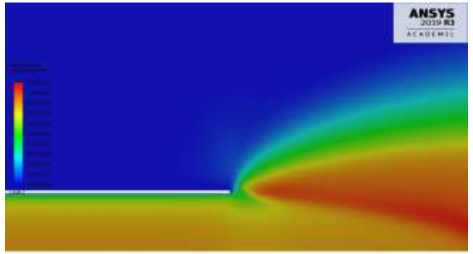
Swirl stabilized
(standard GT)



- Flow deceleration and movement of stagnation point recirculation zone by flame adverse pressure

Unconfined
('jet' flame)





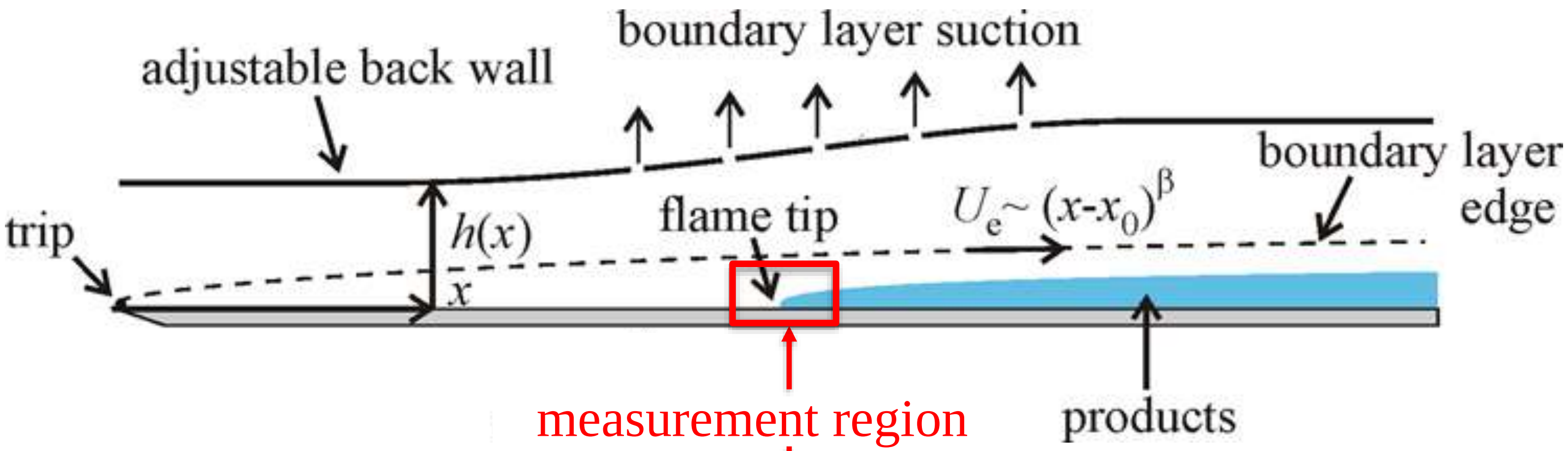
- Local (temporary) flame speed > local (temporary) velocity

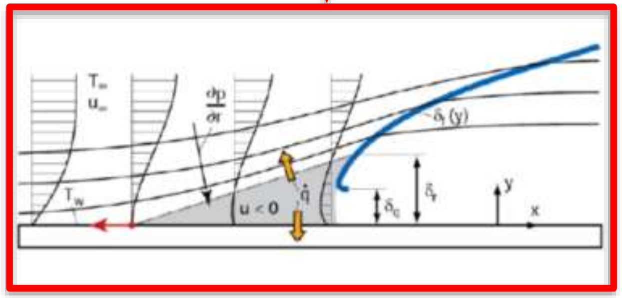
H_2:
- High flame speed
- Lewis number << 1: local enrichment => flame speed ⇧

Flame flashback in turbulent boundary layer on flat plat

Proposed new TTW proposal with TUe

Fully developed flow: e.g. long pipes or channels
Developing flow: e.g. boundary layer > complex, more relevant

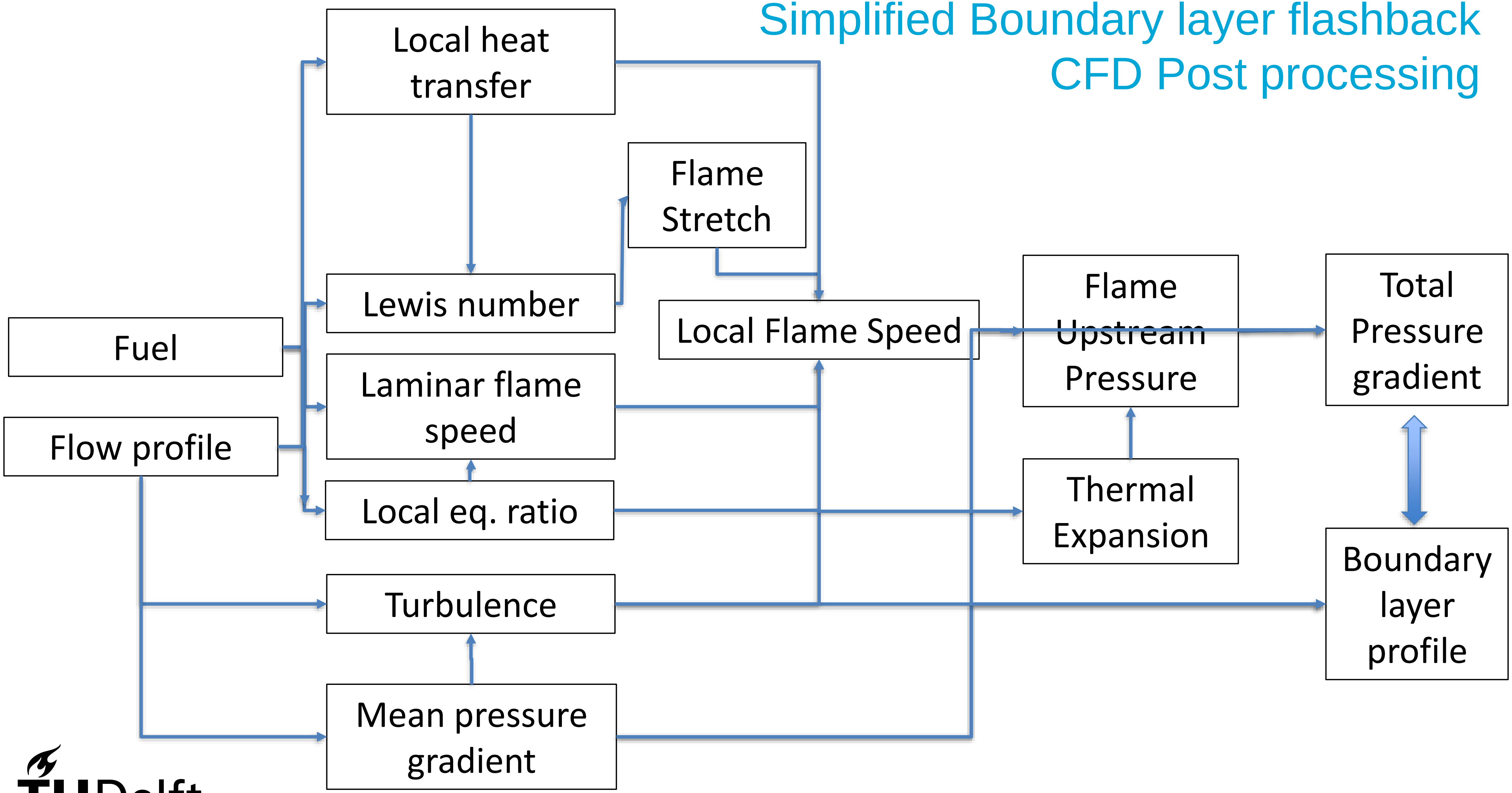




Detailed investigation of flame tip behaviour in near wall region

Optical measurement techniques:
PIV, LDA, CARS, PLIF

Simplified Boundary layer flashback CFD Post processing



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Advertised maximum H_2 vol% for different gas turbine suppliers

		Frequency, Hz	Power Output, MW. Natural Gas, ISO Base Load	H2 Capability, Vol %		
				DLE	WLE	Diffusion, unabated NOx
Heavy Duty	SGT5-9000HL	50	593	30	--	--
	SGT5-8000H	50	450	30	--	--
	SGT5-4000F	50	329	30	--	--
	SGT5-2000E	50	187	30	--	--
	SGT6-9000HL	60	405	30	--	--
	SGT6-8000H	60	310	30	--	--
	SGT-5000F	60	215 - 260	30	--	--
	SGT6-2000E	60	117	30	--	--
Industrial	SGT-800	50 or 60	48-57	60	--	--
	SGT-750	50 or 60	40/34 - 41	40	--	--
	SGT-700	50 or 60	33/34	66	--	--
	SGT-600	50 or 60	24/25	60	--	--
	SGT-400	50 or 60	10 - 14/11 - 15	10	--	65
	SGT-300	50 or 60	8/8	30	--	--
	SGT-100	50 or 60	5/6	30	--	65
Aero-derivative	SGT-A65	50 or 60	60 - 71/58 - 62	15	100	--
	SGT-A45	50 or 60	41 - 44	--	100	--
	SGT-A35	50 or 60	27 - 37/28 - 38	15	100	--
	SGT-A05	50 or 60	4/6	2	15	--

Siemens "Hydrogen Combustion in Siemens Gas Turbines: Sales Information v 3.0," July 2019

	Type	Notes	TIT °C [°F] or Class	Max H_2 % (Vol)
MHPS	Diffusion	N2 Dilution, Water/Steam Injection	1200~1400 [2192~2552]	100
	Pre-Mix (DLN)	Dry	1600 [2912]	30
	Multi-Cluster	Dry/Underdevelopment - Target 2024	1650 [3002]	100
GE	SN	Single Nozzle (Standard)	B,E Class	90-100
	MNQC	Multi-Nozzle Quiet Combustor w/ N2 or Steam	E,F Class	90-100
	DLN 1	Dry	B,E Class	33
	DLN 2.6+	Dry	F,HA Class	15
	DLN 2.6e	Micromixer	HA Class	50
Siemens	DLE	Dry	E Class	30
	DLE	Dry	F Class	30
	DLE	Dry	H Class	30
	DLE	Dry	HL Class	30
Ansaldo	Sequential	GT26	F Class	30
	Sequential	GT36	H Class	50
	ULE	Current Flamesheet™	F, G Class	40
	New ULE	Flamesheet™ -- Target 2023	Various	100

Emerson, B.E. et al., "Assessment of Current Capabilities and Near-Term Availability of Hydrogen-Fired Gas Turbines Considering a Low-Carbon Future", GT2020-15714

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Some References TU Delft

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Link website: https://www.tudelft.nl/en/3me/about/departments/process-energy/people/gas-turbines/sikke-klein/

Some interesting MSc theses in the field of hydrogen

Boundary layer flashback prediction for low emissions full hydrogen gas turbine burners using flow simulation	Olafur Bjornsson	http://resolver.tudelft.nl/uuid:8272a27d-692d-4721-a24c-98ffd4c52511
HYDROGEN AND OXYGEN FIRED TURBINE CYCLE OPTIMIZATION	Bram Schouten	http://resolver.tudelft.nl/uuid:e0d209d5-1cba-4e4b-b2d8-4925b71502a5
Hydrogen flash back experiments	Filippo Faldella	http://resolver.tudelft.nl/uuid:ab0c472e-0dd1-4086-8eeb-18ef14ee226e
Modeling of hydrogen-elektrolysis-storage-utilization chain	Nick Kimman	http://resolver.tudelft.nl/uuid:46183251-f22a-42b5-a994-ed353d4338c0
Numerical modelling of flame flashback in premixed tube burners with turbulent flow and high hydrogen content	Max van Put	http://resolver.tudelft.nl/uuid:84b5e88d-72b8-4663-a597-84993aa347f7

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